Radioactivity from Military Installations sites and Effects on Population Health

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SCOPE-RADSITE
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FOREWORD

SCOPE, the Scientific Committee on Problems of the Environment, was established in 1969 as an interdisciplinary body of ICSU, the International Council of Science. Its mandate is to assemble, review and assess the information available on environmental changes attributable to human activities and the effects of these changes on humans. Its findings are directed to research scientists, scientific advisers to political decision-makers and to the public at large.

The present report, RADSITE, is the latest in a series of SCOPE publications dealing with radioactive contamination of the environment resulting from the nuclear fuel cycle, starting with the 1985/1986 volumes on the ecological consequences of nuclear war (ENUWAR, SCOPE 28 a and b), followed by “Radioecology after Chernobyl” (RADPATH, SCOPE 50, 1993) and “Nuclear Test Explosions” (RADTEST, SCOPE 59, 1999).

While RADTEST addressed the environmental and human health impacts of nuclear weapons tests, RADSITE is aimed at assessing the potential risks to the health of local population groups and to the nearby environment due to the radioactive releases and wastes generated by the development and production of nuclear weapons.

The study covers all phases of the production process, from uranium mining and milling to nuclear reactor operation, reprocessing for plutonium extraction, tritium plants, etc. Information was obtained for sites located in all first five nuclear weapons states: USA, UK, USSR (with East Germany), France and China. It should be noted that, historically, extreme secrecy prevailed for most of the sites involved. The exemplary cooperation of experts from the countries where the sites are located made it possible to obtain the crucial data, without which the project could not have been carried out. Their invaluable help is gratefully acknowledged.

The report presents a unique synthesis of information on inventories of radioactive releases, environmental pathways of radionuclides, environmental contamination levels, site specific radiation dose assessment and health impacts. The human cost of nuclear weapons development and production proved to be very high, as radiation protection was neglected in the early days. In the USSR, particularly, hundreds of thousands of forced labourers were drafted into the programs, many of which died or were severely irradiated.

The report ends with a review of remediation measures and an examination of options for the management of the contaminated sites.

Special thanks are due to the RADSITE project leader, René Kirchmann, who succeeded in completing the project despite numerous difficulties and delays. Tom Hilton is also thanked gratefully for his English editing of several chapters.

We acknowledge with thanks the financial help of The European Union, the substantial support from various Belgian organizations and the material assistance of David Ancia.

Philippe Bourdeau

Chairman, SCOPE RADSITE

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As SCOPE is not a funding Agency, the collaborators to the project have to seek outside their own funding in order to implement the scientific programme.

The first year of the preparatory phase (June 1998-May 1999) was financially supported by the European Commission DGXI and the Initial Workshop held in Brussels (12-14 Nov.1998) received a substantial support from various Belgian organizations such as:

- ONDRAF-NIRAS :Belgian nuclear waste management authority;
- SPRI/DBIS: Belgian service of radiation potection;
- SCK-CEN: Belgian nuclear research centre;
- University of Liège

A Grant Agreement between the Commission of the European Communities and the University of Liège (subv 99/118494) for the “Study of the Pathways in the Envirnment and Assessment of the Biological Effects of the Radionuclides arising from Defence Installations in Europe and CIS” started on 01/09/1999, for a duration of 16 months.

A SCOPE-RADSITE Workshop on “Remediation Achievements after Uranium-Mining and Milling” was held in Munich,08-09 Sept.2000, hosted by the Bundesamt für Strahlenschutz (BfS), with the financial support of the Deutsche Forschungsgemeinschaft (DFG)

Unfortunately no financial support has been received from the US Institutions, in particular from the DOE which was in the beginning, in favour of the RADSITE project. Furthermore a demand to NATO support in order to organize a Workshop at the Savannah River Laboratory failed in the last steps. The American colleagues participated to the RADSITE Project at the expenses of their own Laboratory.

It is worthwhile to underline that the Russian colleagues were partially supported by the RADLEG project, in the framework of the ISTC contracts; the joint meetings RADSITE –RADLEG organized in Russia received a full local support.

Contributors

The project, completed in 2003, involved some 50 specialists from China, Europe, India and Japan former Soviet Union, United States of America, who joined their efforts and expertise.

This international, integrated and critical review strategy produced a comprehensive report

The list of participants to the SCOPE-RADSITE project is provided in another section.

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- **Minutes of the SCOPE-RADSITE Workshop,2 September,2001 Aix-en-Provence,France**

Within the framework of the International Congress on the Radioecology & Ecotoxicology of

Continental and Estuarine Environments (ECORAD-2001) a SCOPE-RADSITE Workshop was convened on Sunday 02 Sept at 15:00 hr in the premises of the Congress Centre. Present :R.Alexakhin,E.Falck, T.Hinton, A.Iskra, R.Kirchmann (Chairman), E.Kvasnikova, Y.Ohmomo (partim), G.Polikarpov (Acting Secretary),V.Popov, K.Wichterey

In attendance : D.Calmet, L.Foulquier, D.Louvat

Apologies for absence : Ph.Bourdeau, A.Cigna G.Collard, M.Goldman, Y.Kutkahmedov, G. Linden, M.Savkin, S.Sheppard, H.Tsukada, C.Vandecasteele, H.Vandenhove, T.Zeevaert

- **SCOPE RADSITE Working Group Meeting Gembloux, 12 June 2002**

Attendees : Ph. Bourdeau, A. Iskra, R. Kirchmann, U. Mishra, G. Polikarpov, V. Popov, C. Vandecasteele.

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EXECUTIVE SUMMARY – *R.Kichmann,A.Cigna*

1 INTRODUCTION

The programme " **RAD** ioactivity from military installations **SITE** s and effects on population health", or **RADSITE,** belongs to the series of numerous studies carried out under the auspices of the **S** cientific **C** ommittee **O** n **P** roblems of the **E** nvironment (**SCOPE**). It falls under the SCOPE's Health & Environment cluster.

Whereas safety and respect of the environment was always given a high priority in civil nuclear programmes, the race towards nuclear arms did not burden itself too much with such preoccupations. For the public, the most obvious manifestation of military programmes are nuclear bomb testing. Since the late 1940's, nuclear test explosions have resulted in the production and dispersion in the environment of enormous amounts of radioactivity. The inventory of the radioactive releases from test explosions and their radiological consequences on human health, specially for the most exposed populations submitted to local fallout, has been addressed by the **SCOPE-RADTEST** programme carried out from 1993 until 1997. The prominent conclusions were published in the SCOPE books series [Warner & Kirchmann, 1999].

Behind the scene, however, less visible activities such as uranium ore mining and milling, uranium isotopic enrichment, spent fuel reprocessing to extract plutonium and R & D on nuclear weapons development, have generated large amounts of radioactive waste that were disposed off with more or less environmental care. In contrast with the well-documented civil nuclear wastes, the military ones is still surrounded by much uncertainty regarding the nature, quantities, the way they were disposed off and the consequence of such disposal for human populations and the environment.

The **SCOPE-RADSITE** Project was launched in 1998 as an integrated scientific study aiming to assess the potential risks to the health of local population groups and to the nearby environment due to the radioactive wastes generated by the development and production of nuclear weapons and their potential releases of radionuclides into the environment.

The relevant issues include consideration of data, models, uncertainties, and new information and insights. Furthermore, clean-up and remedial actions already underway or under consideration are studied in terms of advantages and uncertainties. *It is, however, not the aim to provide an exhaustive inventory of all the sites and options, but to select significant examples and the best assessment tools for action and evaluate qualitative aspects of source terms, pathways, models and consequences of military waste treatment and disposal.* The criteria applied for the selection of most relevant sites include magnitude and potential mobility of radioactive residues, importance of environmental pathways, current site status, and potential impacts on human health and environment.

Chap.1 WISMUT

In the years immediately following World War II, East German mines supplied uranium for the Soviet nuclear weapons program. Even after mining started in the Soviet Union, East Germany continued to serve as the major source of uranium. The most important uranium deposits were in the Erzgebirge in Saxony and the Thuringian Forest in Thuringia.

The peak year was 1967, during which 7,100 metric tons of uranium were produced. In total, about 400,000 people have worked in Wismut mines, producing a total of about 231,000 metric tons of uranium.

These activities have contaminated an area estimated at 100 square kilometres from which the mining operations area is about 37 km 2 . Lake-like basins of mill tailings and associated waste up to 2.5 square kilometres dot the region.

The main sources of contamination in the case of uranium mining and milling sites of WISMUT are :

- Large *underground mines* with near surface workings and shafts as primary source of radon, radioactively contaminated dust release and of groundwater contamination,

- *Waste rock dumps,* mining debris including low grade ore, residues from heap leaching,

- *Radioactively contaminated scrap material* and contaminated equipment,

- *Contaminated mining operation areas, roads and railways,*

- *Mill tailings* as the most important repositories of waste residues producing radon, releasing contaminated dust and contaminated seepage water.

The most extensive contamination is present in area covered by waste rock, tailing embankments and in considerably contaminated groundwater bodies. **This means that at WISMUT mostly volume sources of radioactivity have to be dealt with, in contrast to radioactive contamination by deposition from fallout or washout.**

The relevant exposure pathways in case of WISMUT are ***:***

- **Atmospheric pathway** leading to exposure by inhalation of radon and radon daughters and inhalation of airborne radioactive particles (dust) ;

- **Terrestrial pathway** that can lead to doses due to external radiation in connection with residence on site and ingestion of soil ;

- **Aquatic pathway** that can result in dose exposure due to ingestion of contaminated water or crops irrigated with such water.

The following **dose assessment** for the population is made on the basis of measurements in all relevant environmental media in the surroundings of uranium mining and milling relics at the Ronneburg region in Thuringia in 1994. Higher exposures could be expected during active mining operations but since remediation is rapidly under progress the situation still was improved in the meantime. The pathways, parameters and assumptions used are in accordance with the German guideline "Calculation Instruction for the Estimation of Radiation Exposures caused by Mining Related Environmental Radioactivity" (1999) which is sufficiently conservative, but more realistic concerning existing situations. The critical group of inhabitants in that region is mostly the age group <1 year (of the six age groups given in the Euratom Directive).

Dose assessment for the Ronneburg region (based on average values)

Pathway	Resulting dose for the critical group* (mSv/a)

without backgr. deduction	with backgr. deduction	
External exposure	0.238	0
Inhalation of dust	0.025	0.001
Ingestion of local food	0.155	0.128
Ingestion of water	0.056	0.008
Ingestion of soil	0.153	0.029
Inhalation of radon/decay products (ICRP 65)	0.55	0.11
Sum	1.177	0.256

* Critical group being mostly (except dust) the age group <1year

IMPACTS ON POPULATION HEALTH

During Wismut's entire operational period of mining and processing of uranium ores in East Germany no grave incident with extremely high emissions into the environment occurred. Thus the comparatively low rate of emission from routine releases did not cause acute radiation sickness or other acute illness among the population.

The dose rate was significantly below the threshold for non-stochastic effects. Stochastic radiation injuries that might result from radiation exposures have not been reliably quantified by epidemiological studies.

On another hand the effects of decades of increased radiation exposures and of other unwholesome impacts at underground work places and processing plants were the subject of intensive studying. This was of particular importance for the recognition of occupational diseases and for money compensation involved.

By the end of the 1990s, the WISMUT social security system had conducted a total of 43,743 procedures related to the recognition of occupational diseases in favour of 35,004 persons. Out of this total, 31,325 cases were recognised as occupational diseases. 6,943 cases of radiation-induced cancers were notified of which 5,492 cases were recognised as occupational cancers caused by ionising radiation. These diseases were exclusively lung cancer cases.

ENVIRONMENTAL IMPACTS

- **Nuclear related Impacts**

Over 40 years of radionuclide emissions from uranium ore mining and processing facilities at WISMUT sites has led to environmental accumulations of radioactivity in the air, water and soil. Increase in concentrations

in those media resulted in a transfer to biota.

Activity concentrations in plants

, nuclide transfer could attain radiological relevance in the case of plants intended for human consumption (leafy vegetables, vegetables, fruits), which are grown right next to mining relics. In the surroundings of mining areas specific activities typically measured for 226 Ra were between 1 and 10 Bq/kg , but 130 Bq/kg could be reached on contaminated grounds.

Activity concentration in animal products

In mining regions, Federal Authorities and WISMUT did not carry out systematic studies on radioactivity in animal products except for milk.

Other nuclear directly related impact

Large-scale deposition of radioactive wastes from the mining and milling of uranium ores in the immediate vicinity of residential neighbourhoods has led to the affected areas needing extensive rehabilitation. After the cleanup, reuse of the rehabilitated areas partly will be restricted.

- **Non-nuclear site related impacts**

The enormous/tremendous devastation of the landscape and the related dramatic restriction of land use and impact on the quality of life of the locals must be qualified as the most serious, and at the same time most apparent non-nuclear environmental impact.

Apart from the devastation of the landscape, the pollution of soils and waters with conventional chemical contaminants has to be mentioned among the non-nuclear impacts on the environment. Major contaminants are:

· Arsenic

· Metals (Fe, Ni, Mn, ..)

· Salts (sulphates, carbonates).

Chap.2 P.R.CHINA

Table1 to table 6 in the report illustrated the total activity of different radio-nuclides in gaseous and liquid effluents discharged from six kinds of nuclear industry systems:

- the uranium ore metallurgy system,
- the nuclear fuel element manufacture system ,
- the uranium isotopes separation system,
- the nuclear reactor and spent fuel reprocessing system,

- the nuclear metallurgy and processing system and
- the nuclear engineering research system.

Over thirty years, it was concluded that defining facility year as a unit of statistic up to *93.5%* the annual effective dose equivalent of the key resident group resulted from the gaseous and liquid effluents of nuclear industry was below l mSv and about 6.5% was over l mSv but below 5 mSv.

The main source resulting the collective effective dose equivalent of the residents around the nuclear facilities was the uranium ore metallurgical facility due to the large quantity of radon gaseous discharge. The radon quantity discharged to environment per 100 t of uranium production was much more than that estimated by the UNSCEAR.

The environmental impact of nuclear fuel cycle facilities could be neglected. China as a developing country has a population of 1.2 billion, from the point and statistic of national dose which involves the exposures of national background, professional, public and medical, the nuclear industry led to the public an annual collective dose about 23.1 man Sv which was lower than those of the exposure pathway from aviation (36 man.Sv).

Chap.3 ELEKTROSTAL

Production of radium salts (bromides) at the plant started in 1950 , using uranium ore processing tailings as raw materials.

In the subsequent years manufacturing of fuel elements and fuel assemblies for nuclear power plants, ship propulsion and research reactors was developed. Fuel elements were made of enriched uranium with various levels of 235 U content in the form of uranium dioxide or other compositions. Making of such type of production is going on till the present.

Radioactive wastes, that have resulted from uranium ore processing, radium salt production and nuclear fuel manufacturing, are concentrated in two tailing dumps (No.240 and No.298)

As of 1 January, 2001, total amount of solid radioactive wastes (all of the storage facilities inclusive) was 378.81 thousand tons. The overall radwaste activity accumulated at the enterprise was 4.25 × 10 13 Bq .

All of the uranium chains' radionuclides are characteristic of low root assimilation, that is why radioactive contamination of plants through the root pathway will not be essential. The level of secondary dust formation from the ground covered with vegetation is low. Thus, the external gamma-exposure from contaminated soil is the only significant factor of hazard.

The only hazardous contaminated area outside the plant's industrial site limits is the tailing dump complex. Currently further build up of daughter nuclides resulted from uranium isotopes decay is on, and it will go on in future. The highest fixed gamma-exposure rate at the tailing dumps' territory is 1.86 mRad/hr (16.3 Rad/ yr). Now the tailing dump complex is fenced and provided with warning character plates.

In the area of Elektrostal city distribution of expected effective doses, incurred by adults due to annual permissible EMP radionuclide releases and discharges, all exposure pathways being taken into account were calculated. External exposure, outside the plant area, does not exceed 1 mSv/y.

Chap.4 OAK RIDGE

Oak Ridge is one of the largest U.S. Department of Energy complexes. The Oak Ridge Reservation encompasses about 14,000 contiguous hectares (about 35,000 acres) in eastern Tennessee. It was built during World War II as part of the “Manhattan Project” with a mission to develop the necessary skills and materials to build the atomic bomb

Three facilities were built. The X-10 facility (later called ORNL [Oak Ridge National Laboratory]) was tasked with weapons research and development, especially purification of plutonium.

X-10 released significant quantities of I-131 from 1944 through 1956 resultant from processing spent nuclear reactor fuel using a process that recovered radioactive lanthanum (RaLa). The RaLa operation dissolved some 30,000 reactor fuel slugs in 731 batches to separate some 500,000 Ci (1.9 16 Bq) of radiobarium. During slug dissolution, volatile radioiodine was exhausted as “off gas”, amounting to 8,800-42,000 Ci (2.3 14 to 1.6 15 Bq) of I-131, three quarters of which was in elemental form—the rest was in a volatile non-reactive organic form. The largest releases occurred between 1952 and 1956 when the freshly spent uranium fuel slugs came from Hanford reactors.

Atmospheric dispersion of radio-iodine is the principal issue in almost every discussion of weapons production technology (and in weapons debris as well). Atmospheric reactive elemental radio-iodine is transformed in transit to particulate and non-reactive organic forms within a few km of the processing facility (X-10). The resultant ground deposition concentrations of radio-iodine are influenced by local weather, mixing, wet and dry deposition dynamics and its chemical form.

The materials and activities shown to have the highest potential for **public health hazards** are as follows:

- The release of radioiodine [likely over 3.7 PBq (100,000 Ci)] to the air from radioactive lanthanum ("RaLa") processing at X-10 (now Oak Ridge National Laboratory) from 1944 through 1956;

- The release of 137 Cs and other radionuclides in liquid wastes from chemical separation activities at X-10;

- The release of mercury to the air, soil, and surface waters from Y-12 lithium enrichment operations between 1950 and 1963. About 11,000,000 kg of mercury were handled at Y-12, and 910,000 kg were reported lost or unaccounted for; and

- The release of polychlorinated biphenyls (PCBs) from machining oils, electrical equipment, and other sources in the Oak Ridge area.

T he Oak Ridge Health Studies examine health problems that may have been caused by federal activities in Oak Ridge. The studies are aimed specifically at nearby residents who may have been affected by air or water emissions from the ORR.

Based on the findings of the study, the **Oak Ridge Health Agreement Steering Panel** called for a dose reconstruction for radioiodine, mercury, PCBs, and radionuclides released from White Oak Creek and research into opportunities for analytic epidemiologic studies to identify adverse health effects in exposed populations.

The activities of the weapons production sites for the most part contained radiation emissions within the site boundaries. Population exposures however did occur mainly from atmospheric and aquatic discharges. In the earliest years of nuclear weapons production facilities, i.e., 1942-1952, industrial hygiene and

environmental containment technologies at reactors and separation plants were limited and not well developed.

The study found that two groups of people are were the most likely to receive health problems from contaminants: *Local children* who drank "backyard" cow and goat milk in the early 1950s and *fetuses* carried in the 1950s and early 1960s whose mothers who regularly ate fish from creeks and rivers downstream from Oak Ridge plants. **.**

Conclusions

Activities on the ORR have not been without a price. For more than 50 years,

radioactive, hazardous, and mixed wastes have been buried, poured into ponds

and streams, burned, and discharged out smokestacks. The resulting contamination

affects approximately 10 percent of the Reservation's area and has migrated

off site via air, groundwater and rivers.

Example: Aquatic Life

The State, the Tennessee Valley Authority, the Tennessee Wildlife Resources Agency, and DOE work together each year to develop the TDEC Tennessee Fishing Advisory. The advisories include warnings against the consumption of fish or contact with the water from East Fork Poplar Creek (due to Mercury and PCB contamination) and the consumption of certain species of fish from the Melton Hill and Watts Bar Reservoirs (due to PCB accumulation in their flesh).

The Division worked closely in the last year with ORNL's Biological Monitoring and Abatement Program (BMAP), which is coordinated by the ORNL. **-** Environmental Sciences Division. By documenting the ecological standing of a system, biological monitoring helps identify the causes of ecological damage and assess the effectiveness of remediation.

Chap.5 SAVANNAH RIVER SITE

5.1 Heavy Water Production and Reprocessing Plant

Heavy water was used as a primary coolant and moderator in the SRS nuclear reactors. Heavy water was concentrated from its natural abundance of 0.015% in river water by a dual temperature exchange procedure that required large quantities of hydrogen sulfide under high pressure. Tritium was present in the moderator as a contaminant and was released to the environment whenever there was leakage or evaporation of the moderator. In the early 1960s each reactor held approximately 225,000 kg of heavy water containing about 50,000 TBq of 3 H. *Approximately 1/5 of the heavy water was lost to the environment each year.*

5.2 Fuel and Target Fabrication

The atmospheric releases of U from the fuel and target fabrication facility were minor compared to those from the chemical separations areas. However, the largest releases of uranium on the SRS occurred from

the fuel and target fabrication facility via liquid effluents released into a nearby creek (Tim's Branch) and into a seepage basin that was put into service in 1973. Releases to Tim's Branch peaked in 1969 when over 11,500 kg of uranium were released (approximately 0.3 TBq).

5.3 Nuclear Reactors

Five nuclear production reactors, designated C, K, L, P, and R, operated on the SRS

The reactors were devoted primarily to the production of plutonium and tritium . The reactors released gaseous radioactive contaminants through various process exhaust stacks, and contaminated liquid effluent into site streams and seepage basins. The main source of radionuclide releases to surface water from the reactors was from the disassembly basins; large water-filled basins (approximately 10 million L) adjacent to the reactor building.

Tritium was a major contaminant from the production reactors, and was due almost entirely to releases of moderator, either as liquid or vapour from the reactor systems and from the heavy water rework facility.

Generally, releases of Pu and U from the reactors were minor, particularly when compared to atmospheric releases from the chemical separations facilities

5.4 Chemical Separations Facilities

After nine months storage in the reactor disassembly basins, irradiated target and spent fuel elements were transferred to the chemical separation facilities located in the F-Area and H-Area canyon buildings. Complex chemical and physical processes in the F- and H-Canyon buildings separated uranium, plutonium, and fission products. Exhaust stacks from these facilities have historically had the highest measured atmospheric emissions of alpha-emitting radionuclides, primarily plutonium (238 Pu and 239,240 Pu) and uranium . Important fission product releases were also recorded.

Of all the SRS facilities, the chemical separations facilities were the largest source of airborne tritium releases. For example, in 1971 atmospheric tritium releases amounted to 14,800 TBq from the chemical processing operations, 7,770 TBq from the reactors, and 330 TBq from heavy water recovery ; 94% of the tritium released was to the atmosphere and 6% to effluent streams. Sixty-three percent of the 3 H released resulted from processing the irradiated lithium and U within the separations facilities, the remainder came from various sources associated with the reactor moderator . The chemical separation stacks also discharged the majority of radioiodine, more than 300 times than what was emitted from all the reactor stacks combined ..

5.5 Pathways

Atmospheric Pathways

Screening calculations revealed that 131 I and 3 H were the most important radionuclides in the atmospheric pathway .

Aquatic Pathways

Of the numerous SRS facilities, the main source of radionuclide releases to surface waters was from the reactors.

Terrestrial Contamination

Tritium and 131 I appear to be the only radionuclides of SRS origin detected offsite in vegetation. Greatest releases occurred prior to 1961 The first positive analysis for radioiodine in milk was reported in 1958. There are no apparent spatial trends for tritium, and reported concentrations have been similar in all directions and at all locations for each distance Concentrations appear to decrease as a power function (i. e., concentrations decrease exponentially as distance increases exponentially) with increasing distance from the SRS.

- **Dose assessment**

Major Contributors to Dose

Computer models have been used to reconstruct an estimate of dose to offsite residents that lived adjacent to the Savannah River Site from 1955 through 1996 (Carlton, 1998). Models were based on atmospheric and aquatic releases from the Savannah River Site operations, and included ingestion, inhalation and external irradiation pathways. Total dose, from 1954 through 1996, to a hypothetical, maximally exposed individual from atmospheric pathways was 0.77 mSv. Iodine, tritium, and plutonium were the largest contributors from the atmospheric pathways Total dose, from 1954 through 1996, to the hypothetical, maximally exposed individual from aquatic pathways was 1.4 mSv. 137 Cs, 32 P, and 95 Zr,Nb were the largest contributors from the aquatic pathways, largely from the consumption of fish and saltwater invertebrates.

5.7 Impact on population health

-Possible increase in multiple myeloma in older workers receiving external radiation doses (but not in younger workers with same doses)

-Study of Mortality in workers from 1952-1 974 showed death rates lower than in general US. population, but leukemia was increased in those with external radiation doses.

Nevertheless over the entire length of the CRESP study, SRS workers are no more and no less likely to die of leukemia than the U.S. population. The previously identified excess of leukemia deaths that occurred in the mid-1960's has not continued.

5.8 Impact on environment

The nuclear complex, mostly mothballed reactors and structures devoted to cleaning up the mess made over decades of nuclear weapons production, covers only about 10 percent of the Energy Department's property.

The rest is largely pristine wilderness undisturbed by development for a half century - vast expanse of longleaf pine forests, Cypress swamps, Carolina bay wetlands and a creek that boasts the highest number of different aquatic insect species - 650 - of any river in North America.

(see also chap.12 impacts on biota)

Chap.6 HANFORD

In 1943, the United States Army Corps of Engineers selected an area of nearly 1000 km 2 , in semiarid southeastern Washington State, for producing plutonium and other nuclear materials supporting the United States' effort (known as the Manhattan Project) in World War II. Nine nuclear reactors for the production of plutonium were eventually constructed. Reactor operations began in 1944; the last production reactor was placed in cold standby in 1987.

6.1 Atmospheric Source Term

Scoping studies indicated that the primary radionuclide of interest from the atmospheric pathway was iodine-131 The estimated amount of iodine-131 along with other radionuclides of interest released to the atmosphere between 1944 and 1971 were summarized : the estimated total release of iodine-131 for the period is 2.8x10 16 Bq (762,000 Ci)

6.2 Columbia River Source Term

The Columbia River is the major pathway for water-borne radionuclides.

Scoping studies have indicated that the radionuclides of greatest interest are 65 Zn, 32 P, 24 Na, 239 Np, and 76 As . These radionuclides provide about 94% of radiation doses to people using the river.

6.3 Ground-Water Source Term

The total volume of solid waste in the ground is approximately 625,000 m 3 . Inventories of radionuclides in liquid wastes discharged to ground, decayed to 1989, are listed in Table 6.2. 3.of the report. The total volume of liquids discharged to the ground at the Hanford Site is approximately 1,680,000,000 m 3 .

Comparison of annual measurements in the river upstream and downstream of Hanford indicates that about 200 TBq of 3 H, 2 GBq of 90 Sr and much smaller quantities of 129 I and 99 Tc are being discharged via groundwater into the Columbia River.

6.4 Pathways

Pathways of exposure to historically released radioactive materials from the Hanford site may be broadly broken into two groups, atmospheric/terrestrial and aquatic.

The terrestrial pathways following deposition of atmospheric contamination are complex and widespread, and have been captured in an environmental accumulation model

The commercial milk distribution systems were reconstructed from records and reports. They provide some information on the amount of milk produced and sold in each county, the locations of individual dairies and distributors, and dairy industry practices in the 1940s.

The aquatic pathways are dominated by those associated with the Columbia River. They include direct consumption of drinking water; pathways associated with river recreation such as swimming, boating, and fishing; those associated with contaminated sediments along the river shoreline; pathways resulting from irrigation of farmland for food crops and residential lawns; and those of consumption of aquatic biota.

6.5. Dose assessment

The Columbia River Dosimetry (CRD) [Farris et al.1994] model calculates dose via water immersion, drinking, and consumption by residents of fish, game birds, salmon, and ocean shellfish

The primary thrust of Hanford Environmental Dose Reconstruction (HEDR) modeling effort was the preparation of a complete system by which individuals may receive estimates of their dose from past Hanford Site operations.

The largest doses resulting from Hanford operations occurred in the mid-1940s [Farris et al. 1994a]. The most important radionuclide was iodine-131 released to the atmosphere. *The most important exposure pathway was consumption of milk produced by cows on pasture downwind of Hanford.*

The iodine-131 releases were essentially routine and continuous during the first period of site operation. Infants and young children who drank milk from cows that ate fresh pasture are likely to have received the highest doses. Median doses for individuals in this group ranged from about 0.02 Gy (2 rad) to 2.4 Gy (240 rad) to the thyroid.

The major radionuclides contributing to doses from the river pathway are zinc-65, phosphorus-32, arsenic-76, and sodium-24.

6.6 Impacts on Population Health

“Hanford Thyroid Disease Study”

Study of possible effects of I-131 exposure from Hanford releases in the 1940s and 1950s (9 year study; cost $ 18 million).

-Study 5199 people born during 1940-1946 in seven counties near Hanford

-4875 people were located and invited to join the study

-3441 people were in the study cohort

-3193 (93%) had doses estimated

RESULTS

19 cases (0.6%) of thyroid cancer found in the 3441 participants (5 were not in the study area between 12/1944 and 12/1957)

249 (7.2%) had non-cancerous, benign thyroid nodules

CONCLUSIONS:

1. There was no link between thyroid dose and thyroid disease

- Excess infant mortality was slightly higher in the study group, but this was evident

before the Hanford releases began and is still under study

Chap.7 INDIA

Coal in the only natural resource and fossil fuel available in abundance in India. Consequently, it is used widely as thermal energy source and also as fuel for thermal power plants producing electricity. Most of the available coal contains natural radioactivity due to Uranium and Thorium series of the same order as ambient soils.

The installed electricity generating capacity has to increase very rapidly (at present around 8-10% per annum), as India has one of the lowest per capita electricity consumption Therefore, the problems for future are formidable from ecological, radio-ecological and pollution viewpoints.

India has embarked on a very ambitious programme of nuclear energy applications which includes electricity generation, isotope and radiation sources production, etc. Nuclear power programme is particularly innovative being based on utilisation of nationally available fissile and fissionable materials. Ten NPP's are now in operation at five sites in the country.

There is no place or centre exclusively for weapons programme except for the test site and since all tests conducted so far were underground with no venting, there is no site which can be considered as candidate site for the RADSITE studies.

The environmental and population radiation protection is of special concern at operation of nuclear facilities.

Most radiologically significant radionuclides are 230, Th, 226 Ra, 222 Rn and 210. PoTheir concentrations in surface waters near production sites does not exceed permissible levels. Tailing ponds are local sources of external exposure and inhalation but they are located in non-inhabited sites. NPP's operating in normal conditions create very low doses to local populations: 2 to 30 µSv per year at the plant fence,

Chap.8 KRASNOYARSK-26 (Zheleznogorsk)

The Krasnoyarsk Mining and Chemical Industrial Complex, (MCIC), was initiated in 1950 and was the last of three sites for weapons grade plutonium production and reprocessing. The plant was built underground, it is located 40 km north of Krasnoyarsk and 2,400 km from the estuary of the Yenisey river. The two first production reactors came into operation in 1958 and 1964 respectively, and had only a primary cooling system. The third reactor had a closed primary circuit and a secondary cooling system. The two straight-through cooled reactors were decommissioned in 1992 and the third reactor is supplying the town of Zheleznogorsk and some neighboring settlements with heat and electric power, and it is not possible to decommission it until substituting power capacities are introduced. A reprocessing plant for spent nuclear fuel was built at the site in 1964 and is still operating

The main volume of radioactive waste from the reprocessing process is injected into an underground injection facility. The injection area consists of about 450 m thick clay-sand deposits, and is located 16 km from the facility. The radioactive waste is injected into the permeable sand layers, while the layers of clay in-between are impermeable.

The total activity of direct discharges from Krasnoyarsk MCIC into the Yenisey river is about 2 PBq [decay corrected to 1995).

Ingestion intake is the main radionuclide pathway for internal exposure to the populations living in the settlements located on the banks of the Yenisei River. The following radionuclides were of concern:

- 32 P, 24 Na, 65 Zn, and 137 Cs with fish from the Yenisei River;

- 32 P, 137 Cs, and 90 Sr with milk from cows, pastured on submerged meadows and consuming water from the Yenisei River and hay from contaminated areas.

In case of consumption 2 l/day of such water, the annual effective dose averaged over population is estimated to be 8 m Sv y -1 with range from 5 m Sv y -1 to 40 m Sv y -1 depending upon age-group (the highest exposure is estimated for the children of 1-2 y and the lowest exposure to the adults).

After stopping of the straight-through reactors in 1992 and use of closed loop, the concentration of 24 Na, 32 P, 51 Cr, and 239 Np decreased greatly up to 2-3 orders of magnitude in the river water

Exposure to the populations living in the settlements located in supervision zone from intake of 137 Cs and 90 Sr with foods locally produced was estimated to be in the range (15-30) m Sv y -1 It means that the exposure was within the variation of doses from global fallout typical for the region considered.

Yenisei River's bottom sediments are the main source of radioactive contamination of the river's *biota.* 137 Cs radionuclides are mainly found in fish. Their measured concentrations do not exceed 0.1 % of the permissible level for population (96 Bq/kg) and show a tendency to further decrease. 137 Cs concentrations are measured also in a number of foodstuffs produced in the M&CC affected zone. Levels of 137 Cs concentration in milk are 0.13 Bq/kg (with permissible 50 Bq/kg), in potatoes 0.50 Bq/kg (permissible level: 80 Bq/kg),

Turning to situation around the Severnyi site of liquid radwaste deep well injection, it should be noted, that though the analyses made by IIASA, VNIPIPT and IGEM don't indicate the presence of a potential for significant problems outside the site boundary, significantly contaminated groundwater may remain in both aquifers (horizons I and II) for hundreds to thousands of years.

Chap.9 MARCOULE

9.1 Marcoule fuel reprocessing plant

The reprocessing operations generated about 4.8 EBq of combined 90 Sr and 137 Cs wastes through 1990 (figures not decay corrected). The fission products are stored in liquid form in electrically cooled, double-walled, stainless steel tanks until vitrified in glass

F rom 1980 to 1991 the Marcoule complex discharged about 0.5 PBq of beta-gamma activity (excluding tritium), 4.87 PBq of 3 H and 894 GBq of alpha activity. By excluding tritium, 106 Ru+ 106 Rh accounts for 81.42% of the total beta-gamma activity, while 90 Sr+ 90 Y and 137 Cs contribute 6.88% and 5.57% respectively, the other radionuclides representing contributions of less than 1%.

It must be underlined here that there is a clear decrease of the releases in 1991 due to new treatment process set up since 1990. Such a decrease is continuing also in the following years.

9.2 Nuclear power plants

While the releases from Marcoule reprocessing plant are characterised by 106 Ru+ 106 Rh, the releases from nuclear power plants, when excluding 3 H, are characterised by a number of elements such as 58 Co (39.75%), 90 Sr+ 90 Y (11.98), 60 Co (10.6%) and 137 Cs (7.99%).

Over the period 1980-1991 the nuclear power plants released a total amount of 1.64 PBq of beta-gamma activity represented mainly by 3 H releases (99.2%). When excluding 3 H the total beta-gamma activity is 0.013 PBq. As underlined in the paragraph above mentioned, the total alpha activity released by the nuclear power stations is negligible compared to the releases from Marcoule reprocessing lant, i.e. 0.26 GBq (239+240 Pu are the only radionuclides reported).

9.3 Population exposure

A mathematical model, ATOMED (Simmonds *et al.* , 1995) was developed to predict the dispersion of radionuclides in the Mediterranean Sea and to estimate the exposure of the population of the European Community. A model for the Rhône river was also used to model the dispersion of the radionuclides discharged by the Marcoule plant in a more accurate way.

Ingestion of molluscs is the dominant pathway (60% of the total collective dose).

Ingestion of fish (20% of the total collective dose) and *external exposure* to radioactivity in beach sediments (18% of the total collective dose) *are also significant pathways.* 60 Co (27%), 58 Co (27%) and 106 Ru (13%) are the most significant radionuclides contributing to the collective dose due to external irradiation from beach sediments

Ingestion of crustaceans (less than 2% of the total collective dose) *is negligible* .

Radiological impact of liquid effluents by radionuclide and pathway.

The Marcoule nuclear plant is by far the main contributor to the collective dose arising from man-made radioactivity released routinely into the Mediterranean Sea. The total collective dose associated with the discharges from Marcoule was 1.6 man Sv which is 82 % of the total collective dose delivered by all EC nuclear plants discharging into the Mediterranean Sea.

9.4 Impact on population health

A survey was performed in 1996 on the occurrence of acute leukaemias, lymphomes and thyroid cancers observed between 1985 and 1995 in children 0-14 years old and living at less than 35 km of the reprocessing plant.

The results shown no excess of leukaemias or lymphomas among this young population group which seems exposed to the same risk as other western European populations.

Chap 10 SELLAFIELD

.Construction work on nuclear facilities started in 1947 with the construction of two air cooled reactors **,** known as the Windscale Piles which were used for irradiation of uranium and the subsequent production of plutonium.

A prototype Advanced Gas Cooled Reactor, constructed on site, reached full power in 1963 and was operated until 1981. Oxide fuel from both gas cooled and water cooled reactors has been stored in a number of specially constructed storage ponds pending the start up in 1994 of the **Thermal Oxide Reprocessing Plant (THORP**).This new plant has been designed to very stringent effluent standards taking advantage of new technology, so as to minimize its contribution to discharges of the more

radiologically important isotopes.

Discharges of radioactive effluents from the site to the environment have taken place since commencement of operations at the site in 1951.Throughout the history of the site, the operators have conducted monitoring of the main effluents streams as well as monitoring of environmental materials and foodstuffs to establish the impact of discharges on members of the public. Records of discharges of radioactivity to sea have been made since 1952.The analytical schedule became progressively more comprehensive with time and improved technology, gamma spectrometric methods being introduced in 1962. Determination of additional specific nuclides in liquid effluent were made : 241 Am from 1968 ; 241 Pu from 1972 ; and 3 H from 1963.

10.1 Pathways

The Pile chimneys were identified as giving rise, potentially, to the greatest exposure to the members of the public ; mainly due to external dose from argon-41 discharges formed by neutron activation of naturally occuring argon-40 in the cooling air

Thus, the pathway receiving most attention in the early years for doses to members of public was external irradiation from the effluent plume, with maximum dose rate predicted (from Gaussian plume type models) at about 5 km downwind .

Potential pathways to humans were also examined and assessed in detail, including consumption of fish and seaweed, external irradiation from the shore, ingestion of sand or seawater and the use of seaweed as a fertilizer

By 1970, following the increased radiocaesium discharges from Sellafield, a third pathway of exposure, due to the consumption of fish and shellfish, had become apparent. This route was reported to be the critical pathway from 1974 until the late 1980s and, accordingly, much of the emphasis in U.K. monitoring programs over this period was put on its evaluation, with particular attention being given to critical groups such as consumers in the local fishing community near Sellafield and consumers associated with commercial fisheries based primarily at Whitehaven, Fleetwood and the Morecambe Bay area.

The most exposed group consists of local people living near the site perimeter and who obtain all their food from products produced on land adjacent to the site . The primary goal of these calculations has been to demonstrate that the exposure of this critical group has not exceeded the recommended annual dose limit . Milk has been identified as the most important foodstuff contributing to dose, with infants and children (for which milk is an important part of their diet) receiving the highest dose.

10.2 Dose assessment

Tables 10.4.1. to 10.4.4 of the report. show the collective doses to the UK and Europe and the annual doses to typical individuals from Sellafield nuclear site discharges. Discharges for 1975, 1985 and 1993–1995 have been selected to represent three decades of operation. Average annual discharges over the period 1993–1995 are taken to be typical of the situation in the mid-1990s. The collective and individual doses are used to give a holistic view of the radiological impact of the routine discharges from the UK nuclear industry.

Typical annual individual doses from Sellafield civil nuclear discharges (µSv)

	Individual dose (m Sv)		
	Discharge year		
Discharge	1975	1985	1993-1995*
Atmospheric	2.03 10 1	5.77 10 0	3.48 10 0
Liquid	3.69 10 2	2.71 10 1	6.83 10 0
Total	3.89 10 2	3.28 10 1	1.31 10 1

10.3 Impact on population health

The **IVth COMARE's report** conclude that the excess of leukaemia and NHL in young people in Seascale for the period 1963 to 1992 is highly unlikely to be due to chance alone. Various factors considered in the report could affect the incidence of leukaemia and NHL but no one factor alone could account for the increase. One cannot rule out interactions between different possible factors but, as yet, have no way of quantifying their effects nor of saying why the interaction would be unique to Seascale.

10.4 Environmental impacts

The importance of radionuclide remobilization in the assessment of the environmental impact of radioactive discharges into the marine environment and the realization that sediments can act not just as a sink but also as a potential source of contaminants to the overlying waters has prompted an intensification of interest on the study of the processes controlling remobilization and transfer of radionuclides from historically contaminated sediments

Chap.11 REMEDIATION OF WASTE MANAGEMENT FACILITIES

Poor practices in the placement and management of mill tailings in the past have contributed significantly to the negative legacy of uranium mining. The dangers specific to uranium mill tailings relative to tailings from other types of mines were unknown and they were treated in the same manner. That manner was to dispose of the tailings cheaply and conveniently – in topographic depressions to contain tailings and liquor in wet environments (the depressions may have been valleys, lakes etc), or to pile them on flat areas in drier climates. The main vector for contamination in wetter regions is water erosion, leading to contamination of water courses and lakes, while in dry regions the main vector is dust. The contaminants comprised radioactive material as well as toxic metals and other chemical compounds, in many instances accompanied by acidity and salinity.

The objective of remediation is to remove any potentially harmful effects on the environment and human health and to render impoundments stable over prolonged periods of time. The methods and objectives for remediation are similar to these followed in ordinary closeout of such facilities. *A range of non-technical factors,* described in the report , will influence the choice of technologies to be employed in remediation and the strategy for their implementation.

The remediation program should be adjusted to the economic situation and resource availability with time.

For example, in the FSU, funding is often not available for executing full-scale remedial actions but simple and cheap measures such as prevention of further dispersion of materials, of intrusion and prohibition of well water consumption may be adequate initial measures to reduce health risk.

The report described also a case study of optimisation of remediation of the sites contaminated by the WISMUT uranium mining operations in Germany.

Finally the ***conclusions and recommendations of the SCOPE-RADSITE workshop on remediations achievements after uranium mining and milling*** which were presented at an

International Conference held in Moscow in 1999, are described in the report.

CHAP.12 ENVIRONMENTAL IMPACTS: A CASE STUDY OF THE SAVANNAH RIVER SITE

The Savannah River Site (SRS), a U.S. Department of Energy facility analyzed in Chapter 5, was chosen for a more in-depth analysis of the environmental impacts from operating a nuclear production facility for over 50 years. All of the large industrial facilities described in the previous chapters were associated with nuclear weapons programs during a time when urgency was paramount for competing in the nuclear arms race. Vast quantities of contaminants, many of which were radioactive, were produced along with the nuclear products of interest. Much of the contamination was released into the environment. During the early years of operating these facilities there were few environmental regulations and the technologies for removing contaminants from waste streams were poorly developed.

The SRS was chosen for an analysis of the environmental impacts because the quantities of contaminants released from the SRS were recently estimated by the U.S. Centers for Disease Control and Prevention (CDC). This was part of a large-scale effort to reconstruct the dose experienced by offsite residents due to contaminants released from the SRS during operations from 1951 through 1992

Method of Estimating Environmental Impacts from Radiological Releases

The International Committee on Radiological Protection (ICRP, 1977) and the International Atomic Energy Agency (IAEA, 1992) recommended dose rate limits for organisms exposed to radiation, below which deleterious effects to populations are not expected. They concluded that a chronic dose rate of no more than **10 mGy d -1** *to the maximally exposed individuals in a population of aquatic organisms,* and **1 mGy d -1** *to the maximally exposed terrestrial organisms would ensure protection of the population.*

To estimate the dose rates received by SRS biota an approach that the Department of Energy recently proposed (DOE, 2000) was used. It is a graded methodology that starts with a generic, conservatively based screening model, and then progresses to more detailed and site-specific analyses. The DOE model estimates dose rates to biota from 23 radioisotopes via three pathways: ingested contamination, external exposure to irradiation, and, for terrestrial animals, inhalation.

Conclusions and Uncertainties

The rather simplistic approach used to examine the radiological impacts of operating a nuclear weapons complex for over 50 years revealed the following:

- During the early years of operating the SRS, releases from nuclear reactor effluents to Steel Creek, the most contaminated stream on the SRS, were probably sufficient to generate dose rates in excess of the IAEA's guidelines for riparian animals (1 mGy d -1).

- There is no evidence that such dose rates were sufficient to cause mortality to biota. Chronic exposures might alter reproductive performance and thereby affect population dynamics. The probability, type and extent of sublethal damage from chronic, low level exposures to radionuclides are currently the subject of international debate.
- Of the 23 radioisotopes within the DOE's model database used in this exercise, 137 Cs was the contaminant that dominated dose rates to biota. The importance of 137 Cs as an environmental pollutant mirrors earlier studies that documented its importance to offsite human doses via aquatic pathways (RAC, 2001).
- The most visually striking, and best-documented environmental impact to onsite streams, was not caused from radioactive releases but by the increase flow and elevated temperatures from the reactor effluents.
- Isolation of the SRS from development and public occupation has had obvious positive environmental impacts that offset the negative ones caused from reactor effluents.

Major CONCLUSIONS of the SCOPE-RADSITE Project

As it was recalled in the Introduction, the race towards nuclear arms did not burden itself too much with safety and respect of the environment. The most evident manifestation of military programmes are nuclear bomb testing, whose consequences were already been addressed by the SCOPE-RADTEST programme carried out from 1993 until 1997.

Countries primarily involved in re-processing and waste disposal (apart from small amounts arising from medical procedures) are U.S.A., Russia, France, U.K., China and Japan. The environmental effects from military installations, rather than civilian, require careful investigation, particular with regard to medium and long-term exposures of populations. .Human exposures result from the transfer processes of the radionuclides released to diverse biological ecosystems under various climatic regimes.

This study focused on the evaluation of risks from the various radioactive releases and wastes resulting from nuclear weapons fabrication and from the equipment containing irradiated fuel. RADSITE seeks to collate and disseminate relevant work, including data, models and knowledge, about the fate of released radionuclides and their possible human health effects in the medium and long-term.

The findings of the RADSITE programme are of relevance not only to those countries involved in reprocessing and waste disposal activities, but also to other countries with an interest in environmental problems associated with the environmental fate of radionuclides.

Some international organisations, such as the International Atomic Energy Agency (IAEA) are heavily involved with the management of civilian radioactive waste, from technical and safety points of view. Co-ordinated Research Programmes, Workshops/Symposia and technical publications are the products of these activities and are outside the scope of RADSITE.

Activities such as uranium ore mining and milling, uranium isotopic enrichment, spent fuel reprocessing to extract plutonium and R & D on nuclear weapons development, have generated large amounts of radioactive waste that were disposed off with more or less environmental care. Much uncertainty regarding the nature, quantities, the way they were disposed off and the consequence of such disposal for human populations and the environment surround such activities.

The relevant issues of SCOPE-RADSITE Project include consideration of data, models, uncertainties, and new information and insights. Furthermore, clean-up and remedial actions already underway or under consideration are studied in terms of advantages and uncertainties.

Obviously this is not an exhaustive inventory of all the sites and options, but it is a selection of most relevant sites including magnitude and potential mobility of radioactive residues, importance of environmental pathways, current site status, and potential impacts on human health and environment.

The principles of radiation protection widely adopted nowadays and accepted by everyone were not applied in the 1940's and 1950's. At that time the knowledge of the effect of radiation was rather uncertain and for the more relevant weight which was attributed to the achievement of a success also at the cost of human lives.

With reference to the latter issue, the protection of a single person was not considered of a primary importance according the same principle, which accepts a certain number of dead soldiers during a military operation.

Therefore in the 1940's and early 1950's the AEC and the US Defence Dept. were fearful that publicity about hazards in uranium mines might jeopardise their procurement of uranium needed for the Manhattan Project and the Cold War defence.

A legal interpretation of the Atomic Energy Act of 1946 brought to assess that AEC had no responsibility for the safety of miners, since it was stated that AEC had the responsibility for radiation safety for work with uranium after it was removed from its place in nature (Archer et al., 2004).

In USSR hundred of thousands of prisoners were charged with mining and the construction of nuclear plants. Emergency situations were solved according the principle of saving the production of plutonium at the expense of people irradiation. It must be stressed that also some scientists (e.g. Kurchatov) participated to such a dangerous operation (Medvedev & Medvedev, 2003).

We must acknowledge the contribution of lives and illnesses by so many unknown persons who were sacrificed in the last century.

References.

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Medvedev R. & Medvedev Z., 2003 - The Unknown Stalin. The Overlook Press, New York.

Executive Summary (final version) *R.Kirchmann*

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INTRODUCTION

R.Kirchmann

1.1. Background

During the SCOPE (Scientific Committee On Problems of the Environment)-RADTEST Workshop held in Barnaul, September 1994, the RADTEST Executive Committee suggested that the quantities of radionuclides released to the environment from the entire military fuel cycle warranted an examination of the resulting dose to populations. Recognizing the global problem of radioactive waste disposal (particularly that arising from military installations) and its associated environmental and health effects, Acad. V. A. Koptyug, SCOPE's Vice President, proposed the initiation of a new study that would build upon the ENUWAR, RADPATH and RADTEST programs. His proposal for the associated RADWASTE program, later renamed RADSITE, was considered at the 36th Executive Committee meeting of SCOPE in Paris, February 1996, where it gained the interest of SCOPE's President, Prof. Ph. Bourdeau. The Chairman of RADTEST, Prof. Sir Frederick Warner, offered preliminary assistance from the SCOPE Unit based at University of Essex, U.K.

During the RADTEST Steering Committee meeting held in Beijing on 19 October 1996, the background of this new RADSITE Project, with reference to the initiative by Prof. Koptyug, was discussed. The important fact that national authorities would not be as ready to supply information as they had for RADPATH and RADTEST was underlined. At the meeting it was agreed that the first step would be to propose a feasibility study, and later a formal proposal, not restricted to solid wastes, but one that considered the historical practices of the complete fuel cycle.

1.1.1 Feasibility Study

The feasibility-study phase of RADSITE was implemented, following authorization by SCOPE's Executive Committee at its 37th Open Executive Committee Meeting (Feb. 1997, London) endorsing the interest and need for such a program. The study was to comprise a preparatory and a completion phase. The year-long preparatory phase (June 1998/99) sought to clarify goals and assure input, establish RADSITE within the SCOPE structure, and secure a sound financial basis for the project. The three-year completion phase (June 1999/2002) was concerned with collating and synthesizing information for wide dissemination.

1.1.2 *Original Intentions of Project*

The SCOPE-RADSITE Project (RADioactivity from Military Installations SITEs and Effects on Population Health) will provide a unique international scientific study and review of the radioactive wastes generated in the development of nuclear weapons. Slated to be completed in three years (1999-2002), the project will ultimately produce an integrated world-wide assessment of sources of radioactivity, subsequent and potential radionuclide releases into the environment, and associated potential risks to the environment and population health. The relevant issues will be addressed in an objective and dispassionate manner by an international team of experts and will include consideration of data, models, and uncertainties as well as new information and insights. Furthermore, clean-up and remedial actions already underway or under

consideration will be studied in terms of advantages and uncertainties.

The project will include some 50 specialists, operating in teams from four branches; Europe [EU], former Soviet Union [FSU], United States of America [USA] and China, India and Japan [ASIA]. The branches will each develop funding mechanisms to finance their portion of the project and fund necessary travel for their membership. To ensure uniform and equivalent treatment of all components of the study, each branch will include recognised experts in the areas of source terms, environmental pathway assessment, radiation dose estimation, radiation health effects, environmental impacts and remediation/countermeasures. Operating as working groups (WG), branch experts representing each of these components will meet and co-operate during the project to share information and experience. These specialised working groups will also attempt to develop a scientifically based set of assessment tools, comparison models and critical parametric evaluations.

Countries primarily involved in re-processing and waste disposal (apart from small amounts arising from medical procedures) are U.S.A., Russia, France, U.K., China and Japan. The environmental effects from military installations, rather than civilian, require careful investigation, particular with regard to medium and long-term exposures of populations. .Human exposures result from the transfer processes of the radionuclides released to diverse biological ecosystems under various climatic regimes. *Consequently, the study will focus on the evaluation of risks from the various radioactive releases and wastes resulting from nuclear weapons fabrication and from the equipment containing irradiated fuel.* RADSITE seeks to collate and disseminate relevant work, including data, models and knowledge, about the fate of released radionuclides and their possible human health effects in the medium and long-term. The findings of the RADSITE programme will be of relevance not only to those nations involved in reprocessing and waste disposal activities, but also to other countries with an interest in environmental problems associated with the environmental fate of radionuclides.

Some international organizations, such as the International Atomic Energy Agency (IAEA) are heavily involved with the management of civilian radioactive waste, from technical and safety points of view. Coordinated Research Programmes, Workshops/Symposia and technical publications are the products of these activities and are outside the scope of RADSITE.

1.1.3 *Principal Tasks of RADSITE*

(1 *)* Study of radioactive releases and wastes arising from military installations

(a) History of the nuclear facilities operations
- uranium mining and milling
- uranium enrichment facilities
- nuclear material production facilities
  - tritium
  - plutonium
- nuclear reprocessing facilities
- nuclear waste repositories

(b) Collection of data on emission monitoring
(c) Inventory of the potential radiation sources released

(2) Human population e xposure assessments from radioactive releases and radioactive waste disposal

(a) Reconstruction of past doses and current contamination
- Medium term effects
- Long term effects

(b) Collection, when available, of results from site specific models

(3) Taken or foreseen remedial actions relative to clean-up

(a) Limitations of societal resources
(b) Effectiveness of countermeasures (via cost-benefit analyses)

1.2. SITES SELECTED

Each branch selected up to three sites for thorough study, but included information on additional sites where appropriate. Criteria for site selections included the magnitude and potential mobility of radioactive sources, importance of environmental pathways, current site status (i.e. active or not) and potential health and environmental impacts. Final choices were as follows:

- EU: Wismut (Uranium mining and milling), Sellafield/Windscale (reprocessing) and Marcoule (nuclear production facility)
- USA: Hanford (nuclear production facility), Savannah River Site (nuclear production and reprocessing facility) and Oak Ridge (uranium enrichment facility)
- ASIA: India (nuclear production) , China (entire nuclear fuel cycle)
- FSU: Krasnoyarsk, Northwest Russia (plutonium production) and Elektrostal, Moscow (nuclear production)

No classified information was sought or used by RADSITE. Working group meetings and electronic mail exchanges between the participants were used to disseminate relevant information .The unique RADSITE matrix, consisting geographic branches and radiological facilities listed above, provided an unusual opportunity for a focused and unified global review of the subject. Much of the relevant information was only recently been made publicly available, providing the chance to complement and contrast it with all that is known about civilian nuclear programs. RADSITE concentrated on significant aspects of source terms, pathways, models and consequences. It was not possible or realistic for RADSITE to provide a complete inventory of all the sites and options. RADSITE's goal was to select the most significant examples, the best assessment tools and the most scientifically rational options for action.

RADSITE's aim was to produce a comprehensive report on the impacts of nuclear production facilities. The international, integrated, critical review encouraged a levelling of the playing field of this topic, and created valuable new approaches to independent scientific discussions of problems and remediation/ countermeasures.

1.3. ORGANIZATION

1.3.1 *Respective roles of the SCOPE-RADSITE participants*

- The **Steering Committee (SC) members** performed the general co-ordination and made contacts with potential funding organisationsand other international governmental organisations for scientific and/or moral support.
- The **Scientific Advisers** identified, in their respective fields of expertise, the sources of documents interesting for the various RADSITE working groups, and dealt with the sites selected in the RADSITE project for assessment. The Chairmen of each Branch was also informed of the existence of this scientific material by the relevant scientific Advisers.
- The **Branch Chairmen** proposed to the SC, if needed, the names of relevant experts in the various working groups of their Branch. They organised periodically co-ordination meetings to evaluate the progress and to stimulate contacts with external collaborators that were actively involved in studies

of the sites selected by RADSITE

- The **Experts** collected the existing documents relevant for their respective Branches. Later on the experts were asked to comment and to make a summary of the documents collected, a copy was then sent to both the Branch Chairman and their respective WG Leader.
- The **Working Groups Leaders** evaluated the relevance of the information sent by the experts of their respective WG. They reported periodically to the Chairman of the SC on the progress of the work performed in their WG.
- A rapporteur was nominated for each WG in order to prepare a synthesis of the information dealing with the sites selected by RADSITE. This report was circulated to the respective WG experts for comments and improvement (identification of the gaps, corroboration of the results, etc). The improved report was sent to the SC Chairmen for consideration by the SC members and recommendations for further actions.

1.3.2. *Participants* Steering Commitee

- Chairperson: Ph.Bourdeau (Belgium)
- Vice-Chairs: M.Goldman (USA)
  R.Kirchmann (Belgium)

Members

- V. A. Lebedev(Russia)
- T.Sugahara (Japan)
- Mao Yongze (People Republic of China)

Advisers

- R. Masse (France)
- U. Mishra (India)
- Sir Frederick Warner(UK)
- R. Alexakhin (Russia)
- J. Balogun (Nigeria)

Observers

- P.Benes and B. Myasoedov (IUPAC)
- E. Falck (IAEA)

Scientific Secretary

- C.Vandecasteele (Belgium)

Branch Working Groups

	USA*	EU	FSU	ASIA
Chairmen	M. Goldman	R.Kirchmann	A.Iskra	Japan Repr.
Source-terms	G. Vargo	B.Salbu	E.Stukin †	U.Mishra
			V.Kovalevski	Y.Mao
			V.Popov	
Pathways to Man	B.Napier	A.Cigna	E.Kvasnikova	UIR/IAEA
	W.Templeton	Th.Zeevaert	B.Myasoedov	CRP Repr.
			(IUPAC Repr.)	(M. Frissel)
			G. Polikarpov	
			A.Trapeznikov	
Doses est. Health Impacts	L. Anspaugh	W.Burkart	M.Balonov	Pan Ziqiang
	M.Goldman	R. Masse	V. Shevchenko	S.Nagataki
		S. Kaiser	V. Logachev	
		< Rep>	Geogervsky	
Environ Impacts	T.Hinton	D.Woodhead	G.Romanov †	Y.Ohmomo
			Kutlakhmedov	
Counter measures	To be identified	G. Collard	R.Alexakhin	T.Tsukada
		E. Falck	Y Ivanov	
		(IAEA Repr.)		

The following additional experts provided consulting assistance on a limited basis: Prof. Ward WHICKER, Dr. Stanley AUERBACH, Prof. Art UPTON, Prof. Bernard GOLDSTEIN.

1.3.3 *Publication of Results*

The proceedings of workshops were released on the RADSITE website and some were distributed to the participants as a CD-ROM. A comprehensive RADSITE publication was envisaged upon completion of the Programme and will form a volume in the SCOPE Series.

Chap. 1 WISMUT

Karin Wichterey and Peter Schmidt

- **Generalities**

1.1.1 History and Brief Characteristics of the Object

1.1.1.1 1945 - 1953: Soviet-run Company (SAG) Wismut

In the era of the cold war after 1945, there was a great need for uranium as the crucial raw material for military as well as peaceful uses of nuclear energy. In the fall of 1945, Soviet geologists began assessing historic archive papers of the old mining district in Saxony, in the South of the Soviet occupation zone of Germany (East Germany). In 1946, the production of uranium ore from old waste rock piles, adits and shafts began under supervision of the Soviet military. To cover the reparation claims of the second world war, all mining operations in the Soviet occupation zone were transferred into Soviet ownership in 1947. This constituted the origins of the Soviet company SAG Wismut.

Until 1954, this company was focused exclusively on uranium production. Miners and support personnel from across the Soviet zone of occupation were forced to work in the mines. Private and public properties were occupied without legitimate ownership, and became militarily controlled zones inaccessible to the general public . Wismut became a "state within a state". Employing an enormous workforce (peak of 130,000 people in 1950) mining rapidly spread in the Ore Mountains of Saxony and in East Thuringia regions. Mining operations were characterised by poor working conditions and complete disregard for environmental impacts on the densely populated areas.

1.1.1.2 1954 - 1991: Soviet-German Company (SDAG) Wismut

Founded in 1954, the new bi-national Soviet-German company WISMUT continued the uranium mining with the GDR (German Democratic Republic) sharing equity capital. Intense exploration continuously increased Wismut's reserves, new deposits were discovered. Working conditions gradually improved. Radiation and environmental protection legislation introduced during the 1960's enhanced the awareness of radiation protection requirements. The workforce settled down to a permanent staff of some 45,000 for three decades.

Uranium ore was partly produced by open pit mining, but the majority resulted from underground mining operations. The largest mines were at the following sites:

- Aue - a hydrothermal vein deposit in Saxony (underground mining)
- Königstein - a sandstone deposit in Saxony (underground mining; later also underground leaching of uranium)
- Ronneburg - lenticular/stockwork deposit in Thuringia (underground and open pit mining).

In addition the main sites, exploration and exploitation of uranium was also carried out at many other places. This resulted in a large number of relatively small affected sites which were scattered all over Saxony and Thuringia. After termination of production, some of these sites were transferred into ownership of communities and local companies outside of Wismut. More than one thousand sites are known and registered in the so-called "Register of old mining sites" (Altlastenkataster) established by the German Federal Board for Radiation Protection.

In the early years, very rich ore was hand picked and sent to the Soviet Union without further processing. Later on, the ore was processed in mills to concentrate the uranium before shipment to the Soviets. The most important mills were built in

- Crossen (Saxony) and
- Seelingstädt (Thuringia),

Both mills used chemical leaching methods for extraction of the uranium.
The location of the Wismut mines and mills are shown in Fig.1

Fig. 1 - Map of the Wismut mines and mills.

1.1.1.3 1991: Wismut GmbH

Market economy conditions after German reunification put a sudden end to uranium production on December 31, 1990. The Soviet Union disclaimed its shares under the terms of a State treaty in mid-1991. Wismut became 100 percent property of the Federal Republic of Germany. Following a restructuring of SDAG Wismut, the company was legally changed into a company of western corporate law: Wismut GmbH was established. At the end of 2000, the Wismut workforce was streamlined to 3,000 employees. The status and obligations of the company are to decommission its former mining holdings and actively rehabilitate the landscape and the environment, which have been affected over decades of unrestrained uranium production. The Wismut Rehabilitation Project is a unique large scale project, rivalling even the

largest international projects in the field of mining and environmental restoration. It is estimated that its completion will require 13 billion German Marks (about 6 billion US $) of federal funding over a period of more than 15 years.

• 1.2 Source term

1.2.1 Production Capacities and Operation Characteristics of the Objects

In 1967, the uranium production at Wismut reached its peak with a rate of 7,100 tonnes. By 1990, the production rate was still at about 3,000 tonnes. Until the end of production on December 31, 1990, Wismut's cumulative production amounted to a total of about 231,000 tonnes of uranium. In global comparison, this places East Germany as number three, in the post-war production of Uranium, with America as No. 1 (334,000 tonnes) and Canada as No. 2 (240,000 tonnes. Table 1 gives an overview of the capacities and operation characteristics of the WISMUT sites.

Table 1. Capacities and operation characteristics of the Wismut sites

Site (incl. Sub sites)	Start of operation	Operation characteristics	Ore mined [Mio tonnes]	Uranium produced [tonnes]
Mines · Aue · Königstein · Ronneburg · Small sites	1946 1968 1975 1952 1958 1946	Underground mining Underground mining Underground leaching Underground mining Open pit mining Underground/ open pit	18,1 16,2 136,3 17,9	Delivered with ore 81,200 20,600 110,000 19,200
Mills · CCrossen · SSeelingstädt · SSmall sites	1950 1960 1946	Chemical leaching Chemical leaching Leaching; gravimetric extraction		Uranium processed 74,000 110,000 47,000 (partly as ore shipped to the Soviets)

1.2.2 Characteristics of accumulated radioactive materials (RM) and radioactive wastes (RW)

1.2.2.1 Amount of accumulated RM and RW

The depth of uranium deposits mined by Wismut (shaft sinking to 1800 m) as well as very low ore grades and uranium contents in the ore accounted for the tremendous amounts of wastes that accumulated during uranium production. On average, some 1,100 t of ore were needed to yield a single tonne of uranium. The extraction of this amount of ore involved mining and dumping of an additional 2,100 t of waste rock. Wastes accumulated during more than 40 years of uranium ore mining consequently amounted to more than $3{,}12 \times 10^8$. m^3 of waste rock piled up in 48 waste dumps and to more than $1{,}60 \times 10^8$. m^3 of residues from the processing of uranium ores (known as tailings), which were disposed of in 14 tailings management facilities (known as tailings ponds). Radioactive residues are summarised in Table 2.

Table 2. Wastes from the mining and processing of uranium ores at Wismut

Site (incl.subsites)	Waste rock volume [$10^6.m^3$]	Waste rock piles area [ha]	Tailings volume [10^6 . m^3]	Tailings pond area [ha]
Mining sites Aue Königstein Ronneburg	 47.2 4.5 187.8	 342.3 37.9 604.4	 0.3 0.2 0.25	 3.5 4.6 9.0
Milling sites Crossen and Seelingstädt	72.0	533.1	159.7	706.7
Wismut Total	**311.5**	**1517.7**	**160.5**	**723.8**

Remediation activities in general, and the demolition of structures in particular, have generated and continue to produce partly contaminated components, equipment, debris, and the like. Materials and quantities are listed in Table 3.

Table 3: Materials from the demolition of buildings and structures at WISMUT

Concrete/reinforced concrete:	250,000 m³
Masonry:	100,000 m³
Timber:	16,000 m³
Wooden railway sleepers:	7,200 t
Scrap metal:	ca. 300,000 t

Additional radioactive materials produced as a result of the WISMUT remediation program include the residues from water treatment operations that commenced in 1995. Such residues comprise several thousand tons of sludges and filter cakes that have to be appropriately treated and disposed of (Cf. section 4).

1.2.2.2 Nuclide composition and aggregation state

Predominant radionuclides are the natural nuclides of the uranium decay chains. The following radionuclides of the chains are relevant to doses in both solid and liquid residues:

- 238U chain: 238U, 234U, 230Th, 226Ra, 210Pb, 210Po
- 235U chain: 235U, 231Pa and 227Ac

In accordance with the classification level of 300 ppm (ca. 4 Bq/g 238U) that had been used by Wismut for the separation of ore from waste, typical specific activities encountered in the waste rock material are in the order of = 1 Bq/g of the predominant nuclide (typically 226Ra). As a result of chemical extraction processes, residues from milling (tailings) show more elevated specific activities. In this case the specific activity of the predominant nuclide 226Ra is in the order of 10 Bq/g.

With regard to predominant nuclides, Wismut distinguishes between four source terms as shown in Table 4.

Table 4: Relative importance of major isotopes as a function of source term (normalised to the respective predominant nuclide-marked in bold print)

Source type	characteristic of:	226 Ra	238 U	230 Th	210 Pb
Uranium ore	Waste rock piles	***1.0***	0.95 (*)	0.95	0.91
Uranium concentrate	Contamination with the final product of U-production	0.001	***1.0***	0.001	0.0005

Tailings	Tailings	***1.0***	0.04	0.64	0.95
Radon decay products	Contamination of the area surrounding upcast shafts	< 0.03	< 0.03	< 0.03	***1.0***

(*) Depletion as a result of washout effects from waste rock piles (uranium is more readily dissolved than radium).

Table 5 below gives an overview of typical specific activities in the various waste categories.

Table 5. Typical specific activities in radioactive wastes

Wastes	State	Specific Activity	Comment
· Waste rock	· solid	· 0.3 - 2.0 Bq/g	· on average 0.7 Bq/g
· Tailings	· sludge	· 3 - 20 Bq/g	· on average 10 Bq/g
· Contaminated Scrap	· metal (corroded)	· 0.1 - 20 Bq/cm^2 (total alpha surface activity)	· recommended release level: 0.5 Bq/cm^2
· Demolition materials	· solid	· on average <1 Bq/g	· very heterogeneous activity distribution
· Water treatment residues	· sludgy to solid	· up to20 Bq/g 226Ra	· maximum values of specific activity at Wismut
		· up to 1000 Bq/g 238U	

1.2.2.3 General characteristics of RM and RW management

The enormous amounts of wastes from the mining of uranium ore (waste rock piles) and from uranium production (tailings) will largely be remediated in situ under a cleanup program initiated in 1991. Some small-size dumps will be relocated. Large-size waste rock piles will be regraded and covered. Tailings ponds will be dewatered and covered as well (cf. chapter 11 of this report). Table 2 lists the wastes targeted for *in situ* remediation .
For the management and handling of radioactive wastes from the demolition of buildings and structures, WISMUT has chosen the following options:

Contaminated scrap:	The company developed a release measurement scheme that allows the separation and direct sale to the scrap trade for recycling (smelting) of contaminated scrap having an average specific alpha surface activity of less than 0.5 Bq/cm^2 . Scrap exceeding this limit is either disposed of in underground mines or placed into waste rock piles or tailings management facilities.

Demolition of buildings:	This material which is for the most part low level contamination is used as backfilling in the Lichtenberg open pit (Ronneburg site).

Contaminated timber:	Is either disposed of (in underground mines) or placed in tailings ponds, low level contaminated timber is usually shred and composted.

Residues from water treatment	Specific technologies were developed for the safe encapsulation of water treatment residues (immobilisation, solidification) and appropriate storage sites were selected and approved. Available disposal options include underground storage or placement in waste rock piles or in tailings pond beaches.

In addition to the disposal locations previously mentioned Wismut operates a hazardous waste landfill (150,000 m 3 capacity) to dispose of materials of mixed contamination, i.e. radioactively and chemically polluted materials. This landfill is built with a base sealing and drainage system so as to inhibit water infiltration into the wastes and into the underlying bedrock.

1.2.3 Territories contaminated with radionuclides as a result of the objects' operation

There is no environmental contamination as a result of major accidents or incidents at Wismut sites because no environmentally relevant extra-ordinary incidents happened during the entire period of uranium production.

Nevertheless, over the decades of unrestrained production and processing of uranium ores by SDAG Wismut, the landscape and the environment in the states of Saxony and Thuringia were affected. The intense mining in densely populated areas led to heavy devastation of the landscape. This is evidenced by a large number of shafts, waste rock piles, tailings ponds and the large open pit on the outskirts of the Thuringian town of Ronneburg. The affected area under responsibility of WISMUT totals 37 square kilometres. The underground mine workings of Wismut led to a wide-spread network of adits, shafts, and open rooms. At the end of production in 1990, there were 56 major shafts and 1,400 kilometres of open mining tunnels extended over 110 square kilometres.

The following Table 6 shows data on the different areas affected at the sites.
In the early fifties a few smaller incidents happened. Their environmental impact was of minor importance.

Table 6: Data on the different areas affected at the sites

	Aue	Königstein	Ronneburg	Seelingstädt	**Total**
Total area	569.4 ha	143.4 ha	1670.7 ha	1314.8 ha	**3698.3 ha**
Number of shafts	8	10	38	0	**56**
Mine dumps	20	3	16	9	**48**
- number	342.3 ha	37.9 ha	604.4 ha	533.1 ha	**1517.7 ha**
- area occupied	47.2	4.5	187.8	72.0	**311.5**
- Volume x10 6 . m³					

Tailing Ponds - number - area occupied - Volume x10^6 . m^3	1 3.5 ha 0.3	3 4.6 ha 0.2	3 9.2 ha 0.25	7 706.7 ha 159.7	**14** **723.8 ha** **160.45**
Mine workings - area occupied - extend	30.7 km 2 240 km	7.1 km 2 112 km	73.4 km 2 1043 km	0 km 2 0 km	**111.2 km 2** **1395 km**
Open pits - number - area occupied - Volume x10 6 . m^3	0 0 0	1 0 0	0 160 ha 84 (open)	0 0 0	**1** **160 ha** **84 (open)**

Wismut environmental database, or “register”, can be used to obtain the ambient dose equivalent rate (ADR) measured on the surface of the areas affected. A total area of 11,885 ha has been assessed, with about 238,600 data points recorded. The pattern of ADR is as follows:

- ADR < 200 nSv/h: 84.7 % of the area
- ADR 200 - 500 nSv/h: 11.5 % of the area
- ADR 500 - 1000 nSv/h: 2.4 % of the area
- ADR > 1000 nSv/h: 1.0 % of the area

Remark: A mean 226Ra content of 1 Bq/g, homogeneously distributed in the soil, results in an ambient dose equivalent rate of 530 nSv/h in addition to the terrestrial and cosmic background (typically, the background in WISMUT regions covers 80 - 120 nSv/h).

• 1.3 Pathways

1.3.1 Characteristics of radionuclide releases

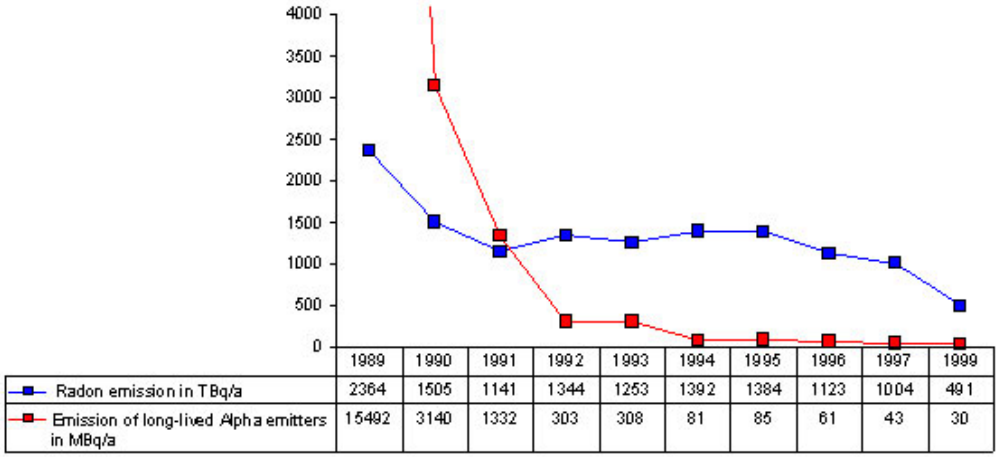
Primary sources of radionuclide release via the atmospheric pathway during production included the discharge of radon and radon decay products as well as of long-lived dust-borne alpha emitters together with exhaust air from underground mine workings. In addition, radon exhalation from piled up processing wastes/tailings and dusting during transportation and processing contributed to atmospheric contamination. Radioactive dust could be whipped up by wind erosion from exposed beaches in tailings ponds composed of the residues from chemical processing .. Via the aquatic pathway, radionuclides were discharged with mine waters and process waters from the mill as well as with seepage from waste dumps and tailings ponds.

Radioactivity releases from mine shaft exhaust air (atmospheric pathway) and waters from mine dewatering and mill effluent (aquatic pathway) were not investigated until the mid-70s. Radioactivity released over the entire period of Wismut operations may be inferred by gross approximation of open mine space and production figures . The following estimates can be made for releases.

- Total air-borne release of radioactivity: 64 000 TBq 222Rn (exhaust air from underground) (all Wismut units) 4 520 tonnes of uranium (from mills since 1984; before 1982: no data)

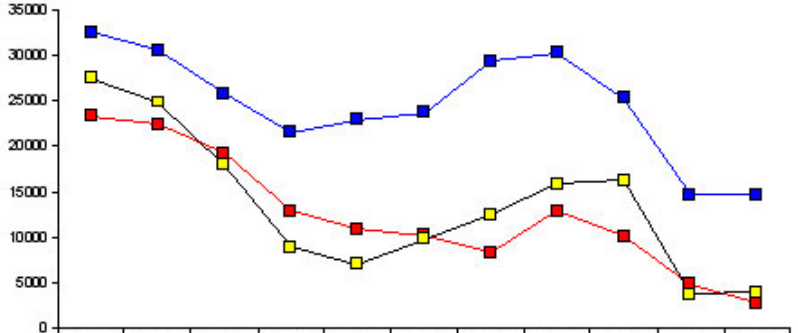
- Total water borne release of radioactivity: 1 530 tonnes of uranium (up to 1990) (all Wismut units) 102 tonnes of uranium (1991 - 2000)

Systematic environmental monitoring by WISMUT GmbH began in 1991. Results obtained since then allow a more detailed description of radioactivity releases and provide details about the time evolution of releases. The data indicate a gradual decrease as remediation progresses.



	1989	1990	1991	1992	1993	1994	1995	1996	1997	1999
Radon emission in TBq/a	2364	1505	1141	1344	1253	1392	1384	1123	1004	491
Emission of long-lived Alpha emitters in MBq/a	15492	3140	1332	303	308	81	85	61	43	30

Fig. 1: Radionuclide release via the atmospheric pathway (upcast air)



	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Ra-226 emission in MBq/a	23421	22360	19242	12879	10868	10178	8301	12889	10136	4886	2699
Uranium emission in kg/a	27490	24868	17942	8916	7103	9781	12388	15849	16335	3776	3820
Water discharge in 10^3m^3	32595	30613	25845	21618	22929	23832	29452	30318	25258	14671	14726

Fig. 2: Radionuclide release via the aquatic pathway and water discharge (mine and process waters)

The increase in water volumes and radioactivity release in the mid-nineties was caused by the start of active water treatment (Pöhla, Aue site; Helmsdorf, Crossen site).

1.3.2 Atmospheric pathways

1.3.2.1 Inhalation of 222 Radon

Taking the uranium-radium-chain as a starting point it is obvious that there is only one gaseous radionuclide: 222 Radon. The inhalation of 222 Rn and its daughters is the most important pathway. 222 Rn-emissions from heaps, shafts and tailings ponds are the main sources leading to enhanced levels of 222 Rn in the outdoor air. However, enhanced concentrations of radon due to the emissions result only in the vicinity of mining sites and tailings management areas. Depending on the orography and other site-specific circumstances such exposures can not be disregarded. Indoor radon concentrations can also be significantly increased by mining activities and residues. In particular, if connections to mine workings occur or if waste rock material is used for building purposes the indoor concentrations of radon can be extraordinarily high. Inhalation of 222 Rn then becomes the most important pathway, in part because of long indoor residence time of inhabitants. Especially important isotopes to doses are the 222 Rn daughter products..

1.3.2.2 Inhalation of dust

Inhalation of contaminated dust is caused by wind erosion from heaps and tailings ponds and has to be considered in the vicinity of mining facilities up to a distance of about 100 meters. During remediation works this pathway can be the most important one. It should not be underestimated because radionuclides can be enriched in fine particles up to a factor of four. Long-lived alpha-emitters are especially relevant to dose. In addition, dust may have an impact on the exposure due to ingestion of locally produced food. For the critical group, the following exposure pathways should be taken into account:

- Air – plant
- Air – fodder – cow – milk
- Air – fodder – cattle – beef

Both pathways, inhalation of 222 Rn and of dust usually occur during outdoor stays. If dwellings are built in the vicinity of or even on heaps the pathways have to be applied to houses as well, using a different equilibrium factor and, respectively, airborne dust load.

1.3.3 Aquatic pathways

Mining and milling have a lasting influence on the aquatic pathway in different ways. During uranium production radioactively contaminated waters were discharged from mines and mills and the radionuclide concentrations in rivers and brooks increased Leaching of waste rocks or tailings by precipitation caused radioactively contaminated seepage water and also affected surface and groundwater. After decommissioning the flooding of underground workings leads to water contaminated by leaching, and this process can result in further environmental contamination .

For the critical group, the following aquatic exposure pathways have to be considered:

- Drinking water
- Water – fish
- Irrigation - plant
- Irrigation – fodder – cow – milk
- Irrigation – fodder – cattle – beef
- Drinking trough - fodder – cow – milk
- Drinking trough - fodder – animal – beef

1.3.4 Terrestrial pathways

Radiation exposure from terrestrial pathways can be caused by contaminated grounds and deposits of contaminated materials. Since the surroundings of mines and mills can be affected by seepage waters, radioactively contaminated dust or mining residues contribute to the contamination of the terrestrial ecosystem.. Both, external and internal exposure can result via the terrestrial pathway. External exposure is caused by gamma-radiation of the radionuclides in soil, especially by the short-lived radionuclides 214 Bi and 214 Pb. Internal exposure is caused by ingestion of food from local production (vegetable and animal food, water), mother's milk and by unintentional ingestion of soil by playing children. The intake of radionuclides via ingestion of food for the critical group results from the following terrestrial pathways:

- Soil – plant

- Soil – fodder - cow – milk
- Soil – fodder - cattle – beef

The external exposure usually occurs during outdoor stays. If dwellings are built in the vicinity of or even on heaps this pathway has to be applied to houses as well, using a shielding factor. Some mining debris and other contaminated materials have been used for building purposes and form an additional source of radiation exposure.

1.3.5 General remarks

All pathways mentioned are illustrated in Fig. 1 - Characteristics of radionuclide releases. Generally only pathways relevant for this site should be applied. Only realistic or foreseen use of the mining areas should be considered. This also means that certain prerequisites must be fulfilled to include a special pathway in the assessment, e.g. there has to be sufficient grassland area to produce milk, or sufficient seepage water to irrigate plants etc. to consider these pathways.

For the age group 0 to 1 year, each of the pathways mentioned above has to be applied again in connection with mother's milk.

References
(Still to be supplied by Karin Wichterey)

- **1.4 Dose assessment**

Dose assessment for residues from uranium mining and milling and a discussion of the related health impacts

Example site: Wismut, Ronneburg region (Eastern Thuringia) Karin Wichterey

Structure

- Development of a specific calculation instruction for dose assessments in mining regions
- Site characterization
- Dose assessment for the Ronneburg region
- Discussion of related health impacts

Summary: radiation exposure

Exposure scenarios:

- Stay indoors (flats, public buildings)
- Stay outdoors
- Ingestion of mother's milk and food from local production (vegetable and animal food, water)

Exposure pathways:

- External exposure due to gamma radiation of the soil
- Exposure by inhalation of dust
- Exposure by ingestion of mother's milk and food from local production (drinking water, fish, milk/milk products, meat/meat products, leafy vegetables, other vegetables)
- Exposure by ingestion of soil

Problems of dose assessment

Limits for NOR in Germany are given as an effective dose *in addition* to the natural background more flexibility (relevant pathways only!) than e.g. specific activities in soil consideration of natural background (3 successive steps of deduction)

- but: Doses have to be calculated! - Questions: How? What assumptions are used? Should scenarios cover everything (extreme behaviour)? etc.

Basis for dose assessments:

- Measuring results of different environmental media (representative?, preferably close to the end-point of the chain)
- Models (how certain?)
- Parameter, assumptions (suitable?)

Differences between dose calculations for the population living around nuclear power plants and in mining regions in Germany

According to ICRP: Broken off practices are world-wide regarded as an intervention! Special situation in Germany after unification: Uranium mining was closed down suddenly, without existing shut-down concept.

nuclear power plants	mining regions
planned situation	existing situation (intervention situation)
high demands, licensing procedure	no or insufficient legal basis
advance protection by technical equipment	subsequent improvement by remediation
meeting lower limits despite conservative assumptions	ensuring limits adapted to nature when using realistic assumptions
predicted doses will never be reached under normal circumstances	possibly real doses

Demand for a separate new Calculation Instruction for intervention situations

Existing „Administrative Regulation according to §45 (new draft: §48) of the Radiological Protection Ordinance: Estimation for the Radiation Exposures Caused by Emissions of Radioactive Substances from Nuclear Facilities“ not applicable for intervention situations!

- legal problems: not valid, no licensing procedure, different limits
- practical problem: high unrealistic doses calculated (e.g.>6 mSv/a by ingestion only), never reached in reality

Establishment of a new „Calculation Instruction for the Estimation of Radiation Exposures Caused by Mining Related Environmental Radioactivity“ for dose assessments (1999) with some important differences

- following the existing provision (main pathways, models, dose conversion factors etc.), but without dispersion models and considering new pathways (soil ingestion, mother's milk) and „dilution“ (75%) with uncontaminated food
- adapted to specific conditions of naturally occurring radionuclides (natural back-ground, almost no radioactive decay, etc.)

Principles of the new Instruction

- Standard assumptions (living habits of a reference person, consumption rates) are as realistic as possible, but sufficiently conservative
- Different site-specific assumptions are possible, if more appropriate

- Calculation of all relevant pathways depending on the scenario of use
- Application for existing and foreseeable (not hypothetical) use only
- Dose assessment preferably based on measuring values than on calculations
- Consideration of six age groups (in accordance with the Euratom Directive)
- Site-specific investigations required, deduction of natural background (in 3 steps)

Characterization of the Ronneburg region

- Located in Eastern Thuringia, flat land, mainly agricultural use
- No historical mining like in Saxony
- Uranium mining for 40 years (1952-1990, U-bearing ores partly up to the surface, average U-contents: 0.07-0.2% (rel. poor)
- Open pit and underground mining with an area of about 2000 ha altogether (open pit: 160 ha, heaps: 1085 ha, tailings ponds: 707 ha)

- Production of 96,000 t U = 40% of total WISMUT-production, (with altogether 114 Mio. t ore, of them 18 Mio. t from open pit mining)
- Usually no public access to tailings and industrial sites, heaps without fence

Use of waste rock material for building roads, squares – sometimes illegal, transport losses, partly insufficient remediation

Measuring results in different materials

Waste rock materials	< 200 - 1,000 Bq/kg 226Ra
Waste rock materials (close to ores)	900 - 2,000 Bq/kg 226Ra
Tailings	5000 –15,000 Bq/kg 226Ra
Soil	30 - 400 (9,000) Bq/kg 226Ra

Gamma-dose rate	70 - 610 (8000) nSv/h
Surface water	0.01 – 0.05 mg/l U nat
Milk, meat	12 - 130 mBq/kg wet matter
Vegetables	40 - 180 mBq/kg wet matter
Grass	200 - 3,000 mBq/kg wet matter
Radon outdoor concentration	20 - 120 Bq/m 3

Dose assessment for the Ronneburg region (1)

Calculations according to the new Instruction/compared to the dose limit (1mSv/a)

1. Without background deduction
2. With general background deduction
3. With site-specific background deduction

Basis: Situation in 1994, has changed fundamental in the meantime with remediation progress (relocation of heaps to the open pit, covering of tailings ponds and some heaps, closing down of shafts, etc.)

Dose assessment for the Ronneburg region (2)
(based on average values)

Pathway	Resulting dose for the critical group* (mSv/a)	
without backgr. deduction	with backgr. deduction	
External exposure	0.238	0
Inhalation of dust	0.025	0.001
Ingestion of local food	0.155	0.128
Ingestion of water	0.056	0.008
Ingestion of soil	0.153	0.029
Sum	0.627	0.146
Inhalation of radon/decay products (ICRP 65)	0.55	0.11

* Critical group being mostly (except dust) the age group <1year

If maximum values are used, 1 mSv/a is by far exceeded– already for external exposure only! But conservative assumptions are not justified for the whole year and the total region. Remediation necessary for important single sites, but not only for radiological protection reasons.

Discussion of the related health effects

- Dose-effect-relationship still unproved in low-dose range, but usually assumed for reasons of taking precautions
- Evaluation of doses always related to risk – what risk is acceptable? ICRP 60: 1 mSv/a corresponds to a risk of 4*10 -3 (for lifetime: 75 yr.), or 5*10 -5 /a. Comparison: 10 -6 for single chemical harmful substance. Tolerable risk depends on many factors within society (not to be discussed here)
- For naturally occurring radionuclides: comparison with/ consideration of natural background is the only reasonable solution Problem: extreme variation range of naturally occurring radon exposure
- Remediation down to the range of natural background (including radon: 1-10 mSv/a, average: 2.4 mSv/a) Special case: exposure to radon in houses, most important dose contribution (1.1 mSv/a on average; sometimes extraordinarily high in mining areas)

Evaluation in Germany

Still in discussion: Radon included in dose criterion or separate Rn-criterion?

Pros and cons: (mSv = mSv!, inconsistency with accepted radon levels in houses)
Political decision!
According to recommendations of the Commission on Radiological Protection in Germany concerning uranium mining:

- Dose criterion of 1mSv/a in addition to the background - oriented to natural range of terrestrial radiation exposure
- Separate: Exposure due to outdoor radon (limit: 80 Bq/m 3 altogether, 50 Bq/m 3 source-related) – oriented to local background + natural range of radiation exposure
- Separate: Exposure due to indoor radon (limit: 250 Bq/m 3)

International suggestions

According to ICRP-publication 82:
< ~10 mSv for existing annual dose (summation of all [prolonged] annual doses attributable to all sources of prolonged exposure in a given location)
Concept: Generic reference level for interventions not likely to be justifiable
(below which intervention is optional but not likely to be justifiable, and above which intervention may be necessary)

1.5 Impact on population health

Health studies

During Wismut's entire operational period of mining and processing of uranium ores in East Germany no grave incident with extremely high emissions into the environment occurred.Thus the comparatively low rate of emission from routine releases did not cause acute radiation sickness or other acute illness among the population. For an individual of the population at large, the environmental impact due to mining activities resulted in an effective dose of up to a maximum of a few mSv per year, locally possibly more. The dose rate was significantly below the threshold for non-stochastic effects. Stochastic radiation injuries that might result from radiation exposures have not been reliably quantified by epidemiological studies. A representative study of population health in former uranium mining regions in East Germany is not available.

The effects of decades of increased radiation exposures and of other unwholesome impacts at underground work places and processing plants were the subject of intensive studying. This was of particular importance for the recognition of occupational diseases and for money compensation involved. The findings of such investigations will be presented below.

Radiological exposures to miners and to workers in processing plants

A retrospective recording of work place exposures was conducted by WISMUT in co-operation with the mining trade association [BBG-98]. For the purpose of these studies, the time frame from 1946 to 1990 was subdivided into three stages according to external features and to technological and technical characteristics, followed by a fourth state (remediation) that commenced in 1991 These stages reflected the radiation exposure.

1 st stage (1946 to 1955, popularly called the "wild years"): During this period the company operated nearly 400 shafts. This stage is characterised by natural ventilation and dry drilling methods as well as by bad working and living conditions. It is assumed that with a heavy labour turnover, the workforce was in the order of between 100,000 and 120,000 miners. For those employees, radiation exposure was very high as is exemplified by the following radiological parameters:

- internal exposure through inhalation of short-lived Rn decay products: **20 - 300 WLM/a** (more recent investigations put maximum values retrospectively up to 400 WLM)
- internal exposure through inhalation of dust-borne long-lived alpha-emitters: **2 - 20 Bq/m³** 238U
- external exposure through gamma radiation: **30 - 50 mSv/a** .

According to [ICRP 65] one WLM (Working Level Month) equals a dose equivalent of 5 mSv.

Based on the assumption of a radioactive equilibrium between all long-lived alpha emitters of the 238U decay chain and taking also the nuclides 210Pb, 235U, 231Pa and 227Ac into account, the inhalation of air with an activity concentration of 238U = 2 Bq/m³ for a working period of 2000 h and at a breathing rate of 1.2 m³/h would lead to an effective dose of 240 mSv per year (dose factors according to Council Directive 96/29/Euratom).

2 nd stage (from 1956 to 1970): Due to the natural exhaustion of reserves, the number of operating shafts was down to some 90 and employment was reduced to nearly 20.000 miners in underground mines. The installation of powerful mine fans, the introduction of wet drilling methods , the sealing of open mine workings, and the targeted deployment of radiological measuring devices in conjunction with statutory requirements resulted in a significant reduction of radiation exposure:

- internal exposure through inhalation of short-lived radon decay products: **1 - 10 WLM/a**
- internal exposure through inhalation of long-lived alpha emitters < **0,5 Bq/m³** 238U
- external exposure through gamma radiation: **2 - 5 mSv/a** .

3 rd stage (from approx. 1971 to the termination of mining in 1990): Constant improvement of mining techniques, ventilation in line with radiation protection criteria and the implementation of an integrated ventilation system in Thuringian mines were crucial contributions that helped stabilise the trend for the better at a relatively high level of radiation protection. During this stage, radiation exposure to the some 20,000 employees was relatively low:

- internal exposure through inhalation of short-lived radon decay products: **Ø 2 WLM/a**
- internal exposure through inhalation of long-lived alpha emitters: **Ø 0,5 Bq/m³** 238U
- external exposure through gamma radiation: **2 - 5 mSv/a** .

4 th stage (rehabilitation of the uranium mining and processing legacy, ongoing): The decline in underground work and the degree of remediation progress achieved entailed a further reduction in the average radiation exposure to workers.

Figure 4.1. below illustrates the development over time of the dominant radiation exposure component, namely the inhalation of short-lived radon decay products. For Object 09 at the Aue site of the former SAG/SDAG WISMUT this graphic exemplifies underground exposures recorded by WISMUT and determined at a later stage within the framework of a detailed retrospective dosimetry study performed by the mining trade association (BBG study).

According to [ICRP 65] one WLM (Working Level Month) equals a dose equivalent of 5 mSv.

Based on the assumption of a radioactive equilibrium between all long-lived alpha emitters of the 238U decay chain and taking also the nuclides 210Pb, 235U, 231Pa and 227Ac into account, the inhalation of air with an activity concentration of 238U = 2 Bq/m³ for a working period of 2000 h and at a breathing rate of 1.2 m³/h would lead to an effective dose of 240 mSv per year (dose factors according to Council Directive 96/29/Euratom).

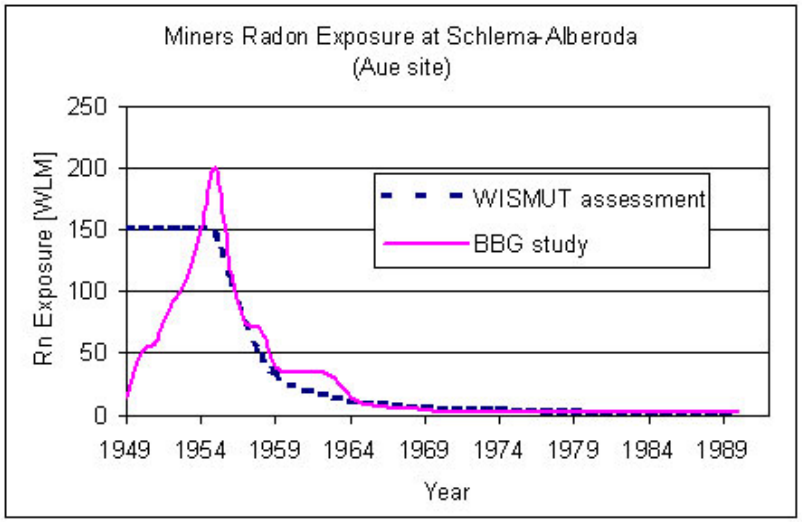


Fig. 4.1 Evolution of radiation exposure to miners at the Aue site for the exposure pathway inhalation of short-lived Rn decay products

Recognition of occupational diseases at WISMUT

Occupational diseases caused by many years in uranium ore mining include:

· Silicosis/silicotuberculosis (pulmonary diseases caused by inhalation of silica dust)
· Radiation-induced lung cancer (also known as Schneeberg lung disease)
· Vibration and stress injuries
· Occupational hearing loss
· Occupational skin diseases / industrial dermatosis / other occupational diseases

By the end of the 1990s, the WISMUT social security system had conducted a total of 43,743 procedures related to the recognition of occupational diseases in favour of 35,004 persons. Out of this total, 31,325 cases were recognised as occupational diseases. 6,943 cases of radiation-induced cancers were notified of which 5,492 cases were recognised as occupational cancers caused by ionising radiation. These diseases were exclusively lung cancer cases.

From 1991 to the end of 1999 the trade associations dealt with an additional 14,426 notifications related to the existence of an occupational disease, with 6,245 notifications relating to a disease caused be ionising radiation. In 4,620 cases it was established that the disease and the practised occupation were causally related. In 2,203 cases the disease was caused by ionising radiation. This puts the total number of radiation-induced cancers that were recognised as occupational disease between 1952 and 1999,at some 7,700.

Some 17 % of all disabled individuals have suffered multiple injuries. A bronchial carcinoma following a previously recognised silicosis was the most frequent combination.

While the frequency distribution of occupational diseases in the GDR for almost the same period shows noise-induced hearing loss at the top followed by skin and infectious diseases with pneumoconiosis only as number four. Thus the order of occupational diseases in uranium ore mining is quite different

.**Silicosis/Silico tuberculosis**

Accounting for almost 50 % of all industrial diseases among uranium miners, pulmonary diseases caused by silica dust outnumber all other mining-related diseases. Dust diseases account for 86 % of all occupational diseases recognised during the period from 1952 to 1960. The main causes for the emergence of dust-induced lung diseases were: extremely high dust loads with inadequate dust control (dry drilling methods), considerable physical stress due to mainly manual work routine and low degree of mechanisation, as well as the great number of exposed persons which for the most part lived in camps under insanitary conditions during the early "wild" years of WISMUT operations.

Radiation-induced cancer of the lung / Schneeberg lung disease

At a relatively early stage, the abundance of cancer of the lung among silver miners in the Schneeberg mining district (Aue site) was diagnosed as occupationally-induced. As early as 1925, this disease was included in the 1 st German Register of Occupational Diseases. Lung cancer, which is mainly caused by the inhalation of short-lived Rn decay products, is the second most frequent occupational disease immediately after silicosis/silicotuberculosis and accounts for about 17 % of the industrial diseases among uranium miners at Wismut.

Occupational hearing loss /vibration and physical stress injuries

Hearing loss due to work area noise represents approximately 15 % of all industrial diseases at WISMUT. Hearing loss ranks almost equally with vibration and physical stress injuries (approx. 16 %) and cancer (approx. 17 %).

Occupational skin diseases / industrial dermatosis / other occupational diseases

With a share of some 2 %, industrial dermatosis plays only secondary role among industrial diseases at Wismut. Industrial diseases of low occurrence are summarised under the category "Other industrial diseases".

Literature to the Chapter:

[BBG-98] F. Lehmann, u. a.: Belastung durch ionisierende Strahlung im Uranerzbergbau der ehemaligen DDR, Abschlußbericht zum Forschungsvorhaben, Bergbau-Berufsgenossenschaft - BBG, Bochum, Dezember 1998.

[ICRP-65] ICRP Publication 65, Protection Against 222Rn at Home and at Work, 1994.

1.6. IMPACT ON ENVIRONMENT

1.6.1 Nuclear impact

Over 40 years of radionuclide emissions from uranium ore mining and processing facilities at WISMUT sites has led to environmental accumulations of radioactivity in the air, water and soil. Increase in concentrations in those media resulted in a transfer to biota.

Activity concentrations in plants

Systematic studies of activity concentrations in living matter performed at WISMUT and by Federal Authorities were mainly restricted to plants. A broad range of transfer factors for the transition of radionuclides from the soil into the plants was in the order of 10^{-3} to 10 -1 (here the transfer factor denotes the ratio of activity concentration in the herbaceous fresh mass to that in the dried soil mass).

Radionuclide contamination in tress and shrubs were approximately 1 Bq/g from waste dumps and plant areas, 0.1 Bq/g from 226 Ra and 210 Pb and 0.01 Bq/g from the other nuclides of the uranium decay chain.Individual plant compartments (e.g. bark, roots) showed a higher enrichment of radionuclides than found in the trunk (226 Ra in particular, with measured peaks of 1 Bq/g in the bark of trees grown on soils with a local specific activity of 5 Bq/g 226 Ra). Transition of radionuclides in the wood did not cause any restriction in the use of the wood.

By contrast, nuclide transfer could attain radiological relevance in the case of plants intended for human consumption (leafy vegetables, vegetables, fruits), which are grown right next to mining relics. Transfer factors caused activities in foodstuffs of 0.01 to 7.6 Bq/kg fresh weight (FW) from 226 Ra and 210 Pb, less from 238 U, 234 U and 210 Po. The resulting mean values are about 0.5 Bq/kg FW, which is - compared to the natural background - an enhanced level due to some clearly affected products.

For fodder plants, there was a similar situation. In the surroundings of mining areas specific activities typically measured for 226 Ra were between 1 and 10 Bq/kg , but 130 Bq/kg could be reached on contaminated grounds.

Activity concentration in animal products

In mining regions, Federal Authorities and WISMUT did not carry out systematic studies on radioactivity in animal products except for milk.

Measurements of raw milk from the Ronneburg region during the uranium production in the Seventies caused specific activities of 226 Ra to be 0.03 to 0.14 Bq/kg FW with a median value of 0.06 Bq/kg FW. These values were reduced in the 1990s after rehabilitation of the area to 0.01 to 0.1 Bq/kg FW with a median value of 0.02 Bq/kg. For 210 Pb the measurements in 1993 showed even lower values of 0.007 to 0.023 Bq/kg FW. In regions not affected by mining typical specific activities for 226 Ra were about 0.02 Bq/kg FW.

Additionally, there are some measurements in beef or game, respectively, in entrails (liver, kidney). The range of specific activities was from 0.06 to 1.8 Bq/kg FW for 226 Ra in these products, and from 6.5 to 11.3 Bq/kg FW in bones from beef, and from 27 to 66 Bq/kg FW in bones from game. In 1992, BfS examined private small livestock products near an uranium pile. Values for 226 Ra in meat (chicken, rabbit, sheep) ranged between 0.02 and 0.18 Bq/kg FW and for 210 Pb between 0.03 and 0.55 Bq/kg FW. For liver the corresponding values for 226 Ra were from 0.02 to 0.36, for eggs 0.52 Bq/kg FM 226 Ra and for bones between 1.5 and 44.5 Bq/kg FW 226 Ra, and between 0.6 and 13 Bq/kg FW 210 Pb, respectively. These values are slightly enhanced, but usually within the natural range given in literature.

There exist a few measured data. for uranium and 226 Ra in fishes that were caught in the supernatant water of a tailings pond (carp species: 0.5 Bq/kg to a maximum 7.4 Bq/kg 238 U; 0.7 to 2.7 Bq/kg 226 Ra and 210 Pb). Given the uninviting appearance of the water body, it could be excluded that such fish were consumed in large amounts by the local population.

As a rule, investigations on radioactivity in animal life beyond that were only performed within the framework of exposure pathway analyses. These started from the radioactivity observed in the environmental medium (soil, water) and the ingested radioactivity was estimated from transfer factors (soil ® plant ® animal; water ® fish) taken from literature. Typically, it turned out that this exposure pathway at

WISMUT sites was not relevant in radiological terms. Only in some single situations are more detailed investigations necessary in order to evaluate possible consequences for further use.

1.6.2 Other nuclear directly related impact

Large-scale deposition of radioactive wastes from the mining and milling of uranium ores in the immediate vicinity of residential neighbourhoods has led to the affected areas needing extensive rehabilitation. After the cleanup, reuse of the rehabilitated areas partly will be restricted.

These areas include:

· Waste dump footprints (total of 1,518 ha)

· Tailings management facilities (724 ha) and

· Open pit mine (160 ha)

Also parts of the plant areas (e.g. at the sites of the former chemical processing plants in Crossen and Seelingstädt) are contaminated by radioactive and partly also by chemico-toxic pollution to such an extent that the cleanup to pristine levels will not be possible and that reuse of the areas will be restricted. Anyhow, construction of homes or of playgrounds at the remediated sites will have to be ruled out.

Radioactivity dispersal and local accumulation of radioactivity, in particular via the aquatic pathway, are the reasons why specific activities of > 1 Bq/g of the predominant nuclide were encountered in some areas (e.g. river flood plains, sedimentation sinks in water bodies). Site-specifics and existing or intended use of these locations may give rise to the need for their rehabilitation.

Increased radon concentration also exist in quite a few buildings (both residential and industrially used structures) in former uranium mining regions which constitutes one major radiological environmental impact. These high concentrations are due to, e.g.:

· use of waste rock material as aggregate in the building industry and

· near-surface underground mining operations.

The affected buildings have to be either rehabilitated or their use has to be restricted.

Furthermore, the radon outdoor concentrations are enhanced near surroundings of some piles or tailings ponds, as well. Depending on many parameters like activity, grain size and height of the deposited materials, local orography and climate conditions 222 Rn concentrations at piles can be significantly increased. Since 222 Rn concentrations decrease within short distances, only in a few residential areas they exceed the upper end of natural background levels (80 Bq/m^3).

1.6.3 Non-nuclear site related impact

The enormous/tremendous devastation of the landscape and the related dramatic restriction of land use and impact on the quality of life of the locals must be qualified as the most serious, and at the same time most apparent non-nuclear environmental impact.

The municipality of Schlema near the Aue site, for example, was one of the leading German radon spas before the war. Uranium mining immediately after the end of the war, put a sudden end to the continued operation of the spa facilities. During the years of intense uranium ore mining, waste rock piles of a total volume of some $40x10^6$. m^3 were dumped around this township, completely ruining the beauty of the landscape. Intense transportation operations and the local economy being geared to a single-product left their mark on the site. Only when first rehabilitation successes became apparent in the mid-nineties, did spa activities resume and new vistas for this affected area were opened (see photos below).

....

Figure 5: Schema during the sixties and today (shown here: the rebuilt spa centre)

Apart from the devastation of the landscape, the pollution of soils and waters with conventional chemical contaminants has to be mentioned among the non-nuclear impacts on the environment. Major contaminants are:

· Arsenic
· Metals (Fe, Ni, Mn, ..)
· Salts (sulphates, carbonates).

Small receiving waters in particular were polluted by seepage from waste dumps and plants as well as by residues of uranium ore processing. This resulted in the destruction of aquatic communities and restricted the use of water bodies by the local population.

Mining damage constitutes another non-nuclear environmental impact. Underground mining operations in the Aue region were extended upwards very close to the surface level and have led to geotechnical settlement phenomena. Buildings were also affected by the release of geotechnical stresses (cracks, breaking of seals).

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Chap.2 - P.R.CHINA
Mao Yongze, Lu Jiandong, Pan Ziqiang

2.1 Generalities (Mao Yongze)

2.1.1 Foundation and feature of nuclear fuel cycle facilities (Li jue et al,1987a ; Pan Ziqiang,1997a)

The Chinese government started constructing the nuclear fuel cycle facilities and associated nuclear industry early in *1955*. The leading feature of their rapid development was to serve the purpose of national defense. The nuclear industry as a part of the National Department of Science and Technology for Defense carried out the guiding principle of "focus on military needs" Under the goal of military application an integrated nuclear industry was quickly established.

It laid the good foundations for further developing the application of nuclear energy and better serving the purpose of construction of national economy with nuclear technology.

The practice of nuclear industry over three decades revealed a fact that the safety record of nuclear industry was pretty good. The environmental impact of China's nuclear fuel cycle has been negligible.. China as a developing country has a population of 1.2 billion, from the point of national dose which involves the exposures of national background, professional, public and medical, the nuclear industry delivers to the public an annual collection dose of about 23.1 man-Sv which was lower than those of the exposure pathway from aviation (36 man-Sv).

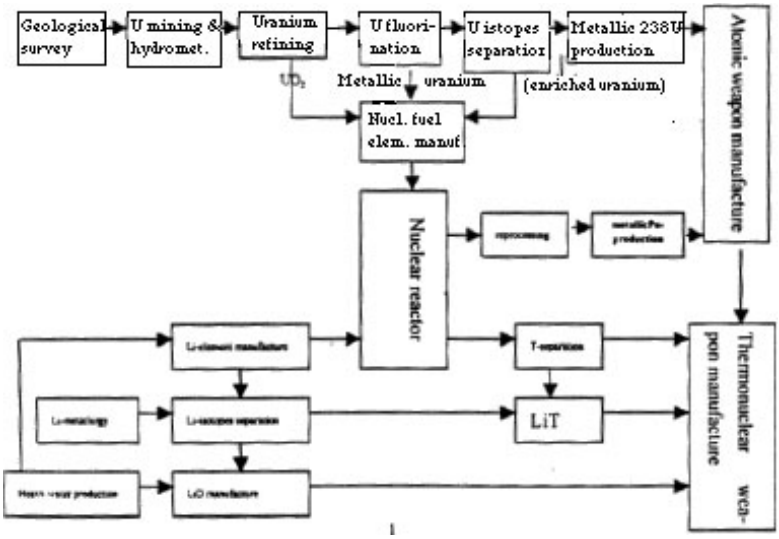

Fig. 1 The main technological process of nuclear industry for national defense in China

2.1.2. Overview of foundation of nuclear fuel facilities.

2.1.2.1 Uranium ore mining, uranium extraction and refinement (Li jue et al,1987b *;* Deng Zuoqing,1994 *).*

In 1955, uranium ore deposits were discovered by the Department of Uranium Ore Geology in China. The first batch of uranium ore metallurgy engineering projects "three mines and one plant" began construction in 1958. “Three mines” represented the uranium ore mines found in Hunan and Jiangxi provinces, while “one plant” was the uranium ore hydrometallurgical facility found in Hunan province. They were established and put into production in 1963. Since then several uranium ore bases, uranium ore metallurgical plants, a complex of uranium ore mining and metallurgy and complementary facilities for scientific research, design, mechanical repair and manufacture were established, thus, creating a complete uranium ore industry system. Uranium ore and uranium dioxide products were produced in sufficient quantity to satisfy the requirement for the production of nuclear fuel.

Well-mining technology and some open cast mining technique were used in China's uranium ore mining industry. Beginning in the 1960s, chemical methods for uranium ore mining, including pile immersion and ground immersion method were put into research, development and application. The wet metallurgical method was used for uranium extraction and refinement of uranium ore. The plants which were constructed for uranium extraction and refinement were usually called hydrometallurgical plants.Directly extracting nuclear pure products (ammonium uranyl tn-carbonate) from the soaking-out liquid of uranium ore and extracting uranium from low temperature fired uranium-bearing coal for electricity generation represented China's specific technology for uranium ore metallurgical engineering.

2.1.2.2 Uranium isotopes separation (Li jue et al,1987c , Qian Gaoyunî,1994 *)*

In China the gaseous uranium hexafluoride diffusion technique was used for the separation of uranium isotopes in order to obtain enriched 235 U.The first gaseous diffusion (235 U enrichment) plant started construction in the late 1950s in Gansu province. It was completely established and put into production in July 1964. In the early 1970s production capability of the plant was further expanded and since then new-type diffusion devices were developed and applied in China. From the late 1950s to the early 1980s various new-type diffusion membranes were developed and used for uranium isotopic separation.

To complement the gaseous diffusion plant factories for producting of intermediate chemicals (uranium tetra-fluoride and gaseous uranium hexa-fluoride) were constructed and operated in the year 1962 to 1963. Initially, wet technology was used for the production of uranium tetra-fluoride, but later a dry technology was adapted.. In the process of producing gaseous uranium hexa-fluoride a median temperature electrolyzer for producing fluorine gas and an advanced stand-up fluid type fluorination furnace were developed .These were used for large scale production of gaseous uranium hexa-fluoride.

2.1.2.3 Manufacture of nuclear fuel elements

Nuclear fuel elements composed of cylindrical metallic natural uranium within aluminum alloy tubes were the key parts of a production reactor. Research Development and manufacturing technology for nuclear fuel elements began in 1960. The plant for manufacture of metallic natural uranium nuclear fuel elements, situated in the Inner Mongolia autonomous region, began to provide the products for nuclear fuel loading of production reactor in Oct.1965 and was put into large-scale production at the beginning of 1966.

2.1.2.4 Light-water cooled graphite moderated production reactor (Li jue et al,1987d *)*

The siting of the first production reactor at Gansu province was completed in 1958 and capital construction started in 1960. In 1965 the general description for design of the light-water graphite modulated production reactor was accomplished. Meanwhile from 1960 to the third quarter of 1966 a much research and experimental works was performed including calculation of the temperature coefficients of reactor core, reactor shielding design, process tubing hydro-mechanical test, nuclear fuel elements condition test, control rod system hydro-mechanical tests, simulation assembly for starting of reactor operations, etc. On the basis of successful manufacture of high purity graphite reactor engineering finished the graphite installation in the spring of 1966 and the fission reaction was realized in Oct. 1966. Before the beginning of the coming year operational power was gradually raised and stable operation occurred later on. Since the operation of production reactor until *1985,* renovation of equipment and accumulation of operational experience took place, such that now multi-use of the reactor is achieved.

2.1.2.5 Reprocessing of spent fuel (Li jue et al,1987e , Jiang Yunqing,1994 *)*

Spent fuel from production reactor was reprocessed with the purpose of extracting the military plutonium with highly abundant 239 Pu and recovery of natural U depleted of 235 U . The plutonium product was used for manufacture of nuclear weapon and the uranium product was sent to an uranium isotopes separation plant for further concentrating by diffusion . .

The technology for spent fuel reprocessing was starting with a precipitation method in *1956.* During 1964 on the basis of the results of scientific research an important decision was made to change from the precipitation method to an extraction one. In 1968, a pilot plant using the Purex extraction method was set up and put into operation. It provided the Pu load for China's first test of a thermonuclear weapon. Parallel to the pilot plant a reprocessing plant for military use was constructed and started to provide qualified products. Together with the production reactor the plant became the important part of the Atomic Energy Complex in Gansu Province, China.

2.1.2.6 Thermonuclear materials production (Li jue et al,1987f *)*

During *1958,* the development of a production line for lithium isotopes separation and !ithium-6 deuterate (Li 6 D) was started and was put into normal production in 1965. The first laboratory for manufacturing tritium was established in 1963. A production line was set up and provided qualified products in 1968. A 6 Li 2 DT production line was also constructed later in 1972, resulting in a complete production system for thermonuclear materials in China. Tritium is a radioactive isotope of hydrogen with very low beta energy emission. The technology for 3 H production was established and including manufacturing 6 Li targets, neutron exposure in-pile of reactor, melting and extraction, impurity removal , purifying and isotopic separation.

2.1.2.7 Nuclear weapon R&D (Li jue et al,1987g *;* Song Binghuan,1997 *)*

Since 1958 the framework for research and development of nuclear weapon was organized in China at the Nuclear Weapon Institute in Beijing as well as a nuclear weapon research base in northwest of China. After nearly five years of research and development effort, and the successful full scale simulation test of implosion in June 1964 the first nuclear weapon device was successfully exploded on a

102m high tower at the Xinjiang nuclear test site on 16th Oct. 1964.The device had a yield of 22kt TNT equivalent. About two and a half years later, on 17th June.1967, the first air drop and explosion at the height of 2960m was successfully performed with a yield of 3.30 Mt of TNT equivalent.

2.2 Source term (Mao Yongze **)**

Table 1 Annual mean discharge values (Bq) and range of gaseous and liquid effluent from uranium ore metallurgy system

nuclides	gaseous		liquid						
range	annual mean	range	annual mean						
U	4.56×10^5 ~8.90×10^9	3.58×10^9	1.30×10^8 ~3.46×10^{114}	1.91×10^{11}					
230 Th	2.28×10^5 ~1.09×10^9	3.68×10^8	3.53×10^7 ~4.30×10^{10}	1.22×10^{10}					
226 Ra	$2 . 28 \times 10^5$ ~1.13×10^9	3.94×10^8	5.27×10^7 ~1.54×10^{11}	7.09×10^{1010}	**222 Rn**	7.30×10^{10} ~5.90×10^{14}	2.76×10^{14}	-	-
210 Po	2.28×10^5 ~1.10×10^9	3.72×10^8	$1 . 76 \times 10^7$ ~3.29×10^{10}	1.01×10^{10}					
210 Pb	2.28×10^5 ~1.09×10^9	3.68×10^8	4.39×10^7 ~6.00×10^{10}	1.85×10^{10}					

The quantities of radioactive substances discharged to the environment were determined from the measured volume activity of gaseous or liquid effluent multiplied by the total volume of gaseous effluent or liquid effluent. Table 1 to table 6 illustrated the total activity of different radionuclides in gaseous and liquid effluents discharged from six kinds of nuclear industry systems: the uranium ore metallurgy system, the nuclear fuel element manufacture system , the uranium isotopes separation system, the nuclear reactor and spent fuel reprocessing system, the nuclear metallurgy and processing system and the nuclear engineering research system.

Table2 Annual mean discharge values (Bq) and range of gaseous and liquid effluents from nuclear fuel element manufacture system

nuclides	gaseous		liquid	
range	annual mean	range	annual mean	
U	3.00×10^5 ~1.57×10^{10}	6.70×10^9	6.90×10^8 ~2.91×10^{10}	8.38×10^9

Table3 Annual mean discharge values (Bq) and range of gaseous and liquid effluent from uranium isotopes separation system

nuclides	gaseous		liquid	
range	annual mean	range	annual mean	
U	1.20×10^8 ~2.08×10^{10}	1.76×10^9	4.88×10^7 ~1.37×10^{10}	5.62×10^9

Table4 Annual mean discharge values (Bq) and range of gaseous and liquid effluent from nuclear reactor and spent fuel reprocessing system

nuclides	gaseous		liquid	
range	annual mean	range	annual mean	
41 Ar	1.10×10^{14} ~2.32×10^{15}	1.19×10^{15}	-	-
133 Xe	2.00×10^{12} ~2.82×10^{16}	3.99×10^{15}	-	-
131 I	4.00×10^7 ~2.87×10^{11}	7.94×10^{10}	-	-
85 Kr	1.44×10^{15} ~7.10×10^{15}	4.80×10^{15}	-	-
137 Cs	4.40×10^9 ~1.78×10^{10}	1.29×10^{10}	2.00×10^8 ~3.70×10^{11}	5.76×10^{10}
90 Sr	5.90×10^9 ~2.46×10^{10}	2.60×10^{10}	3.00×10^8 ~5.14×10^{11}	8.94×10^{10}
239 Pu	3.40×10^8 ~5.92×10^9	1.99×10^9	1.30×10^9 ~6.51×10^{10}	9.80×10^9

Table5 Annual mean discharge values (Bq) and range of gaseous

and liquid effluent from nuclear metallurgy and processing system

nuclides	gaseous		liquid	
range	annual mean	range	annual mean	
239 Pu	2.0×10^{8} ~4.8×10^{10}	5.5×10^{8}	4.0×10^{6} ~1.1×10^{7}	7.8×10^{6}
238 U	1.0×10^{3} ~8.1×10^{5}	3.9×10^{5}	3.3×10^{5} ~1.5×10^{9}	2.1×10^{8}
235 U	3.0×10^{2} ~9.1×10^{3}	5.6×10^{3}	1.0×10^{5} ~8.9×10^{5}	5.4×10^{5}
3 H	2.0×10^{14} ~5.0×10^{15}	1.2×10^{15}	-	-

Table 6 Annual mean discharge values (Bq) and range of gaseous and

liquid effluent from nuclear engineering research system

nuclides	gaseous		liquid	
range	annual mean	range	annual mean	
41 Ar	4.10×10^{12} ~5.00×10^{14}	1.25×10^{14}	-	-
131 I	5.60×10^{8} ~9.90×10^{11}	1.32×10^{11}	9.10×10^{5} ~4.06×10^{6}	2.49×10^{6}
3 H	1.70×10^{13} ~5.30×10^{13}	1.39×10^{13}	1.90×10^{10} ~2.30×10^{12}	1.09×10^{12}
125 I	8.40×10^{9} ~1.00×10^{11}	2.20×10^{10}	-	-
90 Sr	5.30×10^{4} ~3.40×10^{8}	4.20×10^{7}	-	-
137 Cs	5.30×10^{4}~3.40×10^{8}	4.20×10^{7}	1.94×10^{4} ~3.30×10^{5}	1.38×10^{5}
60 Co	3.40×10^{4} ~7.58×10^{6}	1.64×10^{6}	1.80×10^{6} ~1.76×10^{8}	7.80×10^{7}

2.2.1 Environmental protection in nuclear industry (Li jue et al,1987h **)**

Since the mid 1950's in connection with the development of nuclear science and nuclear industry, the protection of the environment and public against radiological hazard became an important component of China's nuclear program . The safety and health of the professional workers and the public around the nuclear facilities had been a matter of the utmost concern for the Chinese government using the guiding principle of "before start-up for production, protection shall be under pre-consideration" . In order to protect the environment and reduce the radiation exposure to the public, an As Low As Reasonably Achievable (ALARA) philosophy was applied in the field of nuclear facilities siting, treatment and disposal of radioactive wastes, environmental radiation monitoring, dose evaluation etc.

2.2.1.1 Nuclear facilities siting

Selection of the appropriate natural and social environmental setting represents an important condition for protecting the environment and public against the impact of radioactive substance. During the siting of the first batch of nuclear facilities the following factors were taken into consideration, possible influence on nuclear plants from externally natural and man-made conditions; radioactive substances released during normal and accidental conditions (easily be diluted and diffused); and less population density around nuclear facilities. The hydro-geological condition were generally good at the site of these nuclear facilities. The majority of the plants with large radioactive material discharge applied natural evaporation method in order to avoid the impact on rivers. Additionally the meteorological condition were also good and the sites were located in remote place with low population densities . All of these benefited the protection of residents and the environment around nuclear facilities. Atmospheric diffusion experiments were carried out and the diffusion parameters as well as the limits for concentration and total output of gaseous effluent were determined. In some case the dilution and deposition factors in rivers were also tested in order to control their radioactive contamination.

2.2.1.2 Treatment and disposal of radioactive waste (Qian Gaoyunî ,1994; Sun Donghui,1994 *)*

At an early stage of of uranium mining and hydro-metallurgy, it appeared that too much radioactive substance were in the liquid waste resulting in contamination of rivers. After the technical measure "treatment before discharge" was forced to be taken the quality of river water rapidly improved. Because uranium ore mining and hydro-metallurgy, together with the production reactor and reprocessing plant were the main contributors impacting the environment, a guiding rule was established: "focus on two facility systems and water treatment in chief" . By the 1980's, most of the facilities for uranium ore metallurgy and uranium fuel processing had installed waste water treatment facilities and advanced fluid-bed ion-exchange technologies to remove uranium radioactive isotopes prior to their release into the environment.

P rocess gas waste was treated with general purification assemblies. After recovery of uranium the gaseous effluent was discharged through tall stacks. The solid wastes containing relatively high concentration of uranium were recovered by appropriate treatment.

In the production reactor and spent fuel reprocessing facilities the treatment of wastes was accomplished in three periods. In the early 1960's, low level radioactive liquid wastes were directly discharged to the pool for natural evaporation and attenuation of radioactivity.. In the 1970's, low level radioactive wastes were treated with standard technology ("three stages": precipitation-evaporation-ion exchange) and in the 1980's liquid radioactive wastes were turned to bitumen and cement while high level radioactive wastes solidified into glass.

Since 1977 research on the strategy and technology for final disposal for radioactive wastes has occurred. The disposal of median and low level radioactive wastes should be done at local and appropriate sites. High level radioactive wastes (HLRW) however should be first stored locally 20 to 30 years and then the final disposal should be considered. Research on finally geological disposal of high level radioactive wastes was commenced in 1985 and since then much research work has been conducted, including site pre-selection for HLRW, site pre-selection for underground research laboratory, experiments on radio-nuclides migration, modeling for safely and environmental assessments etc

2.3 Pathways

No specific contribution to this section has been provided as the locations of the military nuclear facilities are unknown. Nevertheless it is worth to mention that an adapted radioecological model, ECOSYS-87 (Muller and Prohl 1993), has being used in Hong Kong:: to evaluate the time-dependent contamination that might occur in food products should a nuclear accident occur at the Guangdong Nuclear Power Station at Daya Bay, and to assess the dose consequence to the local population from ingestion of contaminated foods.

2.4 Dose assessment (Mao Yongze **)**

2.4.1 Environmental evaluation and impact of nuclear industry on environment (Li Jue et al,1987h; Pan Ziqiang ,1994 **;** Pan Ziqiang,,1997b **)**

The environmental qualities of the Chinese nuclear industry over the last thirty years have been evaluated in the six different areas of the nuclear fuel cycle including uranium ore metallurgy, uranium isotopes separation, nuclear fuel element manufacturing, nuclear reactor and spent fuel reprocessing, nuclear metallurgy and processing and nuclear engineering research.

For quantitative estimation of the impact on the environment by the nuclear industry and for convenience of comparison with the results in foreign countries, the radius of area evaluated around the nuclear facility was defined as 80 km.

The method of evaluation adopted was principally the environmental assessment model, in connection with measured results from environment monitoring.

The endpoints of evaluation were the maximum personal effective dose equivalent and the collective effective dose equivalent.

The assessment models included a dose estimation model for routine release of gaseous radioactive effluent, a dose estimation model for routine discharge of liquid radioactive effluent to a river and an accidental radioactive release model.

Under normal operation the quantities of radioactive substances discharged to the environment were determined from the measured concentration of gaseous or liquid effluent multiplied by the total volume of gaseous effluent or liquid effluent. The main radio-nuclides in gaseous and liquid effluents discharged from the six systems mentioned above were 222 Rn, 226 Ra, 210 Pb, 41 Ar, 41 Xe, 131 I, 85 Kr, 137 Cs, 90 Sr, 60 Co, 239 Pu, 238 U, etc.

Over thirty years, it was concluded that defining facility year as a unit of statistic up to *93.5%* of key resident group's annual effective dose equivalent from the gaseous and liquid effluents of nuclear industry was below l mSv and about 6.5% was over l mSv but below 5 mSv. In comparison with the national standard "Regulation for Radiation Protection" neither group exceeded the annual dose limit for the public. The annual mean collective effective dose equivalent for the public from the nuclear industry was only 23.l man-Sv which was about 1/10,000 of natural background for the same group of residents.

The main source contributing to the collective effective dose equivalent of the residents around the nuclear facilities was the uranium ore metallurgical facility due to the large quantity of radon discharged. The radon quantity discharged to the environment per 100t of uranium production was much more than that estimated by the UNSCEAR. Further more there were numerous uranium ore metallurgical facilities with relatively high population densities around them, about 64 times higher than the value given in the

UNSCEAR model.

Between 196 and 1985 the collective effective dose equivalent of residents near nuclear industry increased. This was because the scale of production increased with time, as did the population.. After 1978 the collective effective dose equivalent was principally constant, during this time the scale of production was somewhat expanded, but to effective countermeasures the collective effective dose equivalent decreased correspondingly.

The main radionuclides contributors to collective effective dose equivalent of the residents around the nuclear facilities were in decreasing order: 222 Rn, 210 Pb, U(natural), 131 I and 226 Ra. Except for 131 I and U(natural) all the rest of the radionuclides originated from the uranium ore metallurgical discharge with 222 Rn being the maximum contributor.

Since the operation of nuclear industry over thirty years, the probability of occurrence for accidents was small, and when accident did occur emergency protection was taken in time to reduce the hazards. .

There were 19 accidents that impacted the environment. The impacts on the environment and public from all of these accidents were small either from the standpoint of maximum personal effective dose equivalent or collective effective dose equivalent.- For example, neither accident No.12 an 131 I release from a heavy water reactor, nor accident No.9 a ground release of high level waste [90 Sr (8.3 X 10^{11}11 Bq), 137 Cs(4.1 X 10^{11} Bq) 239 Pu (8.l X 10^{7} Bq)] resulted in the maximum personal effective dose equivalent for the residents to exceed the dose limits for public under normal condition defined by the governmental regulation for radiation protection.

In comparison with the major nuclear accidents (25) that occurred in foreign countries the collective effective dose equivalent of residents from accident N°12 was about 4X $l0^{-3}$ or about 0.3% of that resulted from Windscale production reactor nuclear accident, and the collective effective dose equivalent from accident No.9 was about 1.4 X $l0^{-3}$ or about 0.1% of that from the Kyshtym nuclear accident.

The 19 accidents occured mainly during 1967-1978 with the exception of two accidents one in 1980 and another in 1981.

2.4.2 Environmental radiation monitoring and dose evaluation

For the sake of avoiding radioactive contamination of environment in addition to treatment and disposal of radioactive wastes it was necessary to monitor the radioactivity level of environmental medium as well as to evaluate and control the environmental and public exposure for promotion of the safe operation of nuclear facilities. According to the requirements of the national standard "Regulation of Radiological Protection" the laboratory for radiation monitoring was constructed together with the nuclear facilities. One year before the operation of the nuclear facilities the survey for radiation and radioactivity background level was conducted . Then the facility was permitted to be put into operation. Under normal operational conditions routine radiation monitoring was conducted at a fixed time and timely emergency radiation monitoring followed when a nuclear accident occurred.

In addition to the continuous routine monitoring of water bodies by the nuclear facilities, surveys during 1979 to 1980 and 1983 to 1984 showed that the level of contamination of radionuclides in the water bodies near of nuclear facilities was far lower than the defined limits. . During the period of development for nuclear industry radioactive effluent discharge was strictly controlled, Since 1983, the ministry of nuclear industry had executed the project of "overall evaluation for existing situation of environmental radiation and dose impact by nuclear industry".

The main mediums for environmental monitoring were atmosphere, water, soil and biotic body etc and the principal objects of monitoring included the level of gamma radiation above ground and the level of radioactivity (gross alpha, gross beta, 131 I, 125 I, 137 Cs, 90 Sr, U, 226 Ra and 222 Rn) in various mediums.

Under normal operational condition of the nuclear fuel cycle facilities in China for over 30 years, the annual exposure of key group residents was below the dose limit stipulated by the national regulations. A very few facilities caused the annual exposure of the key group residents to exceed 1 mSv ,however, due to effective countermeasures taken after 1980 the annual exposure was dropped to less than l mSv.

Under normal conditions the collective effective dose equivalent was 23.l man-Sv which was about 10^{-4} of the collective effective dose equivalent due to natural background exposure for the residents within an 80 km radius of the nuclear facilities and about $10^{-5}$of the collective effective dose equivalent of the national dose from natural background radiation.

The principal radio-nuclide contributing to the exposure of residents was 222 Rn, among the rest there were 210 Pb, U, 131 I and 226 Ra . These five radio-nuclides contributed about 94% of the collective effective dose equivalent of the residents and about 59% was due to 222 Rn

Uranium ore metallurgy contributed to about 83% of the residents' exposure.

Impact on the environment by the accidental release of radioactive effluents was very small. The total collective effective equivalent for the residents around the nuclear fuel cycle facilities following l9 accidents was only 7.8 man-Sv with the maximum personal dose equivalent being about 1 .7 mSv.

In conclusion the environmental quality was basically good during the development of China's nuclear industry for national defense. This was the result of people's increased awareness of the importance for environmental protection.

2.5 Impact on population health (Pan Ziqiang,1997a **)(** Mao Yongze **)**

The practice of nuclear industry over three decades revealed that the safety record of nuclear industry was pretty good. The environmental impact of nuclear fuel cycle facilities was negligible. China as a developing country has a population of 1.2 billion, from the point and statistic of national dose which involves the exposures of national background, professional, public and medical, the nuclear industry contributed to the public's annual collective dose of about 23.1 man-Sv which was lower than the collective dose from the exposure pathway of aviation (36 man-Sv).

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Chap. 3 - ELEKTROSTAL

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• 3.1 Generalities

The Machinery Plant (formerly – the Plant No.12), one of the oldest enterprises of the Minatom of Russia, is situated in Elektrostal city, about 60 kilometers to the East of Moscow (Fig.1).. In the end of 1945 under the Soviet uranium project the enterprise was redesigned from a plant for making munitions into a chemical & metallurgical plant **. It was the first enterprise in the USSR for industrial-scale production of metallic uranium and making nuclear fuel.**

Beginning with 1946 at the plant uranium-containing ores and concentrates were processed to produce pure uranium salts and metallic uranium. The metallic uranium was subsequently cast, underwent plastic deformation and mechanical treatment in order to obtain molds of necessary configuration for standard uranium slugs. The standard uranium slugs were confined into aluminium clads and sent to Chelyabinsk (later on – also to Tomsk and Krasnoyarsk) to be used in uranium-graphite reactors for plutonium production. At the same time production of metallic calcium was organized..

In 50's they opened up manufacturing of uranium slugs enriched to 2% 235 U for tritium production reactors at the Chelyabinsk Combine No.817 (now “Mayak”). Lithium isotope separation technology with continuous process of 6 Li production was developed at the plant, as well as lithium hydrides and metallic lithium production.
The uranium ore processing was ceased in 1957, and making of the standard slugs ended in 1967

In 1950 they started production of radium salts (bromides) at the plant, using uranium ore processing tailings as raw materials. The process of radium salts production included the following steps : accumulation of a radium mud concentrate in the course of uranium ore processing; gaining of a radium concentrate (“raw” sulphates) of the mud; gaining of a pure solution of radium/barium chlorides; radium separation from barium by means of fractional crystallization.

As a result of the process from the mud concentrate with 60-90 mg of Ra per a ton (dry) pure salt (radium bromide), containing about 58 % of Ra, was produced. On average the recovery of radium was about 93 %. In 1957 the radium salt production was ceased at the plant, and in 1958 manufacturing of various types of radiation sources (radium gamma-sources, Ra-Be neutron sources, etc.), using the accumulated radium salts was started. In 1967 the production of all types of radiation sources was ceased.

In the subsequent years manufacturing of fuel elements and fuel assemblies for nuclear power plants, ship propulsion and research reactors was developed. Fuel elements were made of enriched uranium with various levels of 235 U content in the form of uranium dioxide or other compositions. Making of such type of production is going on till the present.

Primary materials for the nuclear fuel production are received in the form of UO_2 powder and pellets and uranium hexafluoride. A production section for UF_6 (with various levels of enrichment) conversion to uranium dioxide was organized in 60's-70's. At the same time a number of production works (such as lithium isotope separation, making of some types of fuel elements) was stopped.

In the beginning of 90's the enterprise went through a period of definite production recession. By the present the situation has stabilized. Additional production capacities were developed for uranium dioxide, fuel pellets, fuel elements and assemblies manufacturing. **Now the plant is ranked the world's first in uranium dioxide production output (1000 tons per annum).**

Currently the Elektrostal Machinery Plant (EMP) supplies with nuclear fuel all of the Russian nuclear power plants with VVER-440, RBMK, BN, EGP type reactors and several reactors of VVER-1000 type. Fuel assemblies made in Elektrostal are also used at nuclear power plants of Armenia, Bulgaria, Czechia, Finland, Germany, Hungary, Kazakhstan, Lithuania, Slovakia, Sweden, Switzerland and Ukraine.

Last years making of nuclear fuel with burning additives (uranium/gadolinium and uranium/erbium fuel pellets) was developed. The level of all types of fuel pellets production capacity has reached 550 tons per annum.

Besides that, the plant makes currently tubes of special alloys, which are widely used in nuclear reactor cores. In 2001 they plan to manufacture up to 140 km of the tubes.

The plant is also going on with metallic calcium production. In 2001 its annual production output is planned to reach 3000 tons.

Under the program of military production conversion they have developed manufacturing of industrial and domestic air-conditioners, electric heating units for locomotives and cars of electric trains, ferrite & barium ceramic magnets, etc.

FIGURE 1 :Location of Elektrostal City

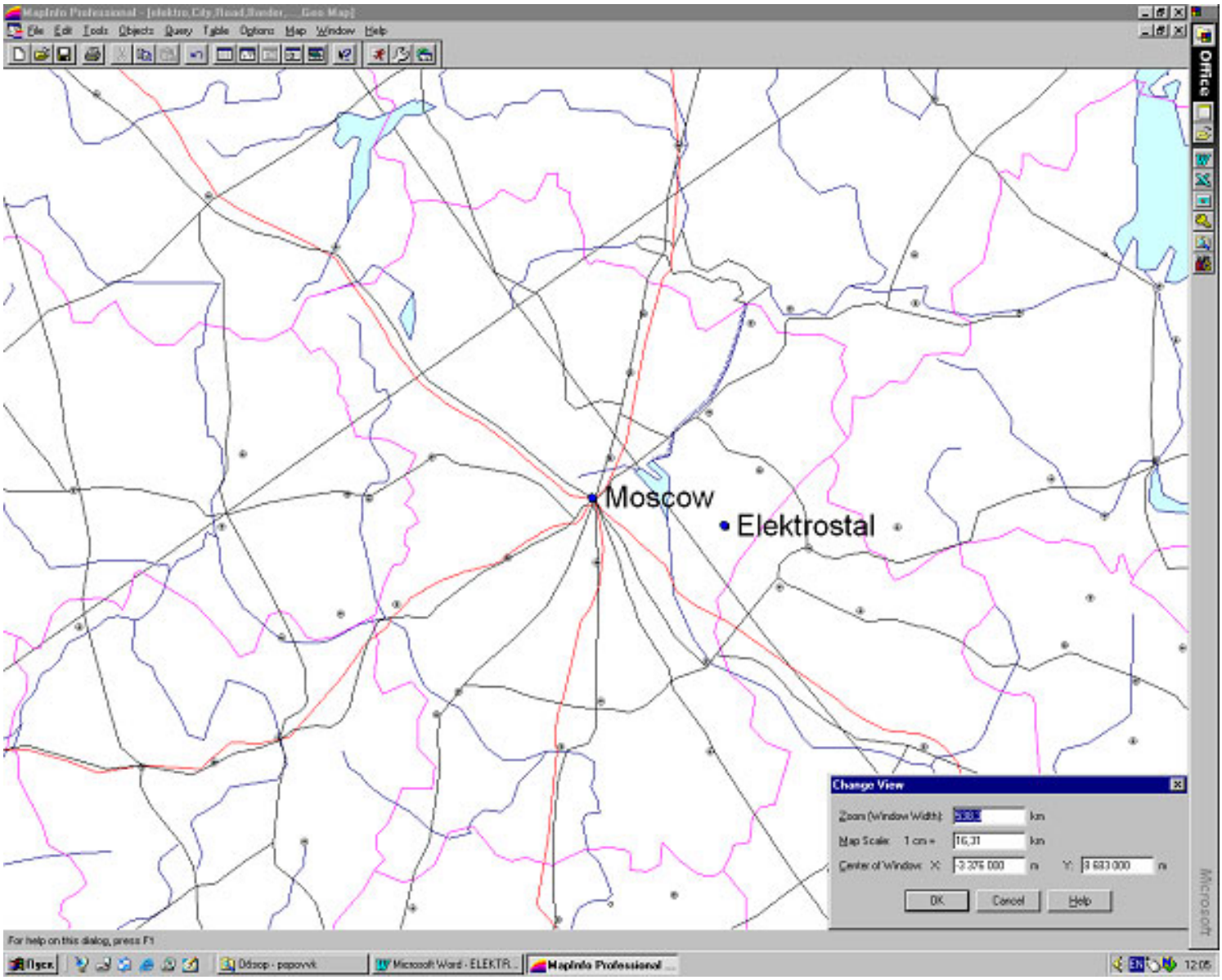


Fig.1. Central area of the European part of Russia. Moscow region.

3.2 Source term

3.2.1. Characteristics of radioactive releases and discharges

Overall radiounuclide releases into the atmosphere (238 U, 235 U and 234 U nuclides) were 6.3×10^8 Bq in 1995 [Egorov et al.,2000], 6.10×10^8 Bq in 1999 and 6.12×10^8 Bq in 2000 with permissible release of 9.25×10^8 Bq [Minatom,2001].

Disposal of sewage waters at the enterprise takes place through several outlets. The concentration of a -active radionuclides in them is lower than 0.4 Bq/l (with the exception of outlet No.5) with permissible concentration of 81.4 Bq/l. Before 1976, waters contaminated with radionuclides were disposed through the outlet No.5, which resulted in accumulation of uranium and radium in silts. Currently radionuclides are gradually being leached from the silts. In 1995 the content of a -active radionuclides discharged from the outlet No.5 was 6.3 Bq/l (2×10^9 Bq for the year), which is less than 10% of the standard disposal [Egorov et al.,2000].

Radionuclide discharges (the sum of uranium nuclides) into natural water reservoirs (Maryinka and Khodtsa

rivers) was 1.179×10^{10} Bq in 1999 and 1.147×10^{10} Bq in 2000. Certain amount of radionuclides is discharged with sewage into the sanitary works. Thus, the overall radionuclide discharge in 2000 was 1.64×10^{10} Bq.

According to data of analysis of underground waters in observation wells, maximum value of average annual a -active radionuclide content in underground waters was 9.9 Bq/kg (the source: tailing dump No.298, well No.83, with 0.81 km distance from the source to the observation well).

3.2.2. Characteristics of accumulated radioactive wastes

Radioactive wastes, that have resulted from uranium ore processing, radium salt production and nuclear fuel manufacturing, are concentrated in two tailing dumps (No.240 and No.298) that are not used now (see Table 1).

These tailing dumps are situated on the territory of the enterprise, and are in form of trenches without filtration-proof barriers. After natural liquid evaporation and filtration, the trenches are filled with non-radioactive wastes, outdated equipment and metallic scrap. The storage facilities have a filled volume of 151 thousand m^3 , are in need of rehabilitation. There are no liquid radwastes in the tailing dumps, which. They contain low-level and medium- level solid radioactive wastes with an overall activity of 4.2×10^{13} Bq, primarily the radionuclides of uranium (the sum of 238 U, 235 U and 234 U nuclides) [Egorov et al.,2000].

Since 1981 radioactive wastes in the form of sludge processed by liming have been sent to surface sludge surface facility No.294a. Its bottom and walls are proteced by filtration-proof clay material (Egorov et al.,2000]. As of 1 January, 2001 the facility was filled with 100, 887 m^3 of waste (including water) [Minatom,2001]. Solid radioactive wastes have a volume of about 5,000 m^3 . These are low-active wastes containing uranium radionuclides whose specific activity is about 1.8×10^4 Bq/kg. Radionuclides placed into the storage facility were 7.4×10^9 Bq in 1995 [Egorov et al.,2000] and 1.85×10^{10} Bq in 2000 [Minatom,2001].

Solid radioactive wastes (all of the storage facilities inclusive) was 378.81 thousand tons. The overall radwaste activity accumulated at the enterprise was 4.25×10^{13} Bq [Minatom,2001].

Table 1. Radwastes storage at the Elektrostal Machinery Plant, as of 01.01.1996 [3]

Storage facility	Period of operation	Area, 10^3 m^2	Volume, 10^3 m^3		Total activity, Bq	Level of the radwaste activity
Planned	Actual					
No.240	1949-1951	9.4	-	16	1.0×10^{13}	Low and medium
No.298	1950-1981	93.75	-	135	3.2×10^{13}	Low and medium
No.294a	1981-present	30.1	120	104	9.2×10^{10}	Low
Total		133.3		255	4.2×10^{13}	

3.2.3 Territories contaminated with radionuclides as a result of the object's operation (Minatom,2001)

Data on radioactive contamination of territories around the EMP resulted from the plant's activities in 40's – 50's are given in Table 2.

For the most part the contaminated areas are covered with clean soil and are located

- in the stream B-2 valley (the source is situated in the tailing dumps zone); the contamination occurred as a result of break of dam of the tailing dump No.298, that had led to spreading of hydrate deposits from uranium ore hydro-metallurgical processing;
- in the area of former uranium ore hip-roof storehouses;
- on the spot of an old pond on the territory of “Fryazevo” state farm: in the time period from 1954 through 1976 the EMP sewage waters were discharged into the pond (the most intense accumulation of uranium nuclides took place in 1964-1965); presently the pond is covered up with earth and is overgrown with shrubs and grasses.

There are also several local contaminated spots (20-30 m^2) with maximum exposure rates within the range of 350 – 1360 m R/hr in the plant's industrial site. Presently the contaminated spots are covered with asphalt coat and green plantations.

In 1990 the EMP sanitary & protective zone (S & PZ) was set up on the 500 m spaced territory around the plants industrial site. For the tailing dumps the S & PZ was set up within the limits of 1000 m of their borders. An observation zone has not been strictly set up. Radiation monitoring is being carried out along the main water currents to the distance of 10 km.

Table 2. Territories contaminated with radionuclides as a result of the Elektrostal

Machinery Plant's activities , as of 01.01. 2001.(x 10^3 m^2)

Contaminated territory	Industrial site				Sanitary & protective zone				Observation zone				Total
Total	With dose rate, m Gy/hr			Total	With dose rate, m Gy/hr			Total	With dose rate, m Gy/hr				
< 0.5	0..5-2.0	> 2.0	< 0.5	0..5-2.0	> 2.0	< 0.5	0..5-2.0	> 2.0					
Contaminated lands	9.38	5.38	3.00	1.00	197.87	139.87	40.0	18.0	-	-	-	-	207.25
Contaminated water areas	-	-	-	-	60.0	30.0	20.0	10.0	120.0	70.0	30.0	20.0	180.0
Total	9.38	5.38	3.00	1.00	257.87	169.87	60.0	28.0	120.0	70.0	30.0	20.0	387.25

3.3 Pathways

During the whole time period of its operation the EMP had to do only with uranium, both natural and enriched to various levels, so that in its release and discharges, in solid and liquid radwastes , and ,therefore, in the environment around the plant only uranium nuclides and their decay products may occur, 226 Ra being

the most hazardous of them.

All of the uranium chains' radionuclides are characteristic of low root assimilation, that's why radioactive contamination of plants through the root pathway will not be essential. The level of secondary dust formation from the ground covered with vegetation is low. Thus, the external gamma-exposure from contaminated soil is the only significant factor of hazard. Ingress of radioactive products into a human alimentary canal (??) in the course of production activities on contaminated territories may also be hazardous to certain degree

3.4 Dose assessment [Belyayev V.A.et al.(1995)., **]** .

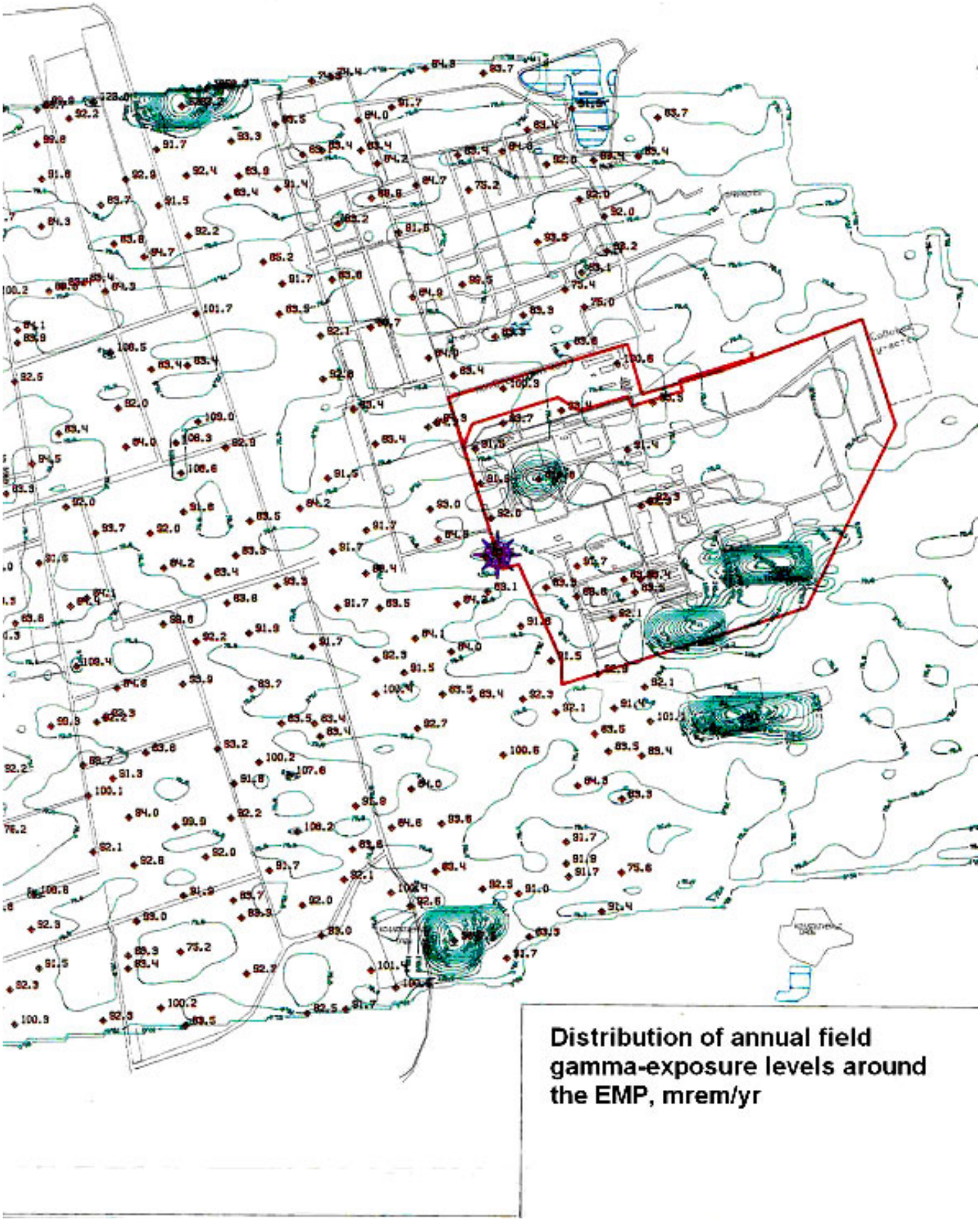
Radon exhalation from parts of territory contaminated with 226 Ra is not high, as compared to other factors. Consequently, it can be stated that for the EMP case (as well as for other uranium production works) the gamma-exposure level in the locality is sufficient to characterize the environmental safety. In Fig.2 annual field gamma-exposures values calculated on the basis of control measurements on the ground are presented. The annual field exposure supposes continuous stay of a recipient in a given point all year long without any protection. Some spots of higher irradiation level on the EMP territory are conditioned by former burials of radium production process equipment. As a rule, higher exposure levels are linked with various earthworks, as formerly covered with soil irradiating structures get revealed. The maximum fixed exposure rate level in these spots reached 1.6 mR/hr (14 R/yr).

The only hazardous contaminated area outside the plant's industrial site limits is the tailing dump complex. Currently further build up of daughter nuclides resulted from uranium isotopes decay is on, and it will go on in future. The highest fixed gamma-exposure rate at the tailing dumps' territory is 2 mR/hr (17.5 R/yr). Now the tailing dump complex is fenced and provided with warning character plates.

The tailing dump complex located nearby the plant's southern borderline is the most radiation-hazardous EMP object. Though it is not an active source of radionuclide releases, mitigation actions in the area are planned to be carried out in this decade: 40 thousand m² have to be remediated in the 2001-2005 period, 120 thousand m² should undergo mitigation works in 2006-2010 [Lebedev V.A,2001].

Most likely, the area will be simply covered with a layer of loamy soil, and this will allow to decrease radically the level of gamma-exposure and reduce to zero the probability of windy raising of radioactive dust and radon exhalation.

FIGURE 2
Distribution of annual field gamma-exposure levels around the EMP, mrem/yr

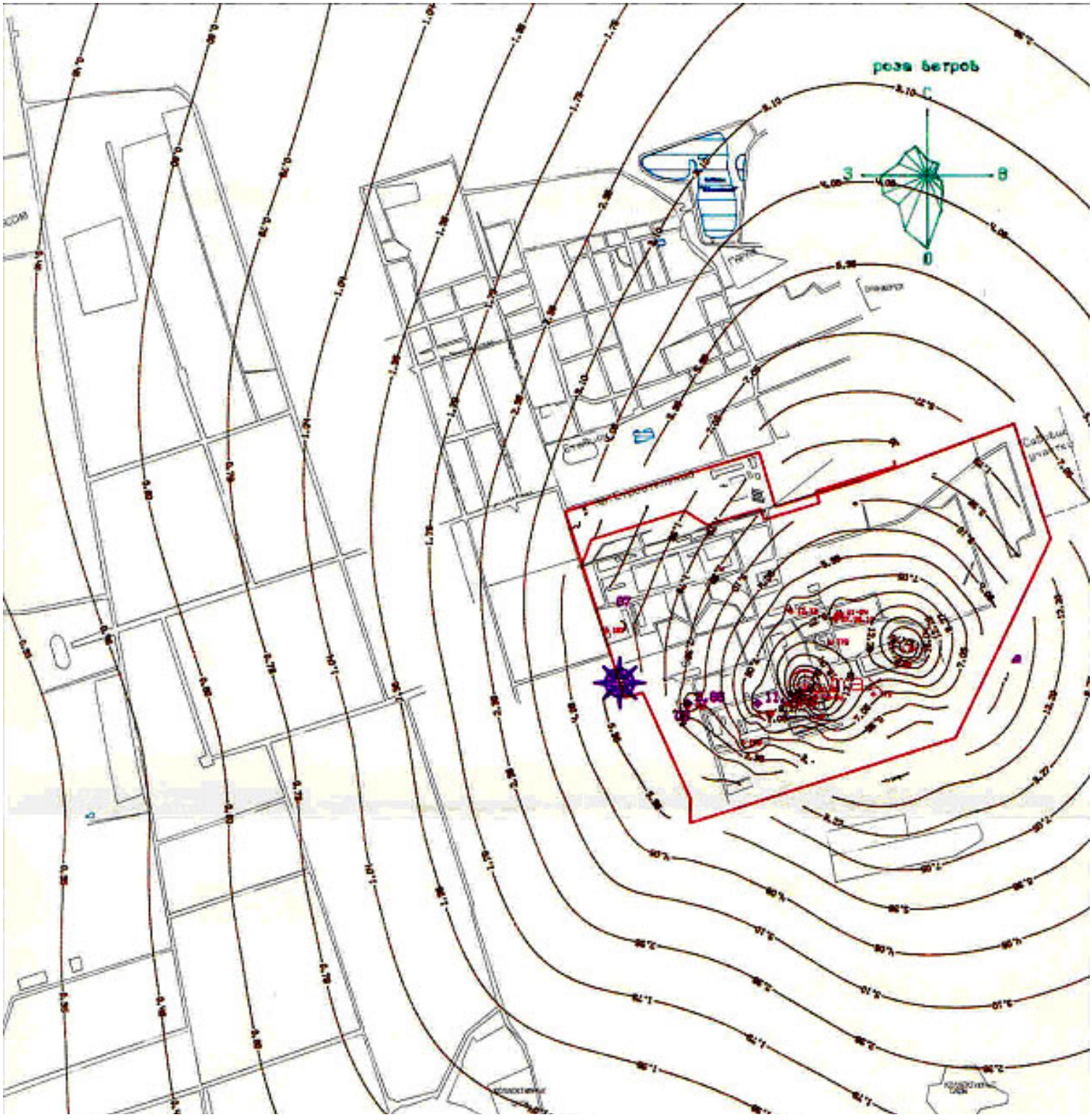


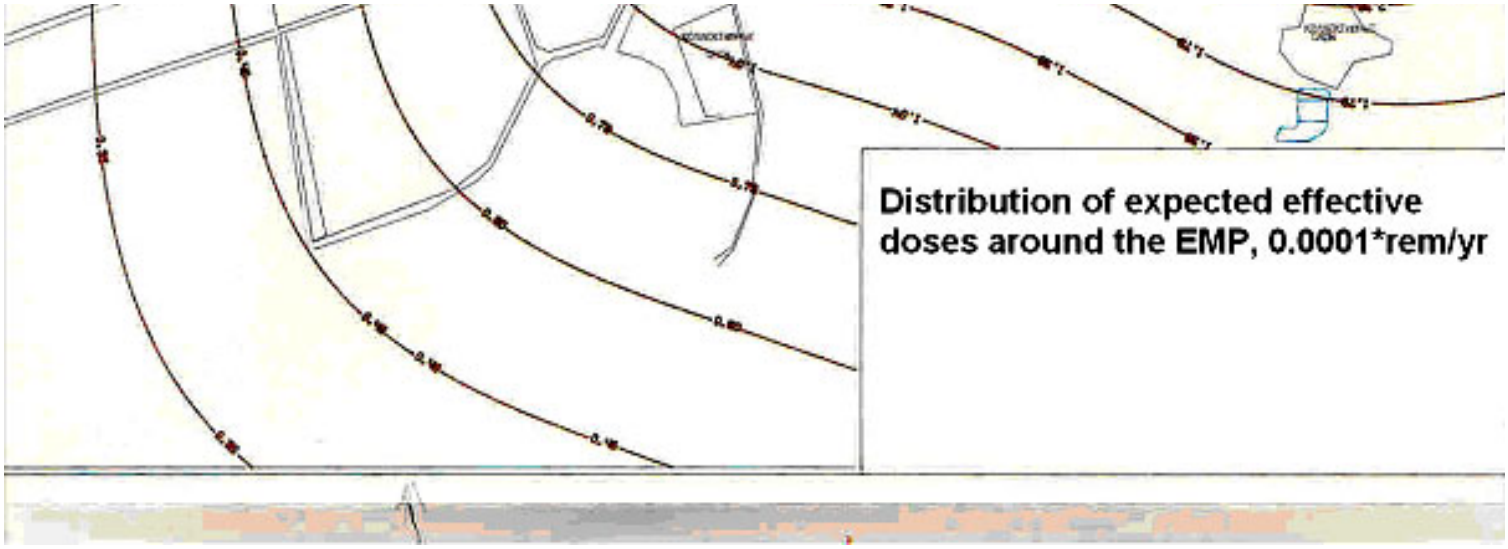
Distribution of annual field gamma-exposure levels around the EMP, mrem/yr

3.5 Impact on population health

Expected annual population doses caused by the EMP activities were calculated taking into account all the pathways, including external gamma-exposure, inhalation and ingestion. Doses linked with radionuclide accumulation in soil were calculated for a 50 th year since starting works with uranium materials. Thereat, not only radioactive decay of the nuclides was taken into account, but also processes of their “biological” taking out due to diffusion into the depth of soil and removal with plants. The dose evaluation results are presented in Fig.3. In the area of Elektrostal city distribution of expected effective doses, incurred by adults due to annual permissible EMP radionuclide releases and discharges, all exposure pathways being taken into account, are shown. When calculating doses at the plant's territory, only direct ways of exposure (external exposure and inhalation) were taken into consideration with the time of stay corresponding to 40-hours workweek 2001 hours per a year).

FIGURE 3
Distribution of expected effective doses around the EMP, 0.1 mrem/yr





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Chap.4 OAK RIDGE

4.1 Generalities

The Manhattan Project: Making of Atomic Bomb is described in the document DOE/MA-0001-01/99 , in Appendix of this synthesis volume.

A very important aspect of this outstanding undertaking was *the radioprotection one* .

The Health and Safety Research Division (HASRD) has an illustrious history dating back to the successful operation of an experimental uranium-graphite pile at the University of Chicago in December 1942. Plans were soon under way for the construction of a Clinton Laboratories pilot plant at Oak Ridge, Tennessee, and larger production units at Hanford, Washington, as part of the Manhattan Project.' The purpose of the pilot plant was to train crews to operate the larger Hanford production units and to demonstrate the safe production and chemical separation of the fissionable 239 Pu isotope from uranium irradiated in the X- 10 pile at the Clinton Laboratories The Clinton Laboratories were renamed the Clinton National Laboratory in 1947 and the Oak Ridge National Laboratory (ORNL) in 1948.

Before the X-10 pile could begin to operate in November1943, numerous health and safety problems had to be solved. Previously, a few people had worked on rare occasions with one or two curies of radium, but the new pilot plant operations would require working with unheard-of quantities of curies of radioactive materials as a routine procedure.

Therefore, a Health Division was established, first at the University of Chicago and then at the Clinton Laboratories. These Health Divisions consisted of a medical group, a biology group, and a physics group, whose efforts were divided along three major lines:'

1. Pre-employment physical examinations and frequent re-examinations, particularly of those persons exposed to radiation, were adopted.
2. Research was carried out on the effects of direct exposure of people and animals from various types of radiation and the effects of ingestion and inhalation of various radioactive and toxic materials, such as uranium, plutonium , and the products of the fission reactions in a pile.
3. Tolerance standards were set for radiation doses, and instruments were developed for measuring the radiation exposures of personnel, continually measuring radiation intensities at various locations in the work place, and measuring for radioactive contamination of air, water , clothing, laboratory desks, etc.

The name “health physicist” was soon applied to those working in the physics groups of the Health

Divisions at the University of Chicago and Clinton Laboratories. Early health physicists, such as K. Z Morgan, H. M. Parker, and E. O. Wollan, brought to this field a thorough knowledge of basic physics and radiation instrumentation. They redesigned and adapted the early ionisation chambers, film meters, electroscopes, electrometers, proportional counters, and Geiger-Muller counters to meet the requirements for personnel monitoring and for radiation survey of buildings and the environment.

A separate Health Physics Division (HPD) was formed at the Clinton Laboratories in 1946 and its first director was K. Z. Morgan Trained as a cosmic ray physicist and thus aware of the importance of fundamental knowledge and research, Morgan instituted a vigorous program to upgrade existing instrumentation

4.2. Source Term (M.Goldman)

Oak Ridge is one of the largest U.S. Department of Energy complexes. The Oak Ridge Reservation encompasses about 14,000 contiguous hectares (about 35,000 acres) in eastern Tennessee. It was built during World War II as part of the “Manhattan Project” with a mission to develop the necessary skills and materials to build the atomic bomb. Three facilities were built. Y-12 enriched uranium using an electro-magnetic process that was later abandoned in favour of the more efficient gaseous diffusion process at the K-25 facility. Y-12 then dedicated itself to precision machining of special nuclear materials for bomb manufacture. The X-10 facility (later called ORNL [Oak Ridge National Laboratory]) was tasked with weapons research and development, especially purification of plutonium. Today Y-12 disassembles nuclear weapons and stores highly enriched uranium. K-25 is now charged with cleanup prior to a transition into an industrial park. X-10 (ORNL), is dedicated to a wide range of scientific research and development

Because each of the three major Oak Ridge facilities had different missions and was located at different neighbouring sites, it is convenient to discuss them individually.

As summarized by Gouge, et al, (SENES 2000), “in the early days of the Manhattan project, Clinton Laboratory, also referred to as X-10 Site and now called the Oak Ridge National Laboratory, was designed to operate for one year as a pilot plant for the Hanford, Washington operations for chemical separation of plutonium”.

Developmental plans were continually being changed and by 1944, the first radioactive effluents were discharged into nearby White Oak Creek and then into White Oak Lake and” were allowed to flow over the White Oak Dam”, some 1 km upstream of the large Clinch River. From 1944 through 1991, about 160,000 Ci (5.9×10^{15}Bq) went to the Clinch River, 91% tritium and the rest mixed fission and activation products.

Direct measurements were made of individual radionuclides from 1949 onward; for 1944-1949, each radionuclide's contribution to gross beta activity measurements was used to estimate quantities. Annual source terms were developed for: 60Co, Sr-90, 95Nb, 106Ru, 131 I, 137Cs, and 144Ce.

X-10 released significant quantities of 131 I from 1944 through 1956 resultant from processing spent nuclear reactor fuel using a process that recovered radioactive lanthanum (RaLa). The RaLa operation

dissolved some 30,000 reactor fuel slugs in 731 batches to separate some 500,000 Ci ($1.9x10^{16}$ Bq) of radiobarium. During slug dissolution, volatile radioiodine was exhausted as “off gas”, amounting to 8,800-42,000 Ci ($2.3x10^{14}$ to $1.6x10^{15}$ Bq) of 131 I, three quarters of which was in elemental form —the rest was in a volatile non-reactive organic form. “The largest releases occurred between 1952 and 1956 when the freshly spent uranium fuel slugs came from Hanford reactors”.

4.3. Pathways (M.Goldman)

Atmospheric dispersion of radio-iodine is the principal issue in almost every discussion of weapons production technology (and in weapons debris as well). Atmospheric reactive elemental radio-iodine is transformed in transit to particulate and non-reactive organic forms within a few km of the processing facility (X-10). The resultant ground deposition concentrations of radio-iodine are influenced by local weather, mixing, wet and dry deposition dynamics and its chemical form.

4.4 Dose assessment

IDENTIFICATION AND SCREENING EVALUATION OF KEY HISTORICAL MATERIALS AND EMISSION SOURCES AT THE OAK RIDGE RESERVATION

(Widner et al.,1996)

In 1991, the State of Tennessee initiated a Health Studies Agreement with the U.S. Department of Energy. It included independent studies of possible adverse health effects in people living near the Oak Ridge Reservation resulting from releases of chemicals and radionuclides since 1942. A Dose Reconstruction Feasibility, the first of a planned sequence of initiatives to evaluate the potential for health effects, included application of screening methods to focus subsequent dose reconstruction and epidemiologic efforts on the materials and emission sources that have historically been most important. The feasibility study produced a history of operations that likely generated off-site releases from the X-10, K-25, Y-12, and S-50 plants, based on reviews of classified and unclassified records and interviews of active and retired workers. The availability of environmental monitoring and research data that would support dose reconstruction was also characterized. Quantitative emission and environmental contamination data were used to identify those materials and plant activities that should receive the highest priority in further health studies. Plausible exposure pathways were identified, and screening methods were used to identify the most important pathways and past activities that appear to be associated with the greatest health hazards. The materials and activities shown to have the highest potential for public health hazards are as follows:

- The release of radioiodine [likely over 3.7 PBq (100,000 Ci)] to the air from radioactive lanthanum ("RaLa") processing at X-10 (now Oak Ridge National Laboratory) from 1944 through 1956;
- The release of 137Cs and other radionuclides in liquid wastes from chemical separation activities at X-10;
- The release of mercury to the air, soil, and surface waters from Y-12 lithium enrichment operations between 1950 and 1963. About 11,000,000 kg of mercury were handled at Y-12, and 910,000 kg were reported lost or unaccounted for; and
- The release of polychlorinated biphenyls (PCBs) from machining oils, electrical equipment, and

other sources in the Oak Ridge area.

Based on the findings of the study, the Oak Ridge Health Agreement Steering Panel called for a dose reconstruction for radioiodine, mercury, PCBs, and radionuclides released from White Oak Creek and research into opportunities for analytic epidemiologic studies to identify adverse health effects in exposed populations.

4.5. Impact on Population Health

4.5.1 Overview (M.Goldman)

The activities of the weapons production sites for the most part contained radiation emissions within the site boundaries. Population exposures however did occur mainly from atmospheric and aquatic discharges. In the earliest years of nuclear weapons production facilities, i.e., 1942-1952, industrial hygiene and environmental containment technologies at reactors and separation plants were limited and not well developed. For example, almost all of the early plants emitted gaseous radio-iodine regularly as part of the production cycle. Some of the early production runs were accompanied by liquid radio-effluent releases.

As has been discussed in earlier sections, these radiation “source terms” and pathways to people resulted in acute and chronic exposures in nearby populations. It appears that population exposures fall into four general classes. First, uranium mining and milling exposed nearby populations to radon, radium and by-products of milling process, by inhalation (radon and daughters) and ingestion (radium in aquifers). Second, production reactors released significant radio-iodine to the atmosphere, causing a thyroid exposure problem to “down-wind” populations. Third, improperly contained, long-lived, high level liquid wastes were released into rivers and then contaminated drinking water, aquatic life and riverine ecology. Finally, long-term storage and disposal of radioactive wastes poses a potential for very long term low level population exposure.

4.5.2. Oak Ridge Health Studies

T he Oak Ridge Health Studies examine health problems that may have been caused by federal activities in Oak Ridge. The studies are aimed specifically at nearby residents who may have been affected by air or water emissions from the ORR.

The Oak Ridge Health Studies Agreement is an outgrowth of TOA. It requires that DOE provide funding for a comprehensive health study in the region. DOE and former Gov. Ned McWherter signed the agreement in 1991. The study evaluates environmental releases from the Oak Ridge facilities and estimates risks to people off site. The Oak Ridge Health Agreement also provided funding to evaluate the quality of the state's cancer registry and to create a birth defects registry.

The Tennessee Department of Health (TDH) is the primary State agency involved in the studies. TDEC and its DOE Oversight Division provide support as needed.

The study was conducted by an independent contractor, ChemRisk, a division of McLaren/Hart

Environmental Services, Inc. The Oak Ridge Health Agreement Steering Panel (ORHASP) guides these studies; this group consists of experts and concerned stakeholders. This year was the final year for the studies, and finalizing them has been the primary goal of ORHASP during1999.

The Oak Ridge Health Studies' primary health focus has been “dose reconstructions”in the four areas described below.

• *Radioactive Iodine Releases* from ORNL - Between 1944 and 1956, ORNL processed irradiated nuclear fuel to extract radioactive lanthanum, a material useful in nuclear weapons testing. The process released radioactive iodine-131 and other isotopes into the air. Because iodine concentrates in the thyroid gland, concern is focused on the fact that these releases may have caused thyroid problems, including thyroid cancer.

• *Mercury Releases* from Y-12 - In the 1950s and the 1960s, Y-12 isolated the lithium-6 isotope for use in nuclear weapons by using a process that used millions of pounds of mercury. More than 350,000 pounds of mercury is estimated to have escaped to the air and into East Fork Poplar Creek. Mercury may cause a variety of health problems, depending on its form. Mercury vapour is primarily elemental and can cause brain damage.

Inorganic mercury, found in soil, water, and food, can damage the kidneys.
Organic mercury, in a form called “methyl-mercury,” is found in fish and shellfish and can cause birth defects and brain damage.

• *PCB Releases* from Oak Ridge Facilities - PCBs were used as a fire-retardant in transformer oils throughout the ORR until the mid-1970s. In the mid-1970s the United States banned the use of PCBs because of evidence that they are harmful to human health, potentially causing cancer and hormone-like effects.

• *Radionuclide Releases* from White Oak Creek - White Oak Cree flows through ORNL and into White Oak Lake, ultimately discharging into the Clinch River. Radioactive contamination has entered the creek from numerous sources, including shallow land burial sites in Melton Valley and waste ponds in Bethel Valley.

This study concentrated on the potential health impact from eight radionuclides: cesium-137, strontium-90, cobalt-60, ruthenium-106, niobium-95, zirconium-95, iodine-131, and cerium-144.

• Project investigators have also screened a wide variety of other materials,including *uranium releases* from Y-12 and K-25. The uranium study, although not a full dose reconstruction, does include a thorough analysis of data quality and an evaluation of potential health effects. Emissions from Y-12 are of particular concern because the Scarboro and Woodland communities in Oak Ridge are relatively close to the plant boundaries.

The study found that two groups of people are were the most likely to receive health problems from contaminants: Local children who drank "backyard" cow and goat milk in the early 1950s and fetuses carried in the 1950s and early 1960s whose mothers who regularly ate fish from creeks and rivers

downstream from Oak Ridge plants.

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CHAPTER 5 SAVANNAH RIVER SITE

T. G. Hinton

5.1 GENERALITIES

The Savannah River Site (SRS) is located along the Savannah between Georgia and South Carolina in the southeastern United States (**Figure 5.1**). The government-controlled site began operation in the early 1950s with the goal of producing plutonium and tritium for nuclear weapons. For security and safety reasons the majority of the industrial complex was placed in the center of a remote 750 km^2 site, fenced from the general public (Bebbington, 1990). Plutonium and tritium were created in nuclear reactors by bombarding target rods containing uranium or lithium with neutrons. To a lesser extent, the reactors were also used to convert thorium to 233 U for a thorium breeder reactor program, as well as to produce numerous other special products, such as 239 Pu for use in thermoelectric generating devices aboard deep space probes, and 60 Co for food sterilization programs. In addition to five nuclear production reactors, the SRS operated:

- a fuel and target rod fabrication facility,
- a heavy water production site (the nuclear reactors used heavy water as a moderator and coolant),
- two chemical separations plants to recover the plutonium and tritium products by chemically dissolving the irradiated target rods, and
- an assortment of waste management facilities.

The periods of operation for these facilities are listed in **Table 5.1** .

FIGURE 1. Location of the Savannah River Site on the boarder of Georgia and South Carolina in the southeastern United States.

5.2 SOURCE TERMS

The complex and diverse operations on the SRS released a wide variety of radioisotopes, each differed in half-life, environmental mobility and propensity to cause damage. The Centers for Disease Control and Prevention (CDC) is currently interested in the dose received by people due to releases from the SRS during its 50-years of operation. The CDC is conducting a large-scale dose reconstruction project for the site. The prime contractor, Risk Assessment Corporation (RAC), has recently completed a source term evaluation for the SRS (RAC, 2001). Using methods presented by the National Council on Radiological Protection and Measurements, RAC conducted screening calculations to determine how important each radionuclide was with respect to the exposure pathway (air or water), and produced a list of key radionuclides for which detailed source term, or release, estimates were developed. **Table 5.2** summarizes Hetrick and Martin's (1990) estimates of the total atmospheric and liquid radioactive releases from the entire SRS industrial complex for the key radionuclides identified in RAC's screening process. The remainder of this section gives a brief description of the various facilities on the SRS and isolates their contribution to the total radiological releases.

TABLE 5.1. Primary facilities on the Savannah River Site and their period of operation (modified from RAC, 2001).

Facility	**Dates of operation**	**Notes**
Heavy Water Plant	1952 - 1981	Heavy water (D 2 O) was concentrated from its natural 0.015% level in river water and used to moderate and cool the nuclear reactors in a closed-loop system.
Fuel and Target Fabrication	1953 to mid-1980s	Produced reactor fuel and target assemblies.
Nuclear Reactors	1953–1964	Irradiated the target rods to produce plutonium and tritium. All nuclear reactors have been shut down and are being decommissioned.
1) R-Reactor	1954–1988	
2) P-Reactor	1955–1985	
3) C-Reactor	1954–1988	
4) K-Reactor	1954–1968;	
5) L-Reactor	and 1985–88	

Chemical Separations Facilities 1) F area 2) H area	1954 to present	Reactor products were separated chemically in two reprocessing canyons.
Waste Management Areas	1953 to present	Includes various seepage basins, disposal pits, tanks and burial grounds.
Replacement Tritium Facility	1994 to present	Today there is no tritium production at the SRS. Tritium that was produced in the past is recycled, mixed, and reloaded in the RTF.

5.2.1.Heavy Water Production and Reprocessing Plant

Heavy water was used as a primary coolant and moderator in the SRS nuclear reactors. Heavy water was concentrated from its natural abundance of 0.015% in river water by a dual temperature exchange procedure that required large quantities of hydrogen sulfide under high pressure. Tritium was present in the moderator as a contaminant and was released to the environment whenever there was leakage or evaporation of the moderator. In the early 1960s each reactor held approximately 225,000 kg of heavy water containing about 50,000 TBq of 3 H. Approximately 1/5 of the heavy water was lost to the environment each year. A heavy water reprocessing facility (built to re-concentrate heavy water that had become contaminated with light water during its use in the reactors) was also on the SRS. Tritium releases to the atmosphere resulting from heavy water reprocessing were measured as stack effluent.

TABLE 5.2. Total SRS radioactive releases from 1954 to 1988 via atmospheric and liquid pathways (Hetrick and Martin, 1990). Radioisotopes shown were identified as the key contributors to human dose using NCRP screening calculations (RAC, 2001). Data are in units of TBq (1 TBq = 10 12 Bq = 27 Ci).

Radionuclide	**Half-life**	**Gaseous Release to Atmosphere (TBq)**	**Liquid Release to Streams (TBq)**	**Liquid Release to Seepage Basins (TBq)**	**Total Release (TBq)**
3 H	12.3 y	894,000	56,000	46,000	996,000
41 Ar	1.8 h	235,000	0	0	235,000
131 I	8 d	93	11	98	202
137 Cs	30 y	0.1	22	49	71
35 S	87.4 d	0	54	11	65
90 Sr	28.8 y	0	3.8	11.1	14.9
32 P	14.2 d	0	1.3	6	7.3
60 Co	5.3 y	0.003	2.4	0.7	3.1
U	4.4 E9 y	0.03	0.9	0.6	1.5

239 Pu	2.4 E4 y	0.11	0	0.29	0.4
129 I	1.6 E7 y	0.2	0.01	0	0.2
238 Pu	87.7 y	0.02	0.003	0.15	0.2

5.2.2. Fuel and Target Fabrication

The production of fuel and target assemblies took place onsite and involved machining and cladding uranium with aluminum. The production generated uranium metal filings and dust, as well as dissolved and suspended uranium in solution. Atmospheric releases of U isotopes occurred from fabrication facility exhaust stacks. From 1975 through 1989, the highest recorded annual atmospheric release of uranium from the facility was 3.7 MBq, or about 140 g of U (Evans et al. 1992). Total reactor power levels during this time period (1975 through 1987) were approximately one-half the total power levels during peak production years (late 1950s and early 1960s; RAC, 2001). The atmospheric releases of U from the fuel and target fabrication facility were minor compared to those from the chemical separations areas. However, the largest releases of uranium on the SRS occurred from the fuel and target fabrication facility via liquid effluents released into a nearby creek (Tim's Branch) and into a seepage basin that was put into service in 1973. Releases to Tim's Branch peaked in 1969 when over 11,500 kg of uranium were released (approximately 0.3 TBq).

5.2.3. Nuclear Reactors

Five nuclear production reactors, designated C, K, L, P, and R, operated on the SRS. The first reactor came online in December 1953, and by March 28, 1955, all five reactors were in operation. The period of operation for each reactor is shown in **Table 5.1** ; no reactors have operated on the SRS since 1988. The reactors were originally designed to operate on natural uranium at about 375 MW of power, but continual design modifications allowed power output to approach 3000 MW through the use of enriched U and improved cooling. The reactor power levels are depicted in **Figure 5.2** . The reactors were devoted primarily to the production of plutonium and tritium. Whereas plutonium production peaked in 1964 at over 2000 kg (**Figure 5.3)** , tritium production peaked in 1958 (**Figure 5.4**), when three reactors were operating on enriched fuel (Stetson et al. 1963).

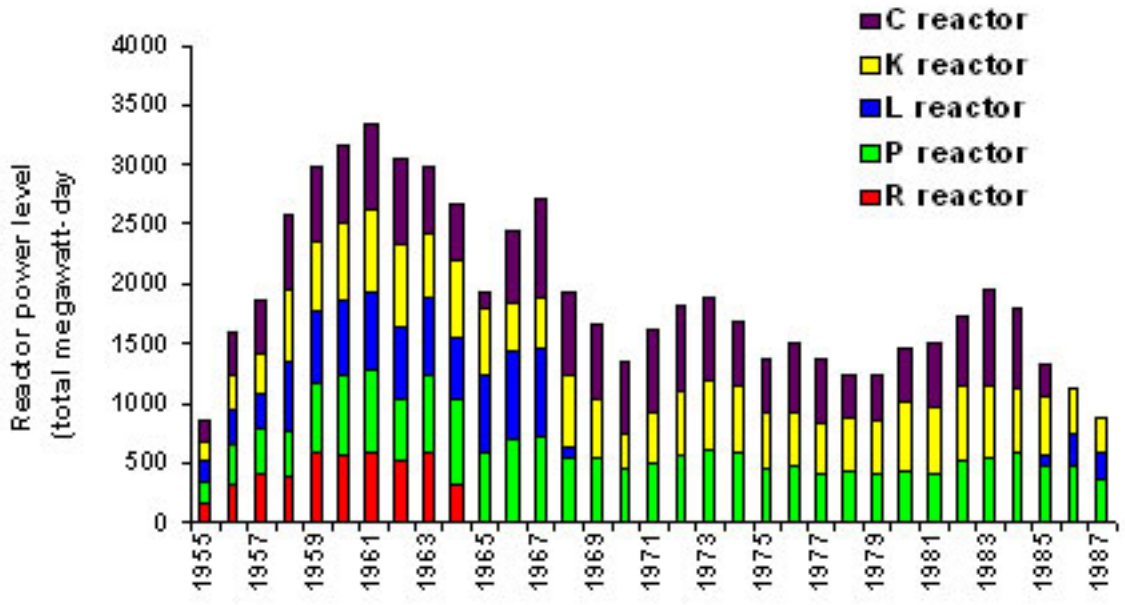

FIGURE 5.2 . Reactor power levels expressed as total gigawatt-days.
The vertical order within the data bars is the same as the order of reactors in the key (from RAC, 2001)

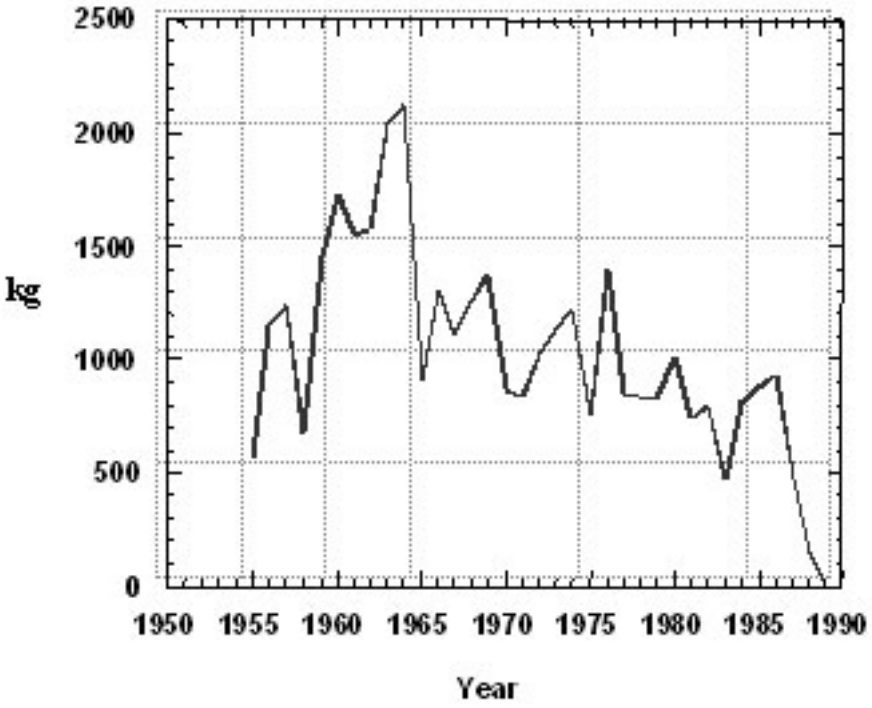

FIGURE 5.3. Plutonium production on the SRS (adapted from RAC, 2001)

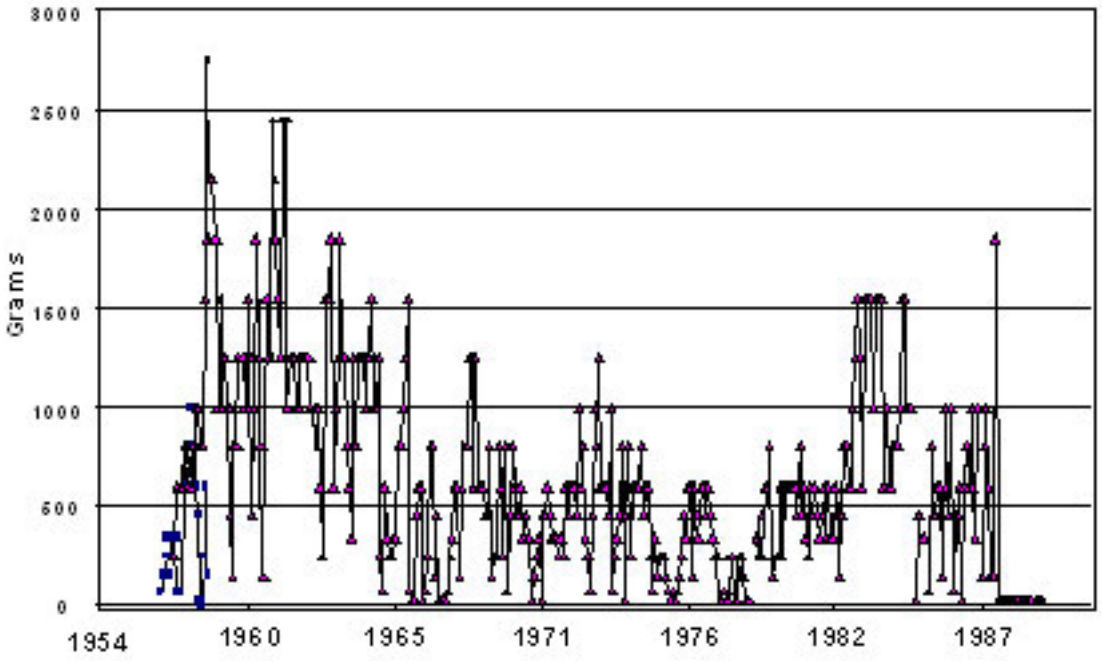

FIGURE 5.4. SRS estimated tritium production (adapted from RAC, 2001)

The reactors released gaseous radioactive contaminants through various process exhaust stacks, and contaminated liquid effluent into site streams and seepage basins. The main source of radionuclide releases to surface water from the reactors was from the disassembly basins; large water-filled basins (approximately 10 million L) adjacent to the reactor building. Spent fuel and irradiated target elements were removed from the reactor and stored in the disassembly basins for approximately nine months during which time short-live radioisotopes decayed away. The water in the basins cooled the components and provided shielding for the workers. Until the mid-1960s, the disassembly basins were continually purged with fresh river water in order to maintain visual clarity within the basins. The purge water was contaminated with radionuclides and flushed to site streams. Contamination in the purge water occurred from small cracks in the fuel and target rods that allowed radioactive materials to seep out during storage. All purging to site streams stopped in 1978 and was rerouted to seepage basins.

Tritium was a major contaminant from the production reactors, and was due almost entirely to releases of moderator, either as liquid or vapor from the reactor systems and from the heavy water rework facility. Atmospheric release data from 1981 (Crawford and Roggenkamp 1983) show the relative importance of three pathways by which 3 H escaped the reactors: 1) 60-m tall exhaust stacks (4,400 TBq); 2) purges into site streams from disassembly basins (200 TBq), and 3) ground-level evaporation from seepage basins (200 TBq). Tritium losses from the reactor area were estimated to be 100% oxide (Miller and Patterson 1956). Total atmospheric 3 H releases from 1959- 1992 from the reactors were estimated at 182,000 TBq (RAC, 2001).

Large releases of 41 Ar occurred from the reactors during the 1960s (**Table 5.2** and **Figure 5.5**). Argon-41 is produced when the air around a reactor is neutron activated. Additional activation products produced within the liquid moderator, or within fuel elements which subsequently developed leaks, had a high release potential, especially during the early years when the reactor fuel disassembly basins were routinely purged into site streams as a maintenance procedure.

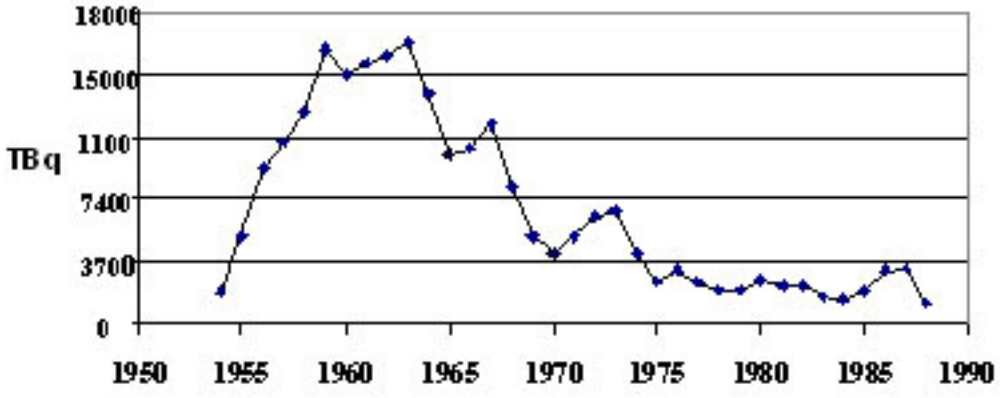

FIGURE 5.5. Estimate of 41 Ar releases from SRS reactors, 1954–1989 (adapted from RAC, 2001).

Generally, releases of Pu and U from the reactors were minor, particularly when compared to atmospheric releases from the chemical separations facilities. However, a failed fuel rod accident in R-reactor in 1957 did cause the release of Pu, U, and numerous fission products into the Lower Three Runs drainage system. This system is where the Par Pond Cooling Reservoir was constructed the following year, resulting in its contamination as well.

Estimates of iodine releases from SRS reactors were made by RAC (2001), and are presented in **Figure 5.6** . Although the majority of the iodine releases from the SRS came from the chemical separations facilities, some releases did occur from the reactors. Based upon measurements at commercial PWRs (Pelletier et al. 1978), it is assumed that about 30% of this total would be elemental iodine and that the remainder would be divided between less reactive inorganic forms (~40%) and organic iodides (~30%).

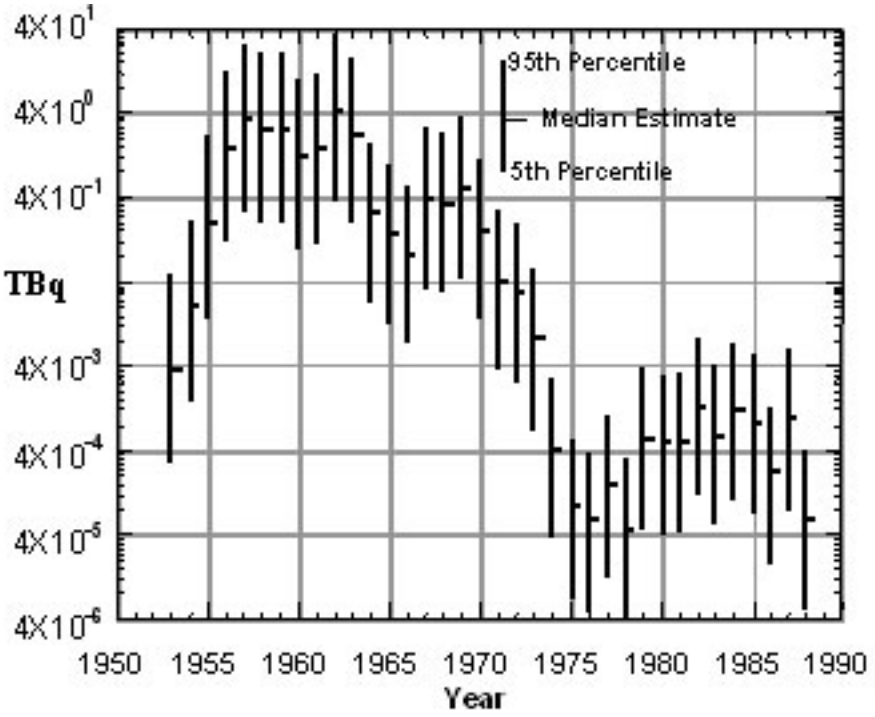

FIGURE 5.6 . Estimated releases of 131 I in TBq from all SRS reactors to the atmosphere (adapted from RAC, 2001).

5.2.4. Chemical Separations Facilities

After nine months storage in the reactor disassembly basins, irradiated target and spent fuel elements were transferred to the chemical separation facilities located in the F-Area and H-Area canyon buildings. Complex chemical and physical processes in the F- and H-Canyon buildings separated uranium, plutonium, and fission products. Exhaust stacks from these facilities have historically had the highest measured atmospheric emissions of alpha-emitting radionuclides, primarily plutonium (238 Pu and 239,240 Pu) and uranium (**Figure 5.7**). Important fission product releases are shown in **Figure 5.8** .

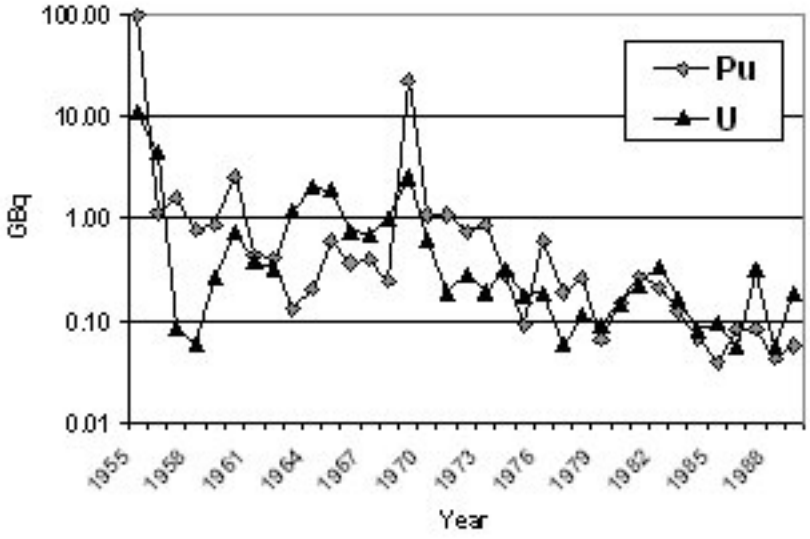

FIGURE 5.7 . Atmospheric releases of plutonium and uranium from the chemical separations facilities (adapted from RAC, 2001).

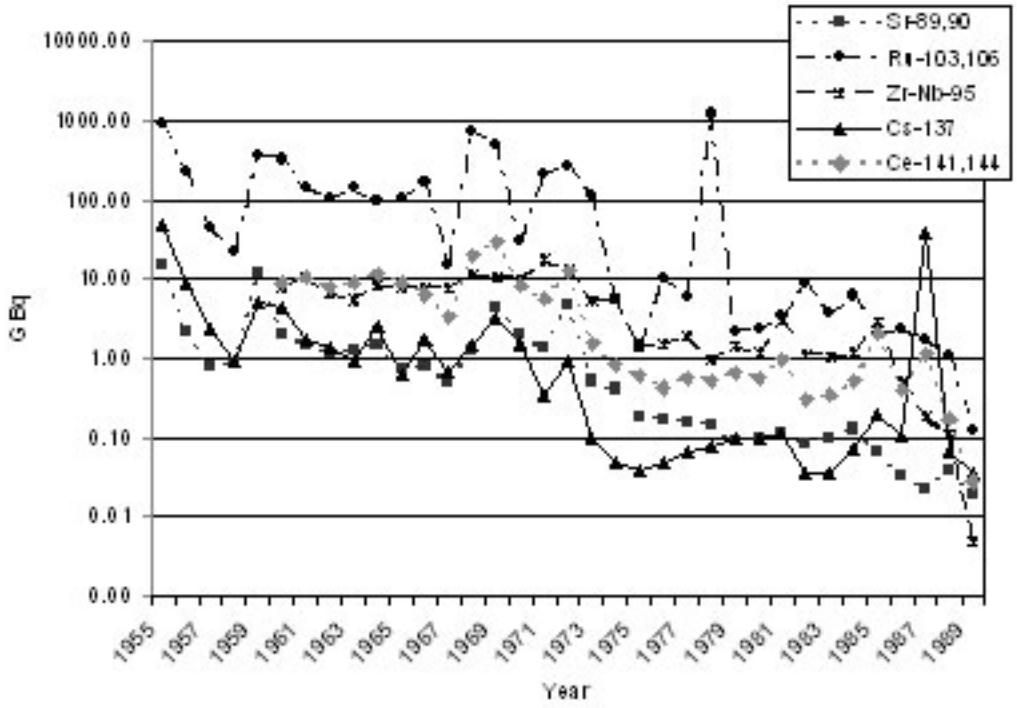

FIGURE 5.8. Radioactive particulates released from SRS chemical separations facilities (adapted from RAC, 2001).

Of all the SRS facilities, the chemical separations facilities were the largest source of airborne tritium releases. For example, in 1971 atmospheric tritium releases totaled 14,800 TBq from the chemical processing operations, 7,770 TBq from the reactors, and 330 TBq from heavy water recovery (Jacobsen 1972); 94% of the tritium released was to the atmosphere and 6% to effluent streams. Sixty-three percent of the 3 H released resulted from processing the irradiated lithium and U within the separations facilities, the remainder came from various sources associated with the reactor moderator (RAC, 2001). Atmospheric 3 H releases from the reactors and the separations areas are compared in **Figure 5.9** . Total amounts from the separation areas were estimated at 637,000 TBq (RAC, 2001).

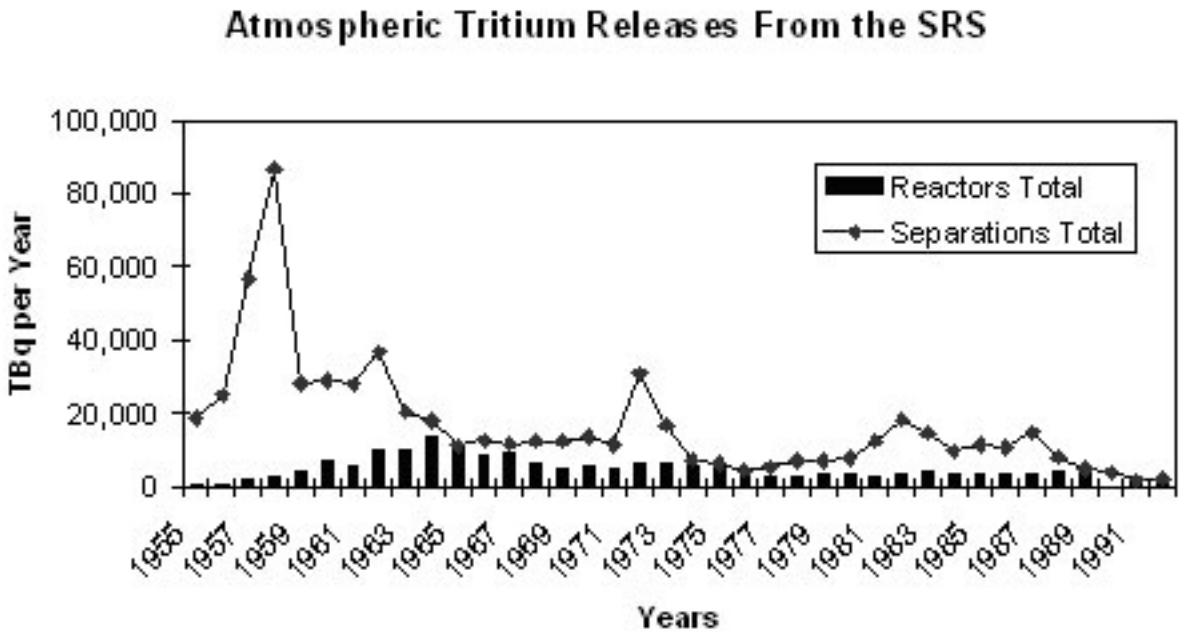

FIGURE 5.9. Atmospheric 3 H releases from SRS reactors and chemical separations facilities (modified from RAC, 2001).

The chemical separation stacks also discharged the majority of radioiodine, more than 300 times than what was emitted from all the reactor stacks combined. RAC (2001) estimated total 131 I releases at 2,000 TBq, of this total about 80% were in organic form. The majority of the releases occurred before 1960 (**Figure 5.10**). The estimated release of 129 I ranged from 190 to 230 GBq (RAC, 201).

5.2.5 Waste Facilities

All of the SRS operations generated radioactive, nonradioactive but hazardous, and mixed (radioactive and hazardous) wastes. Liquid wastes were placed in seepage basins, hazardous solids in disposal pits and waste piles, and radioactive solids were buried.

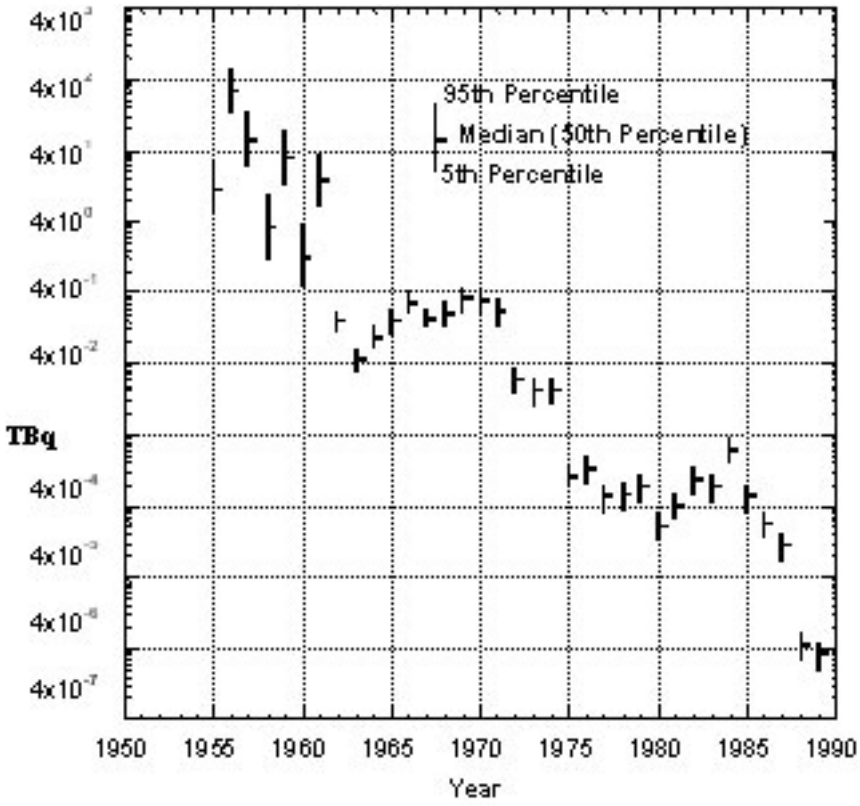

FIGURE 5.10. Estimated releases of 131 I in elemental form (I 2) from stacks in the chemical separations areas (adapted from RAC, 2001).

Over 150 individual waste sites exist on the SRS and 20 have been used as disposal sites for radioactive wastes (RAC, 2001). Radioactive seepage from some of the basins is now cropping out in site streams and in groundwater (**Figure 5.11**). Christensen and Gordon (1983) reported that 0.7 E15 Bq of tritium outcrop each year from shallow contaminated groundwater to surface waters on the SRS.

Additionally, SRS accepted solid radioactive waste from other locations, such as Los Alamos National Laboratory in New Mexico, and plutonium contaminated debris from two U.S. military aircraft that crashed in other countries.

FIGURE 5.11 . Zones of contaminated groundwater on the Savannah River Site.

Waste management facilities were developed as part of the initial construction of the chemical separations facilities; whereas, liquid waste from the reactors areas and the fuel and target fabrication facility were released directly into site streams during the first 20 years of operation. Discharge to site streams from the reactor areas was stopped in 1978. Total activities of radionuclides released to site streams and to seepage basins are given in **Table 5.2** .

High-level wastes (HLW) from the chemical separations facilities were placed in underground carbon steel tanks, and located in reinforced concrete vaults that had steel liners. The first HLW tank was full in June 1955 and additional HLW tanks were built in the 1980s. Most of the low activity liquid waste was concentrated by evaporation, neutralized with sodium hydroxide and stored in other tanks.

5.3 PATHWAYS

Total radioactive releases from the SRS for key radionuclides, as a function of pathways, are shown in **Figure 5.12** . Using NCRP (1989, 1996) methods, Risk Assessment Corporation (2001) screened the radiological releases from the SRS and ranked their importance relative to the potential dose received by the public. Results of such screening calculations depend on the quantity of radionuclides released, the potential for them to concentrate within the environment, and the relative toxicity of the radionuclides as measured by a dose conversion factor.

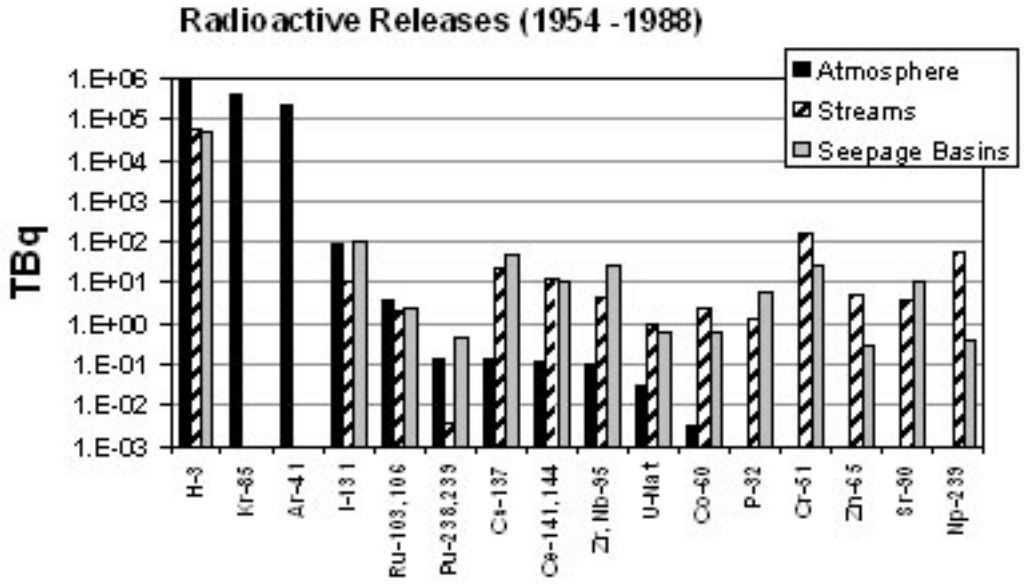

FIGURE 5.12 . Total radioactive releases for key radionuclides from the SRS, as a function of pathways
(adapted from Hetrick and Martin, 1990).

5.3.1 Atmospheric Pathways

Screening calculations revealed that 131 I and 3 H were the most important radionuclides in the atmospheric pathway (**Figure 5.13**). Although some 235,000 TBq of 41 Ar were released from the reactor areas, its short half-life of 1.8 h restricted it presence largely to onsite locations. In contrast, a comparatively small amount (~93 TBq) of 131 I was released to the atmosphere, but its longer halflife of 8 d, and its high biological mobility, caused it to be a potentially important contributor to public dose. Atmospheric releases from SRS were generally the highest and the potential for offsite deposition was the greatest during these early years of operation (RAC, 2001). Routine air monitoring for iodine began onsite, at the site perimeter and at sites on a 40-km radius distance in 1955. Additional sampling was initiated at 160-km distance in 1962. 131 I was detected from 1955 through 1963 at the plant perimeter and 40-km locations. At the 160-km radius, 131 I was detected only during 1962 and 1963. After 1963, only onsite concentrations were consistently measured above the detection limit (RAC, 2001; **Figure 5.14**).

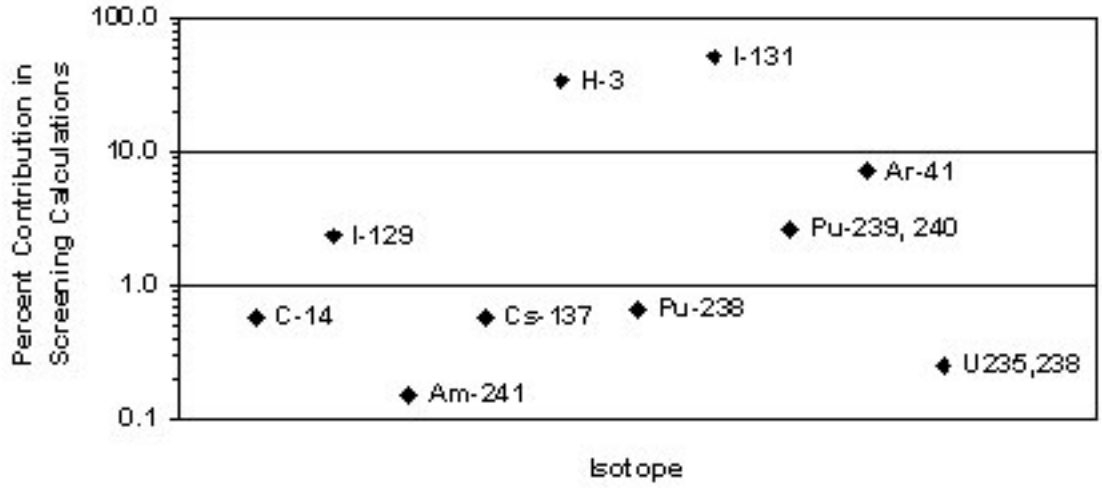

FIGURE 5.13 . Relative importance of airborne radionuclides released from the SRS as potential contributors to dose received by the public.
RAC (2001) performed the calculations based on NCRP guidelines.

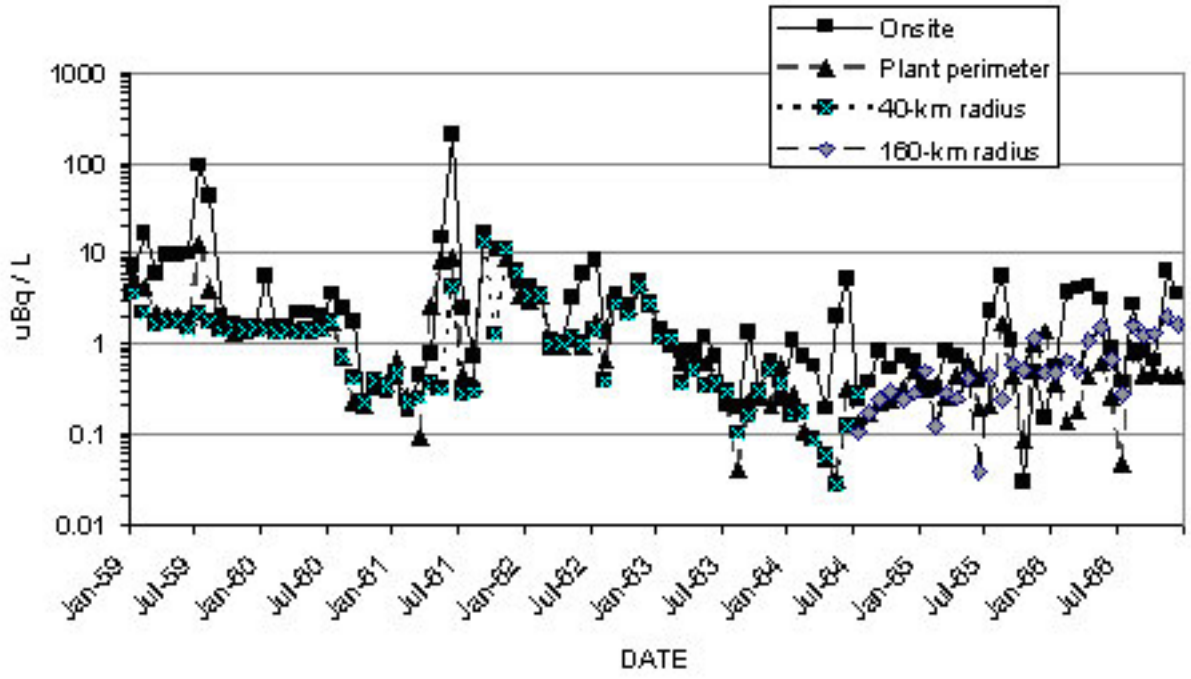

FIGURE 5.14 . Average monthly concentrations of 131 I measured on and off the SRS from 1959 through 1966.
The approximate detection limit during this time was about 1 µBq L -1 (adapted from RAC, 2001).

Releases of tritium were also substantial, and a potential contributor to offsite dose. For example, stack losses from F-area chemical separations facility averaged 1 to 2 PBq per month under routine operating conditions during 1955 and 1956 (RAC, 2001). Total atmospheric releases from all SRS facilities, by year, are depicted in **Figure 5.9.** 94% of the tritium released was to the atmosphere and 6% to effluent streams. A comparison of atmospheric 3 H concentrations as a function of distance from the SRS in 1960 is found in **Figure 5.15** .

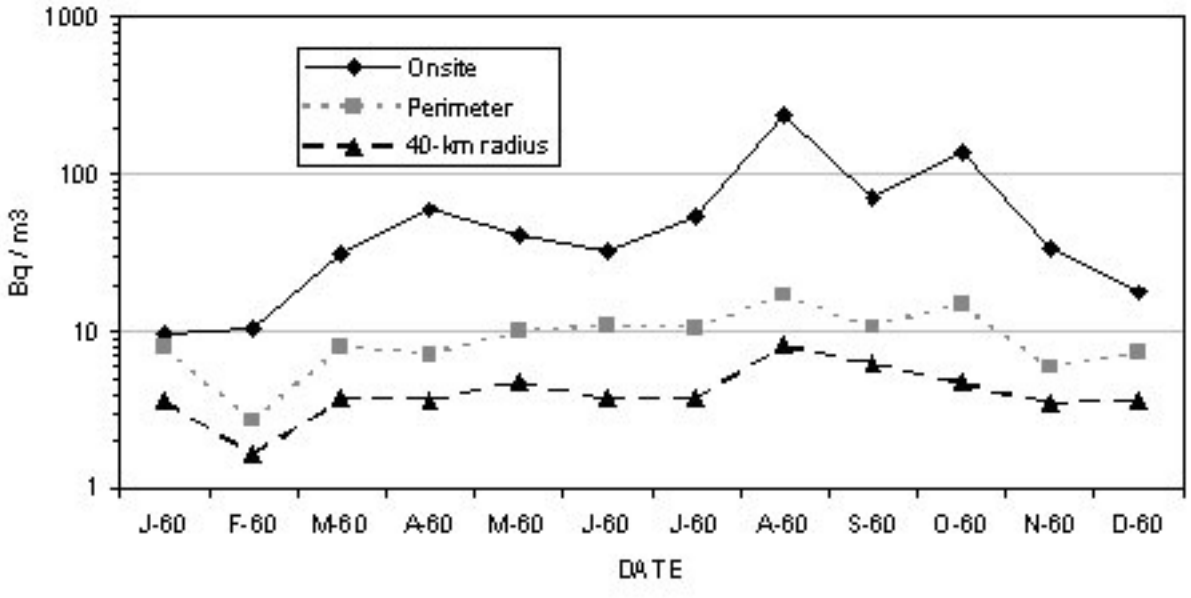

FIGURE 5.15 . Monthly average tritium concentrations onsite, at the SRS perimeter and at a 40-km distance during 1960 (adapted from RAC, 2001).

5.3.2. Aquatic Pathways

Of the numerous SRS facilities, the main source of radionuclide releases to surface waters was from the reactors. The primary source terms were large (~1.5 x10^6 L) water-filled basins adjacent to the reactor building in which spent fuel and irradiated target elements were stored prior to their transport to the chemical separations facilities. In contrast, r eleases of liquid effluents from the chemical separations areas were confined to storage tanks and seepage basins, rather than directly to site streams. However, some of the more mobile radionuclides, particularly 3 H, have leached through the seepage basins, contaminated the ground water and outcropped into site streams. About 800 TBq y^{-1} of 3 H seep from waste sites on the SRS into shallow groundwaters that then crop-out in surface water (RAC, 2001).

For security and safety reasons, the reactors were placed at the center of the 750-km^2 site. An 80-km network of underground concrete pipes, some over 2 m in diameter, provided a conduit for pumping Savannah River water to the reactors. Two onsite lakes, Par Pond and L-Lake (built in 1958 and 1985, respectively), provided additional cooling water. After passing once over the primary cooling coils, the river water was released into site streams. Five streams (Upper Three Runs Creek, Four Mile Creek, Pen Branch, Steel Creek and Lower Three Runs Creek) received secondary cooling water, as well as radioactive effluents from the reactor disassembly basins.

Unlike the production reactors at Hanford, t he reactors on the SRS were cooled and moderated using a closed system of heat exchangers filled with heavy water. The primary, heavy water coolant did not leave the reactor building but was circulated continuously through heat exchangers which it, in turn, were cooled by ordinary rive water (Bebbington, 1990). This heat exchange step was one of the primary reasons for the reduced radioactive contamination of aquatic ecosystems on the SRS.

The onsite streams meander for 8 - 13 km onsite, pass through a swamp system, and then discharge offsite into the Savannah River . The Savannah River has an annual mean river flow of about 300 m^3 s^{-1} . The onsite streams are small creeks with natural flows in the largest of the five systems (Upper Three Runs Creek) of about 7 m^3 s^{-1} . The onsite streams and swamp played an important role in receiving, transporting, removing and diluting materials before they were released offsite into the Savannah River. For example, 22 TBq of 137 Cs were released via site streams, but only about 0.3 TBq reached the Savannah River.

Aquatic releases of key radionuclides are graphed in **Figure 5.12.** Their relative contributions to offsite doses have been estimated in **Figure 5.16** , and reveal the over-riding importance of 137 Cs. RAC's (2001) median estimate of total 137 Cs for all years was about 9 TBq with the 5th and 95th percentiles of the distribution of 4 and 22 TBq. Concentrations of 137 Cs in the Savannah River at a control upstream location and an impacted location downstream of the SRS are shown in **Figure 5.17** . Other important radionuclides include 90 Sr, 60 Co, and 32 P. The median estimate of the total 90 Sr release for all years was about 4 TBq (RAC, 2001).

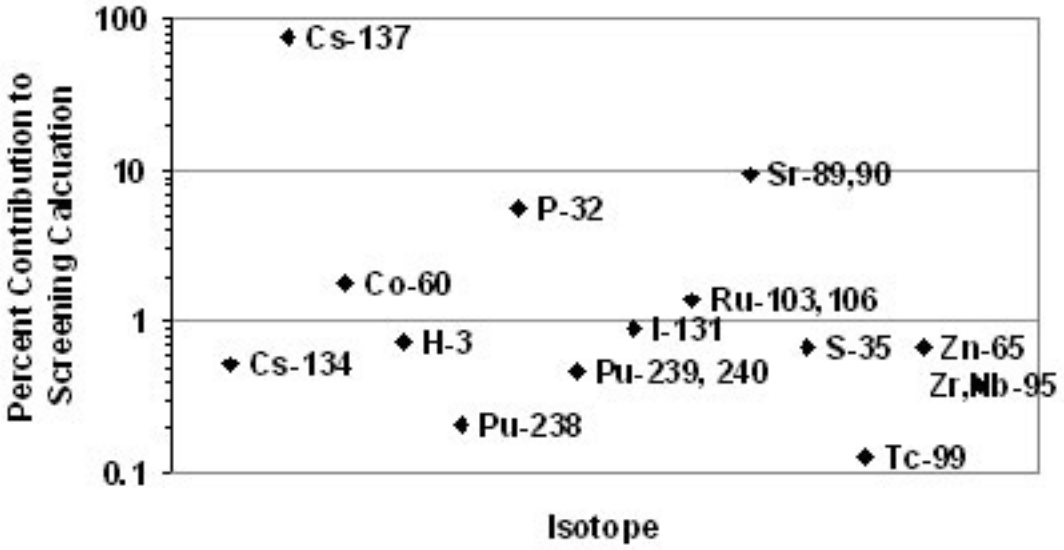

FIGURE 5.16 . Relative importance of aquatic radionuclide releases from the SRS as potential contributors to dose received by the public.
RAC (2001) performed the calculations based on NCRP guidelines.

Fish from the Savannah River represent a potentially important exposure pathway to people who may have relied on them for a significant portion of their diet. Although locations within the plant boundary have not been legally accessible to the general public, some people poached fish from onsite locations, and contaminated fish migrated offsite into public waters.

Based on both flesh and bone concentrations, it is clear that Savannah River fish collected from locations adjacent to and below the SRS were contaminated by SRS activities (**Table 5.3**). Cesium-137 concentrations were elevated at locations adjacent to SRS and below SRS through about 1971, after which concentrations at all locations are near the lower limit of detection (LLD). The same general trends are evident for 89,90 Sr in fish bone (RAC, 2001).

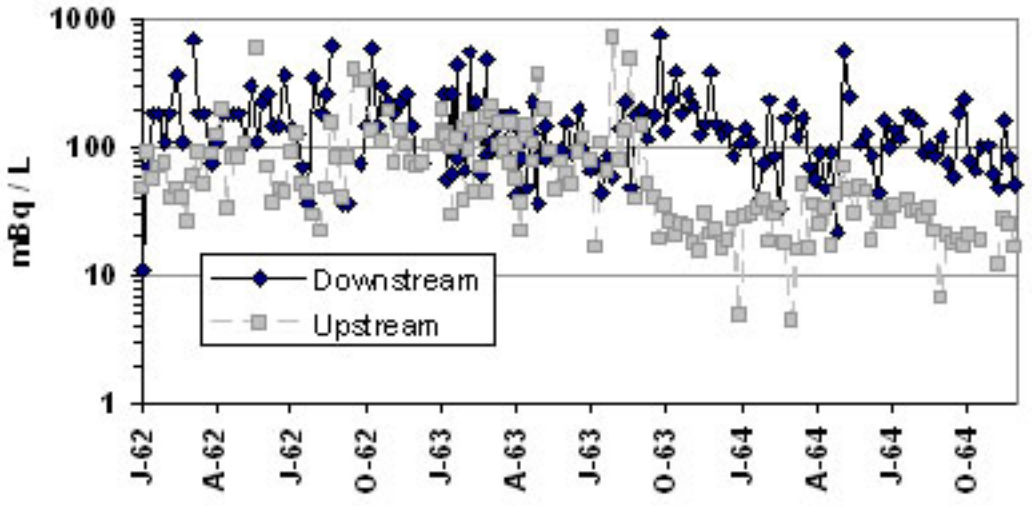

FIGURE 5.17. Cesium-137 concentrations (mBq / L) measured in the Savannah River upstream and downstream of the SRS. The upstream measurements provide a means of quantifying the fallout levels of 137 Cs levels present in the Savannah River. There are periods of time—such as the first three quarters of 1963— when the SRS contribution is masked by global fallout levels (i.e., the upstream measurements are higher than, or indistinguishable from, the downstream measurements). However, by late 1963, the downstream concentrations are consistently higher (adapted from RAC, 2001).

TABLE 5.3. Maximum measured radionuclide concentrations in fish from the Savannah River (downstream from the SRS), Steel Creek Mouth (adjacent to the SRS), and Onsite Locations. Radionuclide concentrations are in kBq kg^{-1} , followed by the year (adapted from RAC, 2001).

Location	137 Cs (flesh)	89,90 Sr (bone)
Savannah River	2.9 (1967)	5.6 (1979)
Steel Creek mouth	10.4 (1971)	5.2 (1971)
Onsite (Steel Creek)	129.5 (1969)	35.5 (1970)

5.3.3. Terrestrial Contamination

Tritium and 131 I appear to be the only radionuclides of SRS origin detected offsite in vegetation. Greatest releases occurred prior to 1961. There are no apparent spatial trends for tritium, and reported concentrations have been similar in all directions and at all locations for each distance (RAC, 2001). Concentrations appear to decrease as a power function (i.e., concentrations decrease exponentially as distance increases exponentially) with increasing distance from the SRS. Concentrations of 3 H in vegetation taken from 1976 to 1991, onsite and at 40 and 160-km radii, are given in **Table 5.4.**

TABLE 5.4 . Median, maximum, and minimum annual average tritium concentrations (Bq / ml) measured in vegetation samples collected at the SRS perimeter, 40-km radius, and 160-km radius

locations since 1976 (adapted from RAC, 2001)

Location	Median	Maximum	Minimum
SRS Perimeter	0.14	1.33	0.05
40-km Radius	0.06	0.18	0.02
160-km Radius	0.02	0.29	0.003

SRS operations appear to have contributed to 131 I in vegetation at the site perimeter during at least the first half of 1957. Based on reported releases for 1955 and 1956, which were greater than for 1957, it is likely that 131 I concentrations in vegetation at the site perimeter locations were also impacted by SRS operations during these years. Resultant exposure to the general public from radionuclides, other than 131 I and tritium, appears almost entirely attributable to deposition from weapons testing fallout (RAC, 2001).

An analysis of the available data suggests that, in general, fallout from atmospheric weapons testing was also the probable source of the radionuclide concentrations measured in milk around the SRS. However, there is evidence that SRS activities contributed to offsite contamination during the early years of operation (RAC, 2001). The first positive analysis for radioiodine in milk was reported in 1958. The average concentration during that year was 10 Bq L^{-1} and the maximum recorded concentration was 40 Bq L^{-1} . The maximum reported concentration of 131 I in milk occurred in 1961 from a cow in a village next to the SRS (202 Bq L^{-1}). 131 I concentrations in milk during 1959 to 1968 from two dairies located approximately 30-km from the SRS are shown in **Figure 5.18.** Sampling of milk for 90 Sr began during the fall of 1958, and monthly average concentrations ranged from 0.5 to 0.9 Bq L^{-1} .

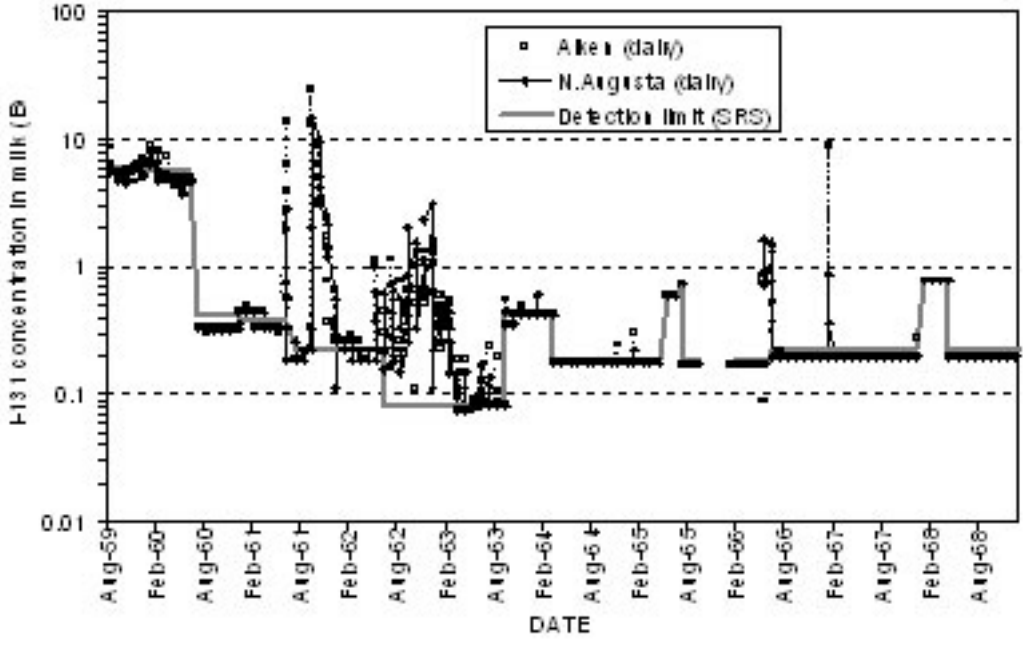

FIGURE 5.18. 131 I concentrations (Bq / L) in milk from 1959 to 1968 at two

dairies approximately 30-km from the SRS (adapted from RAC, 2001).

Plutonium releases from the SRS were small relative to global weapons fallout. Ratios of 238 Pu / 239,240 Pu specific to the SRS allowed researchers to conclude that no Pu of SRP origin was detectable in soil samples from the plant perimeter and beyond (RAC, 2001). **Table 5.5** compares Pu concentrations on the SRS to distant locations.

TABLE 5.5. Plutonium deposition (MBq km^{-2}) in 1973 for onsite and offsite locations, as determined by soil analyses (adapted from RAC, 2001).

Sample Location	239 Pu	238 Pu
Plant perimeter :		
NW quadrant	59.6	7.8
NE quadrant	50.1	3.0
SE quadrant	40.3	2.6
SW quadrant	47.4	2.6
Distant locations :		
Clinton, SC	67.0	3.0
Athens, GA	63.6	7.8
Savannah, GA	62.9	1.8

5.4 DOSE ASSESSMENT

5.4.1 Major Contributors to Dose

Computer models have been used to reconstruct an estimate of dose to offsite residents that lived adjacent to the Savannah River Site from 1955 through 1996 (Carlton, 1998). Models were based on atmospheric and aquatic releases from the Savannah River Site operations, and included ingestion, inhalation and external irradiation pathways. Total dose, from 1954 through 1996, to a hypothetical, maximally exposed individual from atmospheric pathways was 0.77 mSv. Iodine, tritium, and plutonium were the largest contributors from the atmospheric pathways (**Fig. 5.19**). Total dose, from 1954 through 1996, to the hypothetical, maximally exposed individual from aquatic pathways was 1.4 mSv. 137 Cs, 32 P, and 95 Zr,Nb were the largest contributors from the aquatic pathways, largely from the consumption of fish and saltwater invertebrates (**Fig 5.19**). Combining the population doses from both atmospheric and liquid releases resulted in a total population dose from SRS operations, from 1954 through 1996, of 4.9 person-Sv, with the largest annual population dose of 5.8 person-Sv occurring in 1955. The largest contributors to the population dose were 3 H, 65 Zn, and 131 I (**Figures 5.20 and 5.21**).

5.4.2 Dose from Plutonium Contamination

Dose to humans from Pu releases at the SRS have been calculated numerous times and found to be less than those acquired from naturally occurring radionuclides. Corey *et al* . (1982) estimated the dose to humans assuming an annual ingestion of 10 kg of 239 Pu-contaminated wheat grain,

harvested from onsite research plots adjacent to the H-Area separations facility. A mean concentration in the grain of 0.02 Bq 239 Pu kg^{-1} produced a 50-y dose commitment to bone of 4.5 x 10^{-5} mSv. By comparison, naturally occurring concentrations of 40 K in the wheat (155 Bq kg^{-1}) yielded a dose of 1.4 x 10^{-2} mSv; 1000 times greater than that from 239 Pu. Doses from consumption of 10 kg of 239 Pu contaminated root and tuber crops produced higher 50-y bone dose commitments than those generated from consuming the Pu contaminated wheat (carrots: 6.7 x 10^{-4} mSv; onions: 5.4 x 10^{-5} mSv; red potatoes; 1.4 x 10^{-4} mSv; Corey *et al* ., 1982). Peeling the roots and tubers reduced the dose by two orders of magnitude, whereas peeling did not significantly alter the dose from consumption of tubers contaminated with 40 K (approx. 0.05 to 0.2 mSv).

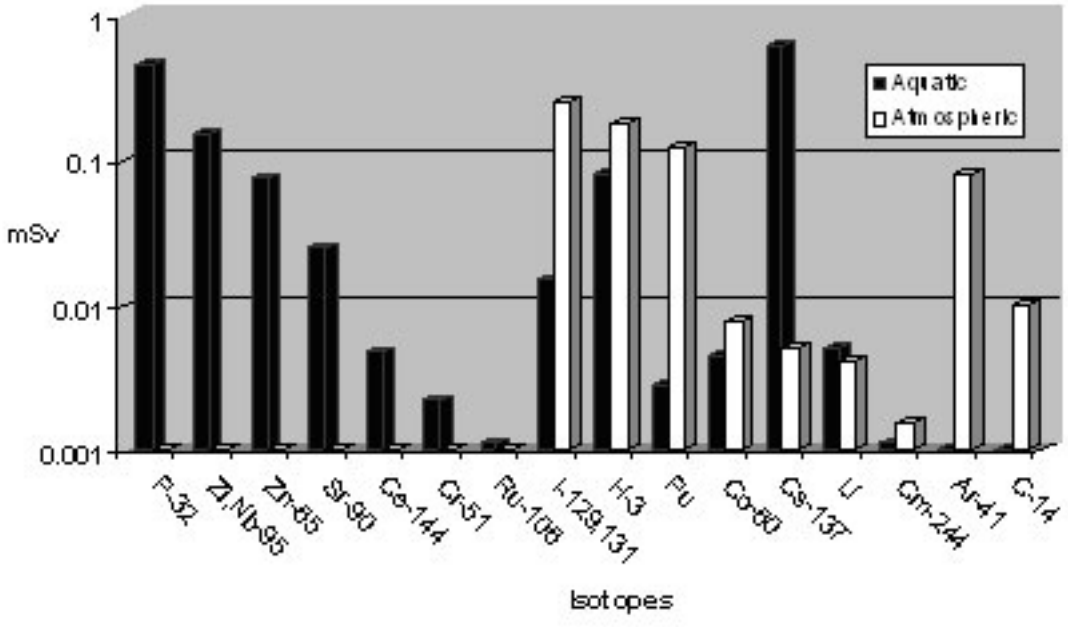

FIGURE 5.19 . Dose (mSv) to hypothetical, maximally exposed individual residing next to the SRS , from 1954 to 1996, from aquatic and atmospheric pathways (Carlton, 1998)

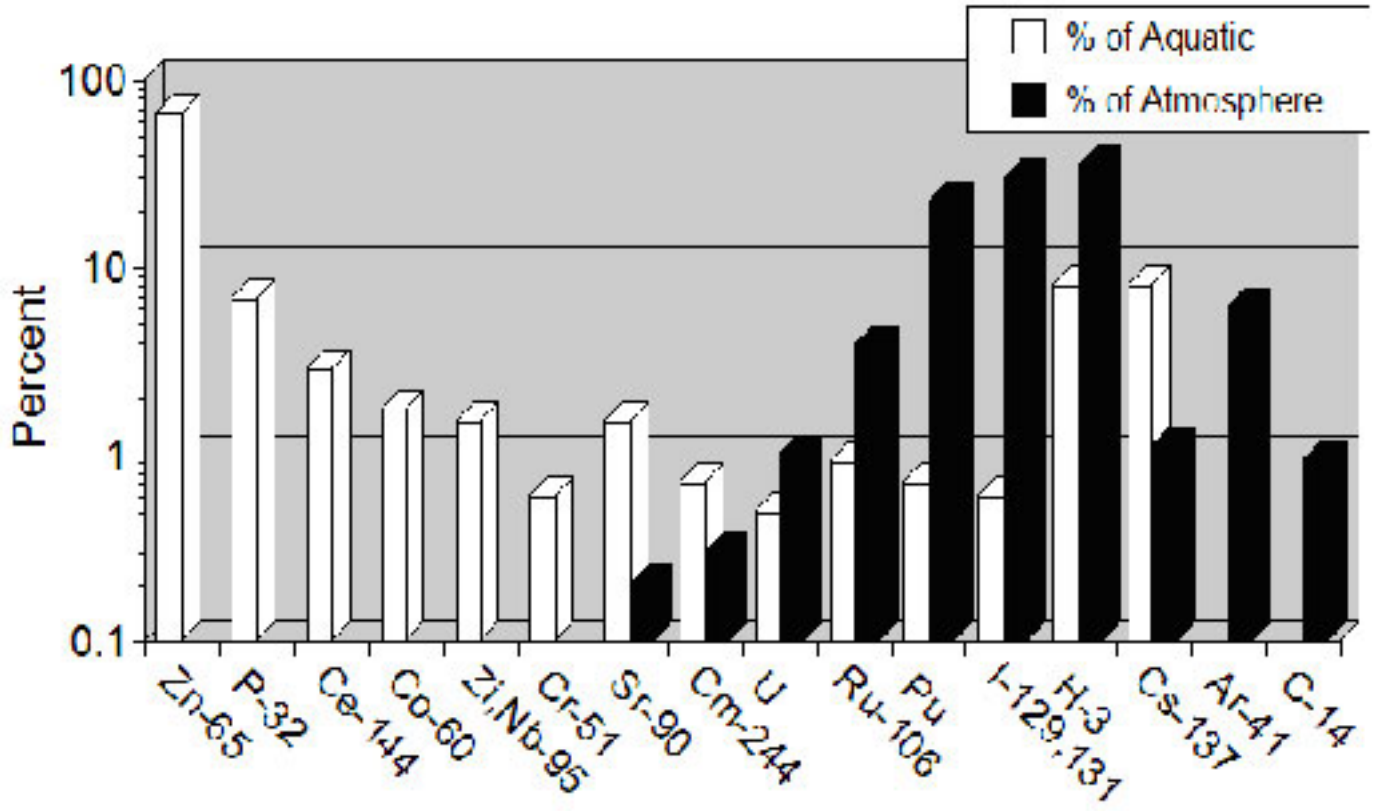

FIGURE 5.20 . Percent contribution to population doses, by isotope, from SRS releases from 1954 to 1996 for aquatic and atmospheric pathways (Carlton, 1998).

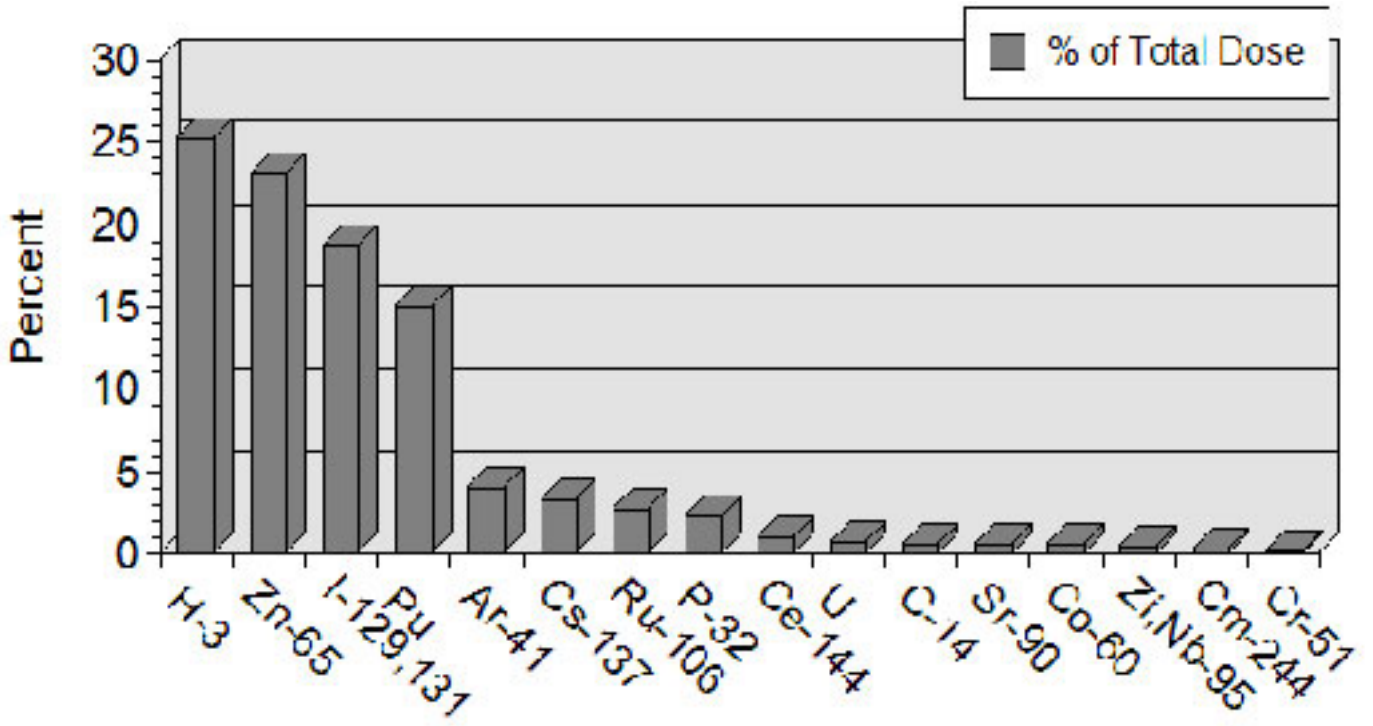

FIGURE 5.21 . Isotopic contribution to population dose from SRS operations (1954 to 1996) for atmospheric and liquid pathways combined (Carlton, 1998)

The largest 50-y bone dose commitment would have been acquired by an agricultural worker (0.35 mSv), assuming the individual drove a tractor for 100x8-h days, and inhaled air with an average Pu concentration of 2 mBq m^{-3} (Corey *et al* ., 1982). 239 Pu concentrations downwind from the edge of

the field averaged 8 mBq m^{-3} , but varied considerable (coefficient of variation = 280%) depending on the type of agricultural operation in progress. Individual values ranged from 0.06 mBq m^{-3} during fertilizing, to 38 mBq m^{-3} during planting and light disking, to 95 mBq m^{-3} during mowing (Corey *et al* ., 1982). Thus, the major dose to man from agricultural land use resulted from resuspension of surface Pu and subsequent inhalation during soil tillage operations.

Interesting dose commitments were calculated for an individual using Pu contaminated tobacco products. Tobacco, an important crop in the southeastern U.S., can potentially contribute to human dose from radionuclides via the inhalation pathway. The researchers assumed 25% of the Pu in the tobacco was inhaled during daily smoking of 40 cigarettes over a 1-year period. The 50-y dose commitment to bone surfaces (0.35 mSv) was 1000 times greater than that from the ingestion pathway for crops grown under identical deposition conditions (McLeod *et al* ., 1984).

Because the production facilities have been shut down on the SRS, current doses lack a stack emission source term and are dominated by ingestion of 137 Cs contaminated food stuffs and external irradiation. For example, dose to a hypothetical resident living on a contaminated shoreline of Par Pond, and deriving his sustenance from radionuclide contaminated biota, was calculated for the inhalation, ingestion and external exposure pathways (Whicker *et al* ., 1993). Dose from 239 Pu was dominated by the inhalation pathway (1.31 mSv), followed by ingestion (0.007 mSv). External irradiation from Pu was not measurable. 239 Pu contribution to the individual's lifetime risk of fatal cancer from all radionuclide contaminants at Par Pond was 2.6%. Exposure to 137 Cs resulted in the largest dose and comprised 96.6% of the cancer risk (Whicker *et al* ., 1993). Thus, doses from exposure to Pu were small compared to natural radionuclides or in comparison to 137 Cs exposure (Whicker *et al* ., 1993).

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Chap.6 - HANFORD

B.A. Napier,M.Savkin

6.1 Generalities

In 1943, the United States Army Corps of Engineers selected an area of nearly 1000 km^2 , in semiarid southeastern Washington State, for producing plutonium and other nuclear materials supporting the United States' effort (known as the Manhattan Project) in World War II. This area, called the Hanford Site (Figure 1), was used for uranium fuel preparation, nuclear reactor operations, fuel reprocessing, plutonium recovery, and waste management operations. Nine nuclear reactors for the production of plutonium were eventually constructed. Reactor operations began in 1944; the last production reactor was placed in cold standby in 1987. Additional support facilities were constructed in the 1940's and 1950's; some of these facilities continue to operate. Hanford Site operations developed and changed as the defense needs of the United States and the understanding of nuclear energy changed. However, with the end of the Cold War and the advent of waste treatment and disposal technologies and environmental management, this original mission has been replaced by cleanup.

The Hanford Site was established to use technology developed at the University of Chicago and the Clinton Laboratory in Oak Ridge, Tennessee, to produce plutonium for some of the nuclear weapons tested and used in World War II. Hanford was the first plutonium production facility in the world. The site was selected by the U.S. Army Corps of Engineers because it was remote from major populated areas and had 1) ample electrical power from Grand Coulee Dam, 2) a functional railroad, 3) clean water from the nearby Columbia River, and 4) sand and gravel that could be used to construct large concrete structures. For security, safety, and functional reasons, the site was divided into numbered areas (Figure 6.1.1).

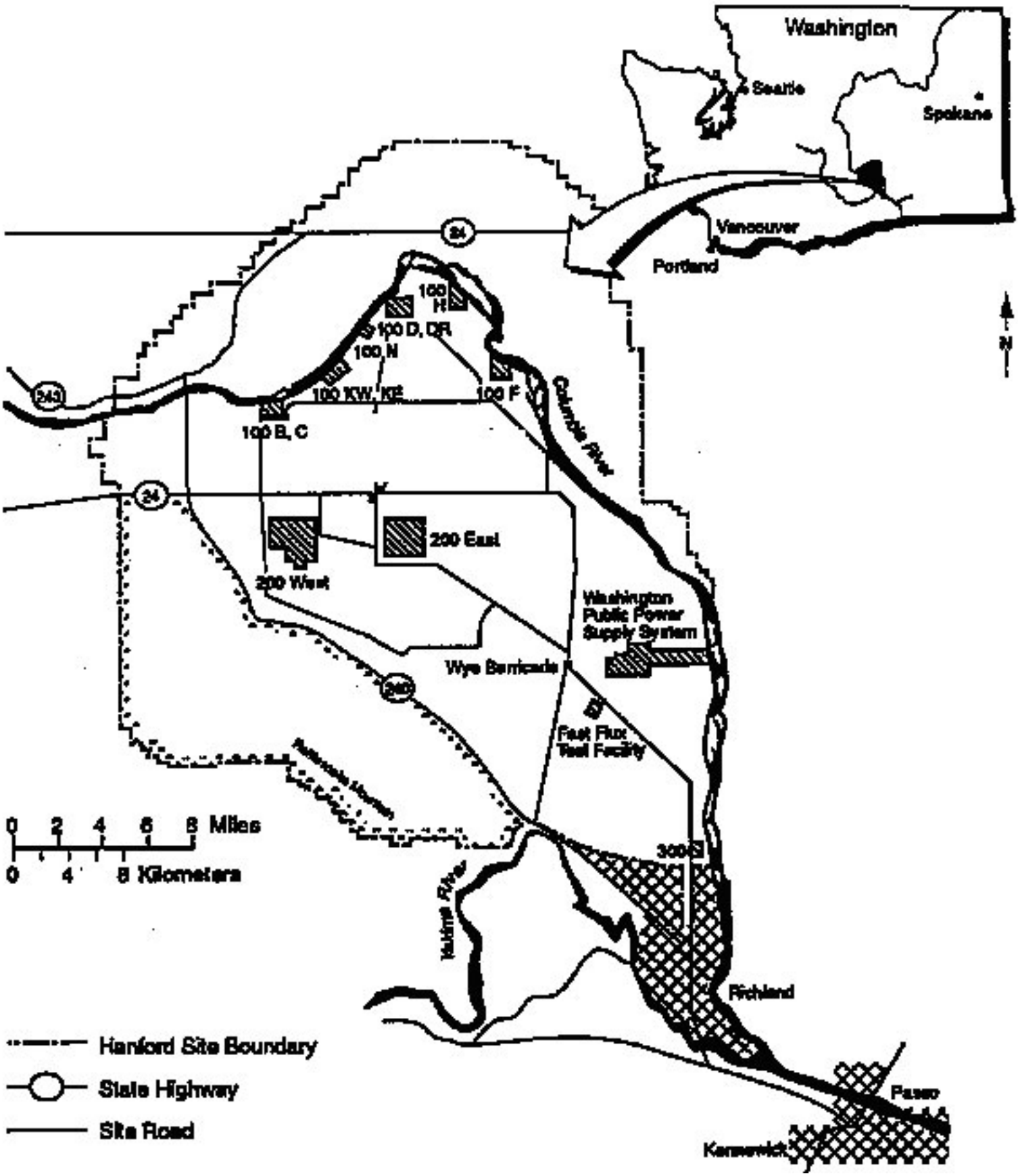


Figure 6.1.1. The Hanford Site

6.2 Source term

Hanford Site operations have produced liquid, solid, and gaseous wastes. Most waste resulting from site operations has had at least the potential to contain radioactive materials. From an operational

standpoint, radioactive waste was originally categorized as “high level,” “intermediate level,” or “low level,” which referred to the level of radioactivity present. Some high-level solid waste, such as large pieces of machinery and equipment, were placed onto railroad flatcars and stored in underground tunnels. Both intermediate- and low-level solid wastes, consisting of tools, machinery, paper, or wood, were placed into covered trenches at storage and disposal sites known as “burial grounds.” Beginning in 1970's, solid waste was segregated according to the makeup of the waste material. Solids contaminated with plutonium and other transuranic materials were packaged in special containers and stored in trenches covered with soil for possible later retrieval. High-level liquid waste was stored in large underground tanks. Intermediate-level liquid waste streams were usually routed to underground structures of various types called “cribs.” Occasionally, trenches were filled with the liquid waste and then covered with soil after the waste had soaked into the ground. Low-level liquid waste streams were usually routed to surface impoundments (ditches and ponds). Non-radioactive solid waste was usually burned in “burning grounds.” This practice was discontinued in the late 1960's in response to the Clean Air Act, and the materials were buried at sanitary landfill sites. These storage and disposal sites, with the exception of high-level waste tanks, are now designated as “active” or “inactive” waste sites, depending on whether the site currently receives waste.

All unrestricted discharges of radioactive liquid waste to the ground were discontinued in 1997. The 616-A crib (also known as the State-Approved Land Disposal Site) receives radioactive (tritium) liquid waste from the 200 Areas Effluent Treatment Facility. This effluent is the only discharge of radioactive liquid waste to the ground at Hanford. All other liquids discharged to the ground are licensed by permit from the state of Washington. National Pollutant Discharge Elimination System permits issued by the U.S. Environmental Protection Agency (EPA) govern liquid discharges to the Columbia River. Permits from EPA, the Washington State Department of Health, and the Washington State Department of Ecology govern the discharge of gaseous effluents to the atmosphere.

The 300 Area

From the early 1940s until the advent of the cleanup mission, most research and development at the Hanford Site were carried out in the 300 Area, located just north of Richland. The 300 Area was also the location of nuclear fuel fabrication. Nuclear fuel in the form of pipe-like cylinders (fuel elements) was fabricated from metallic uranium shipped in from offsite production facilities. Metallic uranium was extruded into the proper shape and encapsulated in aluminum or zirconium cladding. Copper was an important material used in the extrusion process, and substantial amounts of copper, uranium, and other heavy metals ended up in 300 Area liquid waste streams. Initially, these streams were routed to the 300 Area waste ponds, which were located near the Columbia River shoreline. In more recent times, the low-level liquid waste was sent to process trenches or shipped to a solar evaporation facility in the 100-H Area (183-H solar evaporation basins). This practice has been discontinued. At this time, all liquid process waste generated in the 300 Area is treated at the 300 Area Treated Effluent Disposal Facility and released to the Columbia River according to the requirements of a National Pollutant Discharge Elimination System permit. Sewage waste is released into the city of Richland sanitary water treatment system.

Former fuel fabrication buildings and facilities are now used for other purposes or are in various stages of cleanup or restoration. For example, the 313 Building, which houses a very large and unique aluminum extrusion press is, leased by DOE to Kaiser Aluminum and Chemical Corporation.

The 100 Areas

The fabricated fuel elements were shipped by rail from the 300 Area to the 100 Areas. The 100 Areas are located on the Columbia River shoreline, where up to nine nuclear reactors were in operation. The main component of the nuclear reactors consisted of a large stack (pile) of graphite blocks that had tubes and pipes running through it. The tubes were receptacles for the fuel elements while the pipes carried water to cool the graphite pile. Placing large numbers of slightly radioactive uranium fuel elements into the reactor piles created an intense neutron field, and a radioactive chain reaction resulted in the conversion of some uranium atoms into plutonium atoms. Other uranium atoms were split into radioactive “fission products.” The intense radiation field also caused some non-radioactive atoms in the structure to become radioactive “activation products.”

The first eight reactors, constructed between 1944 and 1955, used water from the Columbia River for direct cooling. Large quantities of water were pumped through the reactor piles and discharged back into the river. The discharged cooling water contained primarily activation products from impurities in the river water made radioactive by neutron activation and radioactive materials that escaped from the fuel elements or tube walls during the irradiation process. The ninth reactor, N Reactor, was completed in 1963 and was a modified design. Purified water was re-circulated through the reactor core in a closed-loop cooling system. Beginning in 1966, the heat from the closed-loop system was used to produce steam that was sold to Energy Northwest to generate electricity at the adjacent Hanford Generating Plant.

When fresh fuel elements were pushed into the front face of a reactor's graphite pile, irradiated fuel elements were forced out the rear into a deep pool of water called a “fuel storage basin.” After a brief period of storage in the basin, the irradiated fuel was shipped to the 200 Areas for processing. The fuel was shipped in casks by rail in specially constructed railcars. Most of the irradiated fuel produced by the N Reactor from the early 1970s to the early 1980s was the result of electricity production runs. This material was not weapons grade, so was never processed for recovery of plutonium.

Beginning in 1975, N Reactor irradiated fuel was shipped to the K-East and K-West fuel storage basins (K basins) for temporary storage, where it remains today. This fuel accounts for the majority of the total fuel inventory stored under water in the K basins. From the early 1980s until its shutdown in 1987, N Reactor operated to produce weapons-grade material. Electricity production continued during this operating period but was actually a byproduct of the weapons production program. The majority of weapons-grade material produced during these runs was processed in the 200-East Area at the Plutonium-Uranium Extraction Plant prior to its shutdown. The remainder is stored in the K basins. Approximately 2300 tons of spent nuclear fuel are in the process of being packaged and removed from these basins.

All of the Hanford production reactors and most of the associated facilities have been shut down and deactivated, and each 100 Area is in some stage of cleanup, decommissioning, or restoration. For example, C Reactor has been cocooned and placed into interim safe storage as a large-scale demonstration, a state that it can safely remain in for many years. Of the 24 facilities associated with C Reactor, 23 have been removed.

The 200 Areas

The 200-East and 200-West Areas are located on a plateau approximately in the center of the site. These areas house facilities that received and dissolved irradiated fuel and then separated out the valuable plutonium. These facilities were called “separations plants.” Three types of separations plants were used over the years to process irradiated fuel. Each of the plutonium production processes began with the dissolution of the aluminum or zirconium cladding material in solutions containing ammonium hydroxide/ammonium nitrate/ ammonium fluoride followed by the dissolution of the irradiated fuel elements in nitric acid. All three separations plants, therefore, produced large quantities of waste nitric acid solutions that contained high levels of radioactive materials. These wastes were neutralized and stored in large underground tanks.

Fumes from the dissolution of cladding and fuel and from other plant processes were discharged to the atmosphere from tall smokestacks. Filters were added to the stacks after 1950.

Both B and T plants used a “bismuth phosphate” process to precipitate and separate plutonium from acid solutions during the early days of site operations. Leftover uranium and high-level waste products were not separated and were stored together in large, underground, single-shell tanks (i.e., tanks constructed with a single wall of steel). The leftover uranium was later salvaged, purified into uranium oxide powder at the Uranium-TriOxide Plant, and transported to uranium production facilities in other parts of the country for reuse. The salvage process used a solvent extraction technique that resulted in radioactive liquid waste that was discharged to the soil in covered trenches at the BC cribs area south of the 200-East Area.

After T Plant stopped functioning as a separations facility, it was converted to a decontamination operation, where pieces of equipment and machinery could be radiologically decontaminated for reuse.

B Plant was later converted into a facility to separate radioactive strontium and cesium from high-level waste. The strontium and cesium were then concentrated into a solid salt material, melted, and encapsulated at the adjacent encapsulation facility. Canisters of encapsulated strontium and cesium are currently stored in a water storage basin at the encapsulation facility.

In 1952, U Plant in the 200-West Area, built during World War II but not needed as a processing canyon, was retrofitted as the Metal Recovery Plant. Its mission was to use a new tributyl phosphate/ saturated kerosene extraction technique to recover uranium from the waste stored in Hanford's tank farms. The scarcity of high-grade uranium supplies made this mission crucial and much of the United States' supply of uranium was housed in Hanford's tanks. The separated uranium was purified into uranium oxide powder at the Uranium-TriOxide Plant.

The Reduction-Oxidation and Plutonium-Uranium Extraction Plants used solvent extraction techniques to separate plutonium from leftover uranium and radioactive waste products. Most of the irradiated fuel produced at the site was processed at either of these two plants. The solvent extraction method separates chemicals based on their differing solubilities in water and organic solvents (i.e., hexone at the Reduction-Oxidation Plant and tributyl-phosphate at the Plutonium-Uranium Extraction

Plant). High-level liquid wastes were neutralized and stored in single-shell tanks (Reduction-Oxidation Plant) or double-shell tanks (Plutonium-Uranium Extraction Plant). Occasionally, organic materials such as solvents and resins ended up in high-level liquid waste streams sent to the tanks. Various chemicals and radioactive materials precipitated and settled to the bottom of the tanks. This phenomenon was later used to advantage. The liquid waste was heated in special facilities (evaporators) to remove excess water and concentrate the waste into salt cake and sludge, which remained in the tanks. The evaporated and condensed water contained radioactive tritium and was discharged to cribs. Intermediate-and low-level liquid wastes discharged to the soil from the Reduction-Oxidation and Plutonium-Uranium Extraction Plants typically contained tritium and other radioactive fission products as well as non-radioactive nitrate. Intermediate-level liquid wastes discharged to cribs from the Reduction-Oxidation Plant sometimes contained hexone used in the reduction-oxidation process. Cooling water from the Reduction-Oxidation Plant was discharged to the 216-S-10 pond (B Pond). Cooling water from the Plutonium-Uranium Extraction Plant was discharged to the Gable Mountain and 216-B-3 ponds.

The Reduction-Oxidation and Plutonium-Uranium Extraction Plants produced uranium nitrate for recycle and plutonium nitrate for weapons component production. Uranium nitrate was shipped by tank truck to the Uranium-Tri-Oxide Plant for processing. The Uranium-Tri-Oxide Plant used specially designed machinery to heat the uranium nitrate solution and boil off the nitric acid, which was recovered and recycled to the separations plants. The product (uranium oxide) was packaged and shipped to other facilities in the United States for recycle. Plutonium nitrate, in small quantities for safety reasons, was placed into special shipping containers (P-R cans) and hauled by truck to Z Plant (later called the Plutonium Finishing Plant) for further processing.

The purpose of Plutonium Finishing Plant operations was to convert the plutonium nitrate into plutonium metal blanks (buttons) that were shipped off the site for manufacture into nuclear components. The conversion processes used nitric acid, hydrofluoric acid, carbon tetrachloride, and other organic compounds. Varying amounts of all these materials ended up in the intermediate-level liquid wastes that were discharged to cribs. Cooling water from the Plutonium Finishing Plant was discharged via open ditch to the 216-U-10 pond (U Pond). High-level solid wastes containing plutonium scraps were segregated and packaged for storage in special earth-covered trenches.

All of the former activities in the separations plants, the Reduction-Oxidation Plant, and the Plutonium Finishing Plant have been shut down and the facilities are in various stages of decontamination and decommissioning or alternate use. For example, the former T Plant complex now consists of two operational facilities used for waste sampling and verification, waste repackaging, equipment decontamination, and storage of a small amount of irradiated fuel from the former Shipping-port, Pennsylvania reactor. Untreated low-level liquid wastes are no longer released to surface ponds, ditches, or cribs. These facilities are in various states of decommissioning, decontamination, and restoration.

The 400 Area

In addition to research and development activities in the 300 Area, the Hanford Site has supported several test facilities. The largest is the Fast Flux Test Facility, located ~8 kilometers (5 miles) northwest of the 300 Area. This special nuclear reactor was designed to test various types of nuclear

fuel. The facility operated for ~13 years and was shut down in 1993. The reactor was a unique design that used liquid metal sodium as the primary coolant. The heated liquid sodium was cooled with atmospheric air in heat exchangers. Spent fuel from the facility resides in the 400 Area, while other wastes were transported to the 200 Areas. With the exception of the spent fuel, no major amounts of radioactive waste were stored or disposed of at the Fast Flux Test Facility site. In January 1997, DOE made a decision to keep the Fast Flux Test Facility in standby while evaluating its potential for tritium and medical isotope production, as well as plutonium disposition. However, in December 2000, DOE decided to permanently close this reactor. It is anticipated that deactivation would be complete by 2006.

Historical Releases

The Hanford Environmental Dose Reconstruction (HEDR) Project was initiated as a result of public interest in the historical releases of radioactive materials from the Hanford Site. The scope of work included search for and retrieval of historical operations and monitoring information, and demographic, agricultural, and lifestyle information necessary to 1) reconstruct source terms; 2) model environmental transport in the atmosphere and the Columbia River; 3) model transport and accumulation of radioactive materials in environmental media and food products; 4) determine food consumption and lifestyle patterns; and 5) estimate doses to real and representative individuals who may have lived in the vicinity of the Site during its operation. The following discussion of emissions and releases is a summary of the HEDR results.

Atmospheric Source Terms

Scoping studies indicated that the primary radionuclide of interest from the atmospheric pathway was iodine-131 [Napier 1991, Napier 1992]. The project relied on original records generated during the time period under study. These were supplemented with other reports and summaries. Knowledge of the physical processes, monitoring techniques used, and completeness of records allowed the uncertainty to be estimated for each value. The project generated estimates of the iodine-131 releases on an hourly basis. Other radionuclides were also investigated and monthly release estimates prepared.

The creation of iodine-131 in the reactors was calculated from reactor power records. The calculations were based on the daily power records and took into account the day-by-day changes in the amount of iodine-131 present in the fuel. When irradiated fuel was discharged from the reactors, iodine-131 decayed with an 8-day half-life; the decay time, known as cooling, was inferred from records showing when fuel was discharged from the reactor and when it may have entered the dissolving process.

Dissolving the fuel in the separations plants was a two-step process. First, the aluminum cladding was dissolved with a caustic solution of sodium hydroxide, then the fuel was dissolved with nitric acid. The iodine-131 was released during this step and also during processing steps after dissolving. Detailed plant records on the dissolution of batches of fuel were correlated with reactor discharge records to determine the amount of iodine-131 present during dissolving. The fraction of iodine that was released directly to the stack as well as during subsequent processing was taken into account. The

estimated amount of iodine-131 along with other radionuclides of interest released to the atmosphere between 1944 and 1971 are summarized in Table 6.2.1 [Heeb 1994; Napier 2001]. The estimated total release of iodine-131 for the period is 2.8x10 16 Bq (762,000 Ci). Because of the wealth of original documentation and redundant sources, there is a high degree of confidence that the actual values fall within the computed ranges.

The source term release model (STRM [Heeb 1992]) provides estimates of the hourly releases to the HEDR computational system. Uncertainties in the actual amounts released are addressed through use of multiple Monte Carlo simulations, each of which represents an alternative release history that is consistent with existing knowledge. Together, these alternative release histories represent the range of releases that could have occurred. Approximately 100 separate realizations of the complete hourly release history were prepared with this source term code. Thus, the uncertainty in the amount of each hourly release is represented by a distribution of possible released amounts.

TABLE 6.2.1a. MEAN ESTIMATED MONTHLY IODINE-131 RELEASES FROM HANFORD SEPARATIONS PLANTS, 1944-1947 (Ci/Month)

Month	1944	1945	1946	1947
January		1221	11753	6158
February		2126	7399	3835
March		2082	7952	5617
April		28746	11680	4853
May		74482	13820	3989
June		46466	4609	1652
July		47036	5558	2297
August		72090	8642	1249
September		88682	7670	1206
October		92066	4819	472
November		37752	5525	261
December	2139	62340	7398	261
TOTAL	2139	555089	96284	31848

Table 6.2.1b. Annual Emissions of Iodine-131 and other Radionuclides from the Hanford Site (Curies/ year)

Year	I-131	Ru-103	Ru-106	Sr-90	Pu-239	Ce-144
1944	2139	0.49	0.035	0.021	0.0012	1.57
1945	555089	87	12	6.94	0.39	460.15
1946	96298	87	18	10.53	0.58	650.03
1947	31909	51	12	7.38	0.41	451.30
1948	1842	12	4.6	2.94	0.16	166.82
1949	8694	0.42	0.19	0.12	0.006	6.15

1950	3873.2	0.81	0.35	0.20	0.010	10.40
1951	30180.1	2.4	0.58	0.28	0.014	16.92
1952	1321.4	32	11	0.40	0.013	23.33
1953	856.2	266	89	0.52	0.015	31.05
1954	643.7	485	168	0.67	0.021	40.66
1955	1469.0	6.87	2.00	0.78	0.025	43.30
1956	539.2	5.76	2.63	1.24	0.014	72.88
1957	503.8	12.6	4.58	1.90	0.015	118.73
1958	610.0	16.6	4.38	1.98	0.011	130.08
1959	385.4	15.2	5.27	2.30	0.008	144.41
1960	515.6	16.6	5.84	2.58	0.007	161.88
1961	355.5	15.0	6.16	2.81	0.011	171.68
1962	172.2	9.13	5.39	2.59	0.009	150.80
1963	191.5	7.53	5.10	2.47	0.011	139.79
1964	104.3	9.26	5.77	2.85	0.015	160.78
1965	94.9	7.84	5.40	2.71	0.014	154.25
1966	62.9	5.41	4.75	2.45	0.018	127.84
1967	40.9	3.82	4.35	2.12	0.001	107.41
1968	7.9	1.97	4.78	2.18	0.001	103.48
1969	2.2	0.73	3.61	1.74	0.0004	72.81
1970	0.7	0.19	0.89	0.42	0.0001	17.19
1971	0.3	0.11	1.14	1.09	0.0003	30.34
1972	0.0	0.00	0.12	0.11	0.00003	3.55
Sum	738999	1160	388	64.32	1.78	3770

Columbia River Source Terms

The Columbia River passes through the Hanford Site, and served as the source of cooling water for the original plutonium production reactors. The river water was drawn directly through the reactor core and returned to the river after a short retention time. The Columbia River is the major pathway for water-borne radionuclides. Radionuclide composition and activity level in the discharged cooling water varied considerably as a result of several factors [Walters et al.1992] including the number of reactors and their power levels, seasonal changes in the parent elements in the raw river water (i.e., the elements activated as they passed through the reactor core), chemicals used in water treatment, corrosion rates of piping and fuel element cladding, occasional purging of radioactive film from reactor components, and the length of time effluent was retained in basins before discharge. Another factor was radionuclide releases from episodic fuel element failures. The wide variations in these factors, together with the hydrographic variables of the Columbia River and dam construction, produced a complex combination of river water and reactor effluent during the years of reactor operation. Scoping studies have indicated that the radionuclides of greatest interest to the HEDR Project are zinc-65, phosphorus-32, sodium-24, neptunium-239, and arsenic-76 [Napier 1993]. These radionuclides provide about 94% of radiation doses to people using the river. Chromium-51 emissions, although not of significance to dose, were reconstructed to serve as information for model

validation purposes. Additional short-lived materials were also released, primarily manganese-56. Table 6.2.2 (Heeb and Bates 1994) summarizes the releases of the radionuclides of interest.

The source term river release model (STRRM [Heeb and Bates 1994]) provides estimates of the monthly releases to the HEDR computational system. Uncertainties in the actual amounts released are addressed through use of multiple Monte Carlo simulations, each of which represents an alternative release history that is consistent with existing knowledge. Together, these alternative release histories represent the range of releases that could have occurred. One hundred separate realizations of the complete monthly release history were prepared with this source term code. Thus, the uncertainty in the amount of each monthly release is represented by a distribution of possible released amounts.

Ground-Water Source Terms

Inventories of solid-waste disposal and liquid-waste discharges to the ground are summarized in Hanford Site documents provided by the various Hanford Site operating contractors [Freshley and Thorne 1992]. The amount of detail reported about the numbers of specific radionuclides in the waste stream and when discharges occurred increased with time. The inventories of radionuclides disposed in the greatest amounts in the ground at the

Table 6.2 2 Total Releases of Radionuclides to the Columbia River from Reactors, 1944-1971 (Heeb and Bates 1994).

Radionuclide	Half-life	Release (Bq)	Release (Ci)
Sodium-24	15 hours	4.66×10^{17}	12,582,000
Phosphorus-32	14.3 days	8.48×10^{15}	229,000
Chromium-51	27.7 days	2.66×10^{17}	7,200,000
Manganese-56	2.58 hours	2.95×10^{18}	79,600,000
Zinc-65	245 days	1.52×10^{16}	410,000
Arsenic-76	26.3 hours	9.32×10^{16}	2,519,000
Neptunium-239	2.4 days	2.33×10^{17}	6,309,000

Hanford Site are listed in Table 6.2.3. The inventories of radionuclides are decayed to 1989 (listed as the inventories present during 1989, taking in to account inventory reductions because of radioactive decay). The total volume of solid waste in the ground is approximately 625,000 m^3 . Inventories of radionuclides in liquid wastes discharged to ground, decayed to 1989, are also listed in Table 3. The total volume of liquids discharged to the ground at the Hanford Site is approximately 1,680,000,000 m 3 .

TABLE 6.2. 3. TOTAL RADIONUCLIDE INVENTORIES DISPOSED TO GROUND AT THE HANFORD SITE AS OF 1989 (Ci)

Radionuclide	From Solid Wastes	From Liquid Wastes
Tritium	266,800	423,300
Strontium-90	2,030,600	40,500
Cesium-137	2,541,200	195,000
Technetium-99		960
Iodine-129		9
Carbon-14	6,300	220
Uranium	560	200
Americium-241	1,100	3,800
Plutonium	27,500	13,600
Total	4,875,100	678,000

CURRENT STATUS

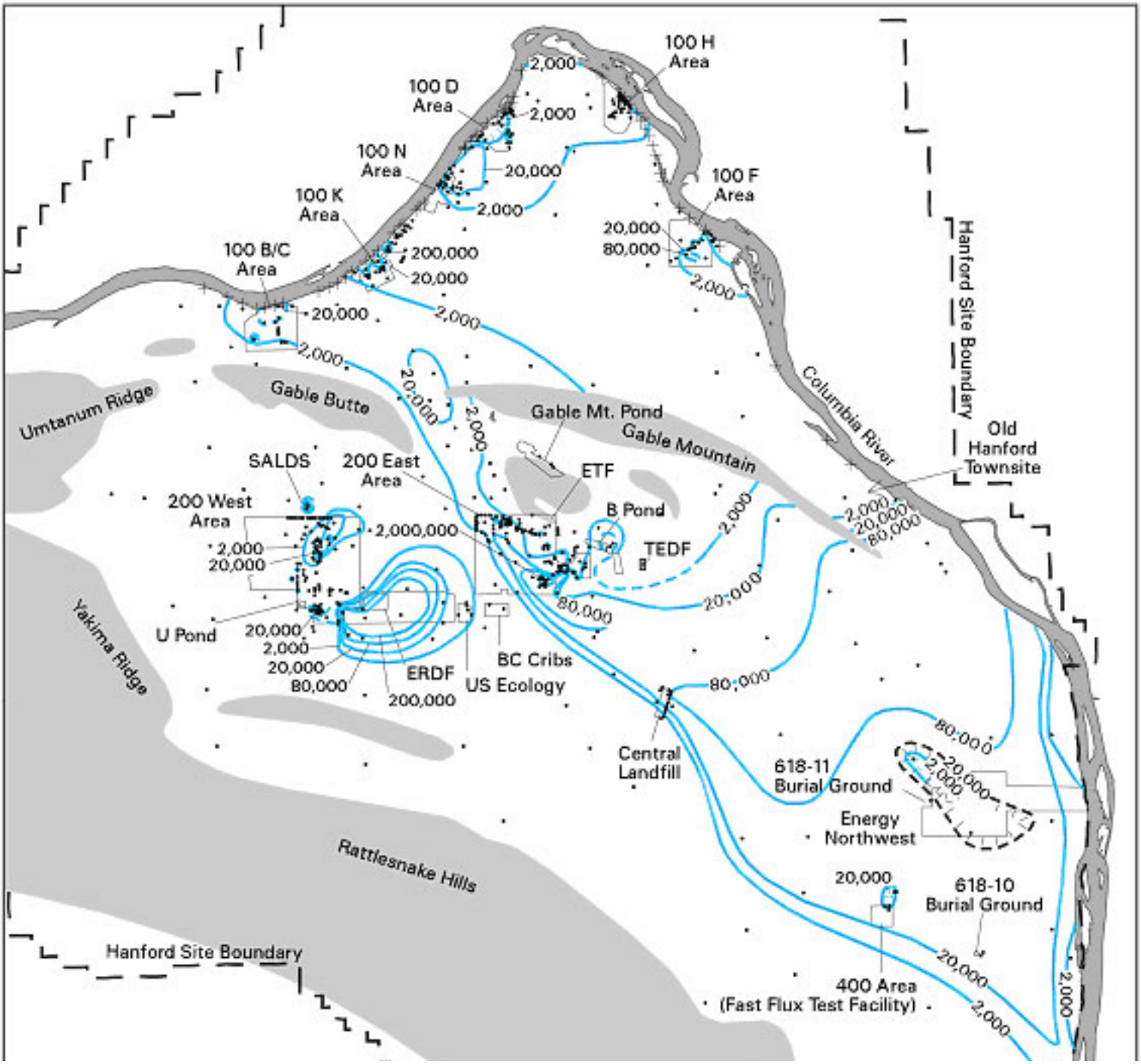
The tanks at Hanford currently contain about 234,000 m 3 of wastes, containing about 7.2 EBq of mixed fission products, primarily 90 Sr and 137 Cs and their progeny, plus about 8.5 PBq of transuranics, mostly 239/240 Pu and 241 Am (DOE 1996). A large fraction of the 90 Sr and 137 Cs inventory was specially separated from the bulk of the wastes and is now stored in capsules, in cooling water basins located about 20 km from the Columbia River. Corrected to 1997, these capsules contain 0.8 EBq of 90 Sr and 1.8 EBq of 137 Cs (DOE 1996). The total inventory in tanks and capsules of 90 Sr and 137 Cs in 1997 is about 3.0 EBq and 3.3 Ebq, respectively.

All production operations in the 200 Areas are now stopped, but groundwater contamination, resulting from ground disposals of solid and liquid wastes, continues to migrate towards and into the Columbia River. Annual measurements in the river upstream and downstream of Hanford may be compared, and indicate that about 200 TBq of 3 H, 2 GBq of 90 Sr and much smaller quantities of 129 I and 99 Tc are being discharged via groundwater into the Columbia River. Groundwater plumes of these radionuclides are tracked, and estimated contours are published annually (e.g., Dirkes and Hanf 1997). Figure 6.2.1. illustrates the current understanding of some of the tritium plumes, and Figure 6.2.2.illustrates the iodine-129 plumes.

The Hanford Surface Environmental Monitoring Program currently monitors for radionuclides in Columbia River water at locations upstream and downstream of the Hanford Site. There is minimal difference between the upstream and downstream values, indicating that current Hanford contributions are very small. For the time period of 1990 through 1996, 90 Sr concentrations have been essentially constant at about 2.4 mBq/L, both upstream and downstream, although several small plumes of 90 Sr-contaminated groundwater are known to be entering the river via riverbank springs. Tritium concentrations have been falling slowly, from about 1 to 0.8 Bq/L upstream of Hanford and from 3 to 2 Bq/L downstream of Hanford (known groundwater plumes of tritium are moving into the river along the Hanford Reach). Measured concentrations of 129 I have been variable, averaging around 300 - 600 nBq/L upstream and 3 - 5 m Bq/L downstream (129 I is also known to be entering the river via Hanford Site groundwater). In 1996, measurements of 239/240 Pu in Columbia River water indicated about 2 ± 2 m Bq /L at the Richland water plant (Dirkes and Hanf 1997).

POTENTIAL FOR FUTURE RELEASES

All of the Hanford radionuclide production facilities are now closed. Current emissions from research facilities are very low. Ongoing groundwater transport of past releases will continue, at levels equal to or less than present day. In general, the existing contaminant plumes are decaying and becoming more dispersed, although at very slow rates. The potential exists for accidental releases from the large amounts of stored radioactive waste. Current plans for the tank wastes are to retrieve the bulk of them and vitrify the materials. High-level wastes will be shipped off of the Hanford Site. Vitrified low-activity wastes (the bulk of the mass) will be disposed of on the Hanford Site in engineered disposal facilities. Studies are underway, too, on methods for stabilizing the old burial grounds. These old disposal facilities cover several square kilometers of the Hanford Site, and will remain indefinitely. Recent studies indicate that releases from these waste sites will be slow, if they occur at all, and future groundwater contamination resulting from them should not exceed the levels that now exist from past operations (Kincaid et al. 1998).



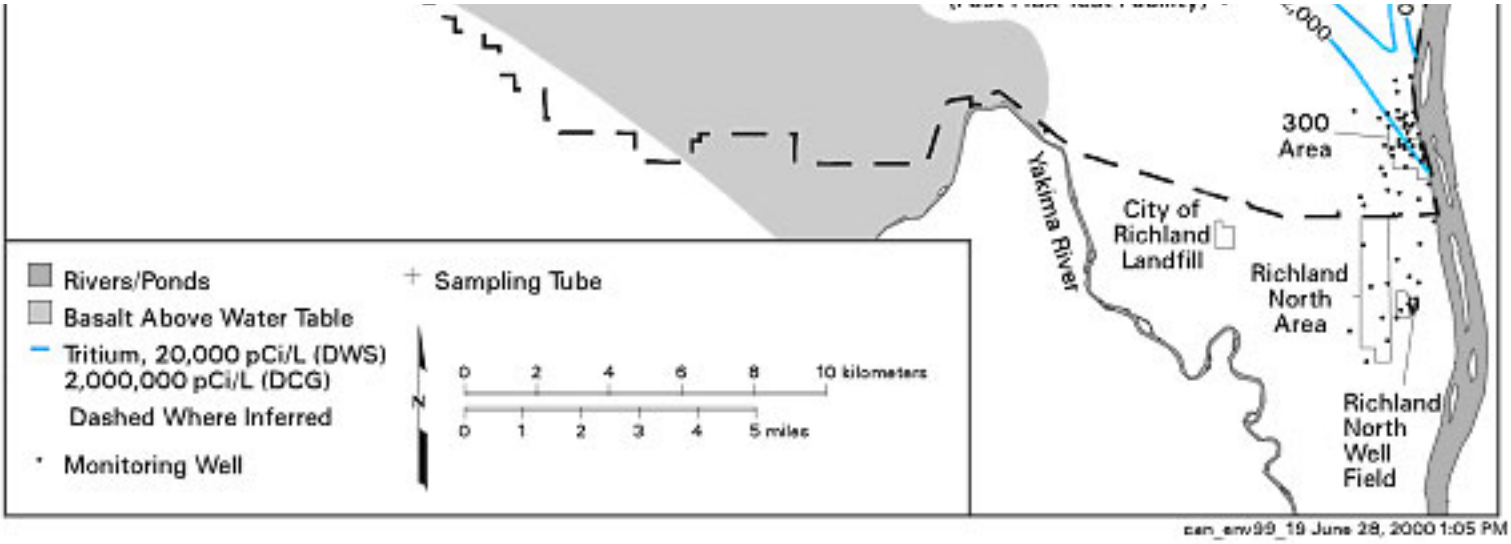
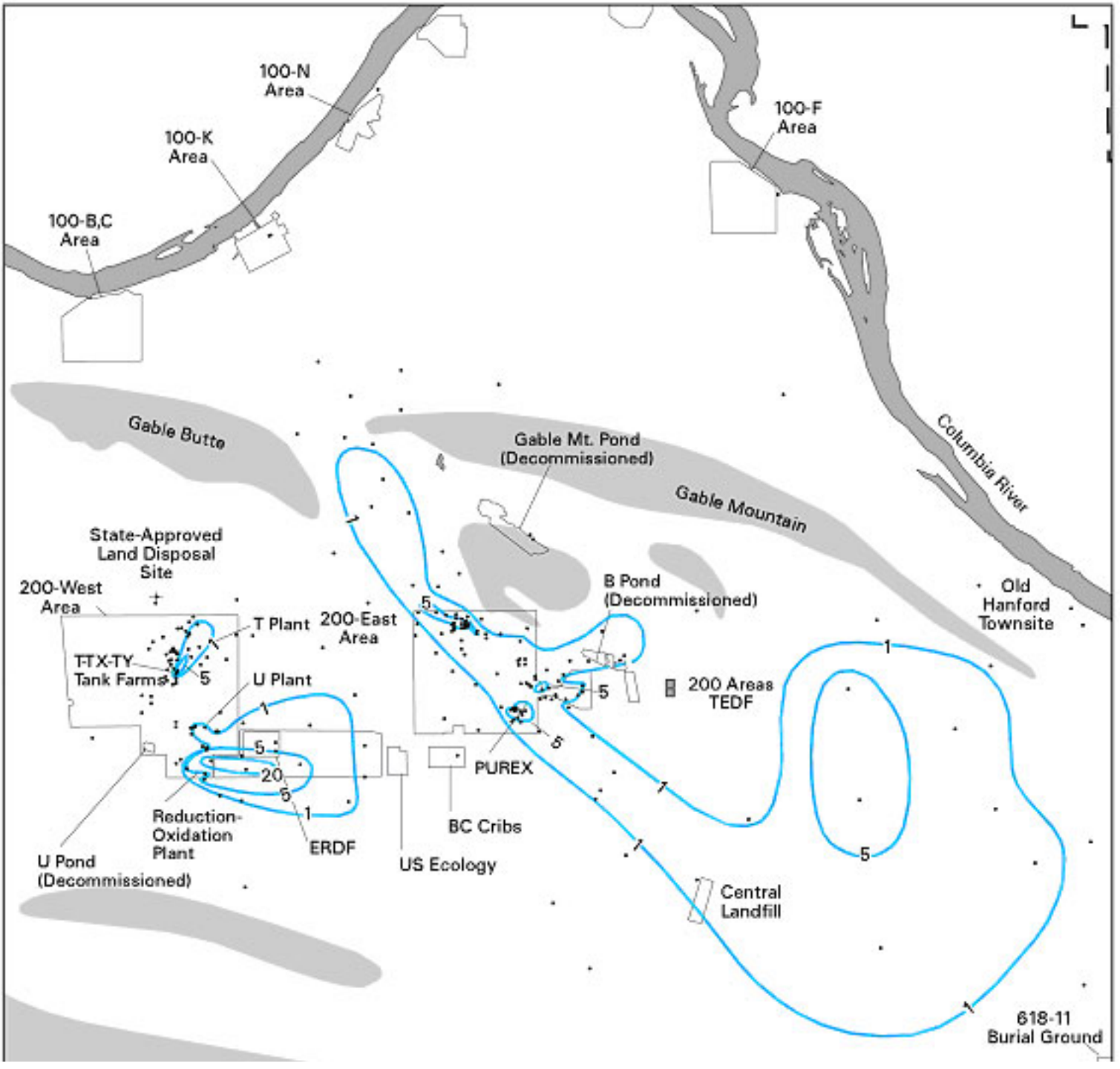


Figure 6.2.1.. The tritium groundwater plumes at Hanford



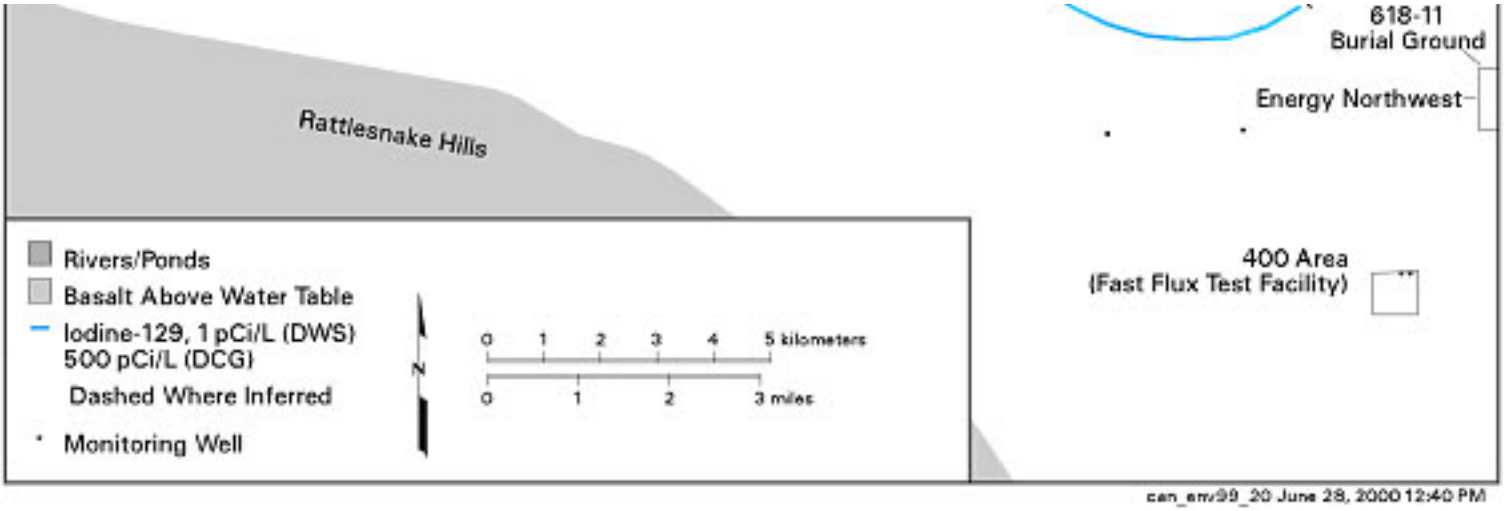


Figure 6.2.2. The iodine-129 groundwater plumes at Hanford.

6.3 Pathways

Pathways of exposure to historically released radioactive materials from the Hanford site may be broadly broken into two groups, atmospheric/terrestrial and aquatic. The atmospheric/terrestrial pathways are those associated with atmospheric releases and subsequent deposition on soils, and the aquatic pathways are those associated with direct discharges to the Columbia River.

6.3.1 Atmospheric pathways

The atmospheric pathways include inhalation of dispersed material and immersion in contaminated air. The terrestrial pathways following deposition of atmospheric contamination are complex and widespread, and have been captured in an environmental accumulation model. The environmental accumulation model provides Dynamic Estimates of Concentrations and Accumulated Radionuclides in Terrestrial EnvironmentS (DESCARTES) [Ikenberry et al. 1992; Snyder et al.1994]. The DESCARTES model tracks and estimates the accumulation and transfer of radionuclides from initial atmospheric deposition and interception through various soil, vegetation, and animal products compartments. The model function may be visualized as a series of sequential operations. The biomass submodel generates daily biomass values for each plant type modeled. These values are then used in the soil and vegetation submodel to determine the daily concentrations of radionuclides in soil and vegetation. Results are estimated for every grid node, providing the concentration in vegetables, grains, and fruits directly consumed by people and in plants (grass, alfalfa, silage, grain) used for animal feed. Animal feed concentrations are then used to determine concentrations in animal products (beef, venison, poultry, eggs, milk), also on a grid basis. Finally, the radionuclide concentrations in commercially-distributed vegetables and milk are estimated.

The commercial milk distribution systems were reconstructed from records and reports available from the U.S. Bureau of Census, the Washington State Dairy Herd Improvement Association, the Washington State Dairy Products Commission, and other governmental and dairy industry organizations [Deonigi et al. 1994]. They provide some information on the amount of milk produced and sold in each county, the locations of individual dairies and distributors, and dairy industry practices in the 1940's. Additional information was obtained through discussions with dairymen,

farmers, ranchers, and agricultural extension agents. These key contacts provided information that was then supplemented and organized by local experts into a detailed source/ distribution network by project domain grid cell. A similar undertaking was needed for the distribution system for fresh leafy vegetables [Marsh et al. 1992].

6.3.2 Aquatic pathways

The aquatic pathways are dominated by those associated with the Columbia River. They include direct consumption of drinking water; pathways associated with river recreation such as swimming, boating, and fishing; those associated with contaminated sediments along the river shoreline; pathways resulting from irrigation of farmland for food crops and residential lawns; and those of consumption of aquatic biota.

Extensive environmental monitoring was performed on aquatic organisms in the Columbia River during the latter years of Hanford Site operations. Many thousands of river water and fish samples were collected [Hanf et al. 1992; Thiede et al 1994]. The HEDR project has cataloged this information and used it to develop location-, seasonal-, and species-dependent bioconcentration factors. The bioconcentration factors were developed for three types of resident freshwater fish; omnivors, first- order predators, and second-order predators. They were also developed for ducks and other birds hunted by sportsmen in the area that might have been contaminated via the Columbia River pathway. The Columbia River supports major stocks of anadromous salmon and steelhead. These fish return to the river to spawn. However, the limited monitoring data indicate that they do not eat while returning upstream, and so their radionuclide concentrations are representative of the portions of the Pacific Ocean where they lived prior to returning to the Columbia River. Annual estimates of concentrations of radionuclides were assembled and used for estimating doses for all locations along the river for people who caught and ate salmon or steelhead. Because of the scarcity of data, an upper bound concentration was assumed based on the bioconcentration factors of second order predator fishes.

It is interesting to note that, along the 350 miles of Columbia River downstream of the Hanford Site, only the three large towns immediately adjacent to the Site used Columbia River water for domestic drinking water [Walters et al 1992]. Drinking water, and potential for removal of radionuclides by municipal water treatment plants, was also considered.

Although the farmland of the Columbia River basin is heavily irrigated, the majority of the water used comes from sources upstream of the Hanford Site. Scoping studies were performed that indicate that the doses resulting from irrigated crops are relatively small [Napier 1991; Walters et al. 1992].

Monitoring results from the 1960s identified low levels of contamination in seafoods harvested along the Washington and Oregon coasts. The primary contaminant in those periods was zinc-65, and the primary pathway was shellfish such as oysters [Napier and Brothers 1992; Napier 1993].

The Columbia River Dosimetry (CRD) [Farris et al.1994] model calculates dose via water immersion, drinking, and consumption of resident fish, game birds, salmon, and ocean shellfish.

6.4 Dose assessment (M.Savkin)

The primary thrust of Hanford Environmental Dose Reconstruction (HEDR) modeling effort was the preparation of a complete system by which individuals may receive estimates of their dose from past Hanford Site operations. The terrestrial dose model, CIDER [Farris et al.1994a], calculates dose for four pathways: submersion in contaminated air, inhalation of contaminated air, irradiation from contaminated surfaces, and ingestion of contaminated farm products and vegetation. The CIDER code treats people differently as they age, including prenatal and nursing periods. The Columbia River Dosimetry (CRD) [Farris et al.1994b] model calculates dose via water immersion, drinking, and consumption of resident fish, game birds, salmon, and ocean shellfish.

The HEDR Project included the concepts of uncertainty and sensitivity analysis from its inception. Uncertainty analyses have been conducted for essentially all dose estimates. These analyses lead to the most appropriate interpretation of the estimated doses because they provide a measure of the precision of the estimates. A Monte Carlo technique was used to estimate all dose uncertainties [Simpson and Ramsdell 1993].

Sensitivity analyses were performed for all HEDR models. Sensitivity analyses provided a method for 1) effectively interpreting the dose estimates, and 2) prioritizing individual parameters according to the uncertainty they contribute to the estimated doses. For the complex set of HEDR models, the sensitivity analyses were done hierarchically, starting with the dose results and working backward through the various pathway, transport, and source term models.

6.4.1 Historical Radiation Doses

The largest doses resulting from Hanford operations occurred in the mid-1940s [Farris et al. 1994a]. The most important radionuclide was iodine-131 released to the atmosphere. The most important exposure pathway was consumption of milk produced by cows on pasture downwind of Hanford. The iodine-131 releases were essentially routine and continuous during the first period of site operation. Infants and young children who drank milk from cows that ate fresh pasture are likely to have received the highest doses. Median doses for individuals in this group ranged from about 0.02 Gy (2 rad) to 2.4 Gy (240 rad) to the thyroid. The uncertainty on the initial dose estimates is fairly large - the 95th percentile reported for Ringold, the location for which the median dose was 2.4 Gy (240 rad) was 8.7 Gy (870 rad).

Recent work has given a better estimate of the overall pattern of iodine-131 deposition. An estimate of the extent of the deposition, scaled to thyroid dose to a reference infant drinking milk from a domestic cow on fresh pasture, is given in Figure 3.6.1 [Farris et al 1994a]. This figure indicates that thyroid doses in excess of 0.085 Gy (8.5 rad) to infants with back-yard cows could have extended to the Washington/Canada border.

Table Below summarizes doses and their uncertainties to maximally exposed individuals at several locations throughout the study area.

Location	Median	Range

Ringold	2400	540-8700
Richland	930	240-3500
Eltopia	730	190-3000
Ritzville	280	74-1200
Spokane	110	28-440
Walla Walla	130	37-440
Pendleton	86	20-300
Lewiston	40	10-150
Yakima	28	6.6-96
Ellensburg	21	5.2-67

Table 6.4.1 Median and Ranges of Thyroid Doses to Infants in the study area Drinking Milk from Backyard Cows on Fresh Pasture (mGy).

Cumulative radiation doses to maximally exposed individuals from releases to the Columbia River range from about 4.6 mSv (460 mrem) to 14.2 mSv (1420 mrem) for the period 1950-1970, which is the period of highest releases. See Table 6.4.1.. The major radionuclides contributing to doses from the river pathway are zinc-65, phosphorus-32, arsenic-76, and sodium-24. The range of doses is largely dependent on the amount of fresh, resident fish consumed. Drinking water contributes only a small dose, although nearly all of the residents of the local downstream communities received one.

6.4.2 Current Radiation Doses

Releases from the Hanford Site are now routinely monitored, and environmental concentrations are reported annually. Radiation doses are estimated for residents downwind and downstream of the Hanford Site, published, and discussed with regional residents [e.g., Dirkes et al 1999; Poston et al. 2000]. Annual results are also available on internet web sites. Doses to maximally exposed individuals near the site are now less than 0.1 µSv per year; the collective dose is estimated at less than 0.0025 person-Sv/year for the population within 80 km.

Table 6.4.2 Cumulative Doses to the Maximally exposed Individual from the River Pathways, 1950-1970 (µSv EDE)

Location	Maximum	Typical
Ringold	14210	510
Richland	13930	290
Snake/Walla Walla Rivers	8810	440
Umatilla/Boardman	7090	260
The Dalles/Celilo	6180	200
Bonneville Dam to River Mouth	4560	150

6.5 Impact on population health

Hanford Thyroid Disease Study of possible effects of I-131 exposure from Hanford releases in the 1940's and 1950's (9 year study; cost $ 18 million).
-Study 5199 people born during 1940-1946 in seven counties near Hanford
-*4875* people were located and invited to join the study
-3441 people were in the study cohort
-3193 (93%) had doses estimated

RESULTS

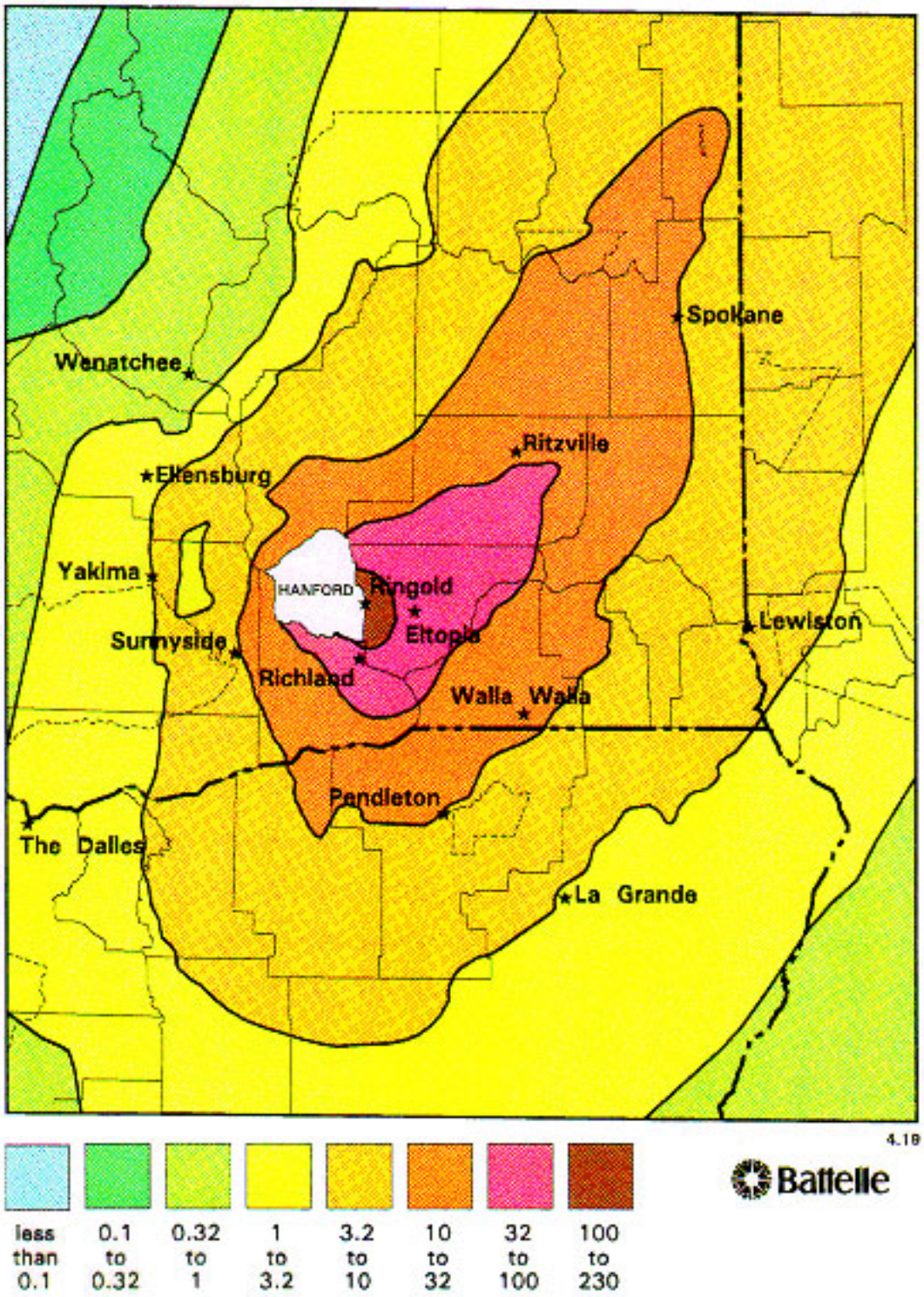
19 cases (0.6%) of thyroid cancer found in the 3441 participants (5 were not in the study area between 12/1944 and 12/1957)
249 (7.2%) had non-cancerous, benign thyroid nodules

CONCLUSIONS:

1. There was no link between thyroid dose and thyroid disease
2. Excess infant mortality was slightly higher in the study group, but this was evident

before the Hanford releases began and is still under study

Figure 6.5.1 . Distribution of doses to reference children, diets include milk from family cow, (cGy)



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Chap.7 - INDIA

U. C. Mishra

7.1 Generalities

7.1.1 Introduction

India has a well- planned programme of exploiting useful applications of nuclear energy and has many special features to ensure safety of occupational workers, members of the public and environment. This is largely due to the following mandate given by late Dr. Homi Bhabha, founder of nuclear programmes in India, in early 60's:

“Radioactive materials and sources of radiation should be handled in the Atomic Energy Establishment (name of the centre at that time) in a manner which not only ensures that no harm can come to workers in the Establishment or anyone else, but also in an exemplary manner, so as to set a standard which other organisations in the country may be asked to emulate”. This mandate was backed by adequate resources and man-power ever-since. The programme has grown many folds and as seen from the map of India given below, instead of one Centre at that time, the centres are now spread all over the country. However, most of them are not dealing with radioactivity or radiation sources and hence do not have possibility of environmental releases or radioactive contamination. There are only 7 places which have possibility of contamination or accidents. These places are the six sites where nuclear power plants are situated namely Tarapur, Rawatbhata, Kalpakkam, Narora, Kakrapar and Kaiga, in the order in which they were developed and Trombay (Mumbai) where there is no nuclear power plant and hence no possibility of off-site or general emergency but since there are two large research reactors and a fuel reprocessing plant, plant and site emergency cannot be ruled out. There is no place or centre exclusively for weapons programme except for the test site and since all tests conducted so far were underground with no venting, there is no site which can be considered as candidate site for the RADSITE studies. Due to special features of the Indian nuclear programme discussed below, it has been possible to ensure at all times that radiation levels at all the centres are well within the stipulated limits.

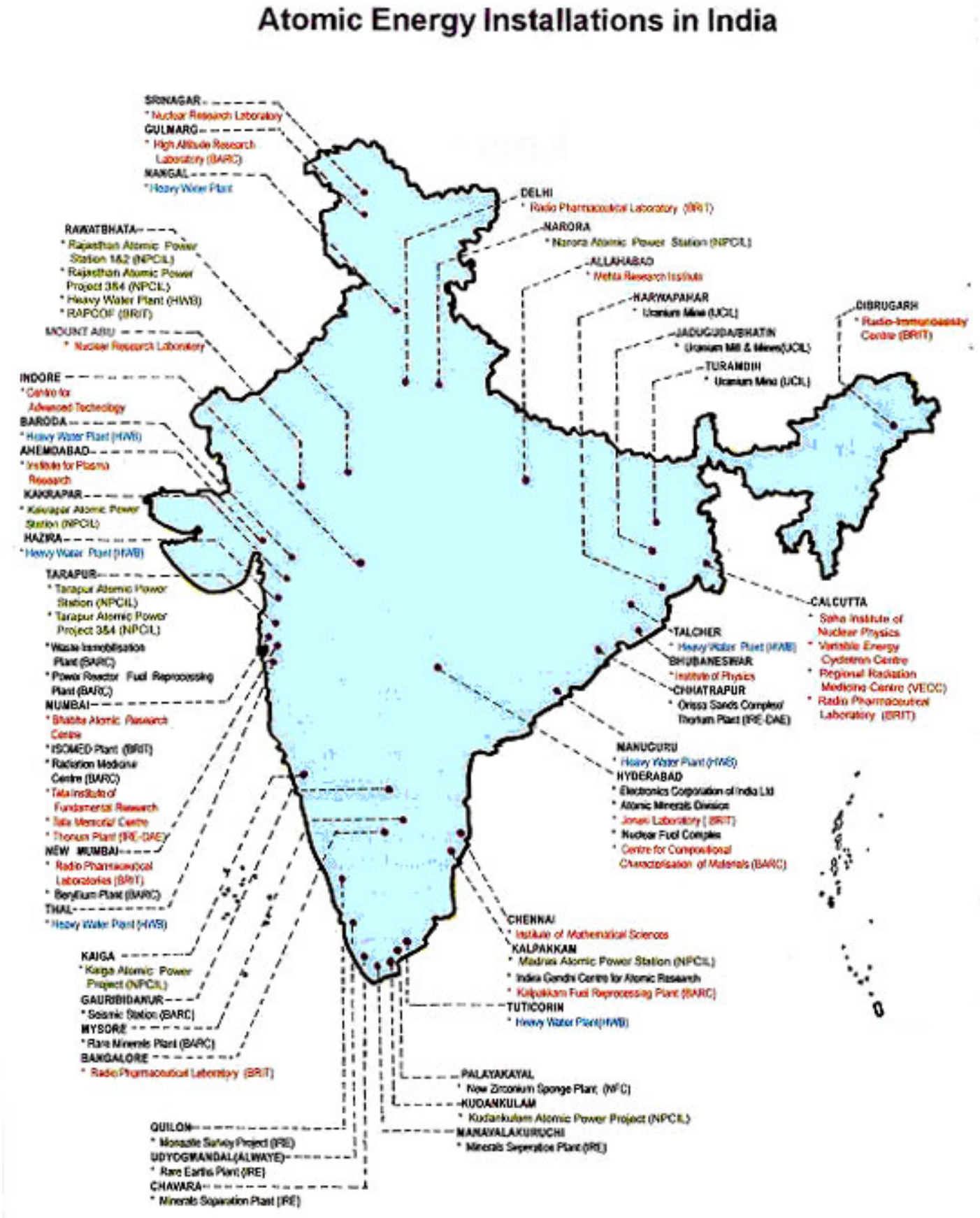


FIGURE 7.1.1. Location of the nuclear sites in India

7.2 Source term

A brief listing of facilities at the seven sites mentioned above in order of their establishment is given below:

1• Mumbai :Bhabha Atomic Research Centre (BARC)

CIRUS Research Reactor (40 MWt) Natural Uranium, Heavy Water Moderator
Dhruva Research Reactor (100 MWt) Natural Uranium, Heavy Water Moderator
Fuel Reprocessing Plant (100 T capacity)

2• Tarapur :

Tarapur Atomic Power Station (TAPS) Two units of about 180 Mwe each, Enriched Uranium BWR type supplied by USA
Power Reactor Fuel Reprocessing Plant (PREFRE) 100 T capacity Advanced Fuel Fabrication Facility (AFFF) for fabrication MOX fuel Waste Immobilisation Plant Two Power Reactors of 500 MWe each, Natural Uranium, Heavy Water Moderator, CANDU Type of Indian design (Under construction)

3• Rawatbhata (Rajasthan)

2 Power Reactors of CANDU type (230 MWe) design capacity built with support from Canada
2 Power Reactors of CANDU type (235 MWe) capacity of Indian Design Heavy Water Plant

4• Kalpakkam (near Cheenai, earlier called Madras)

2 Power Reactors of CANDU type (230 MWe) of Indian design (called MAPS) Proto-type Fast Breeder Reactor (PFBR) 40 MWt (15 MWe) using Plutonium-Uranium Carbide as fuel, liquid Sodium as coolant

5• Narora

2 Power Reactors of CANDU type (230 MWe) of Indian design

6• Kakrapar

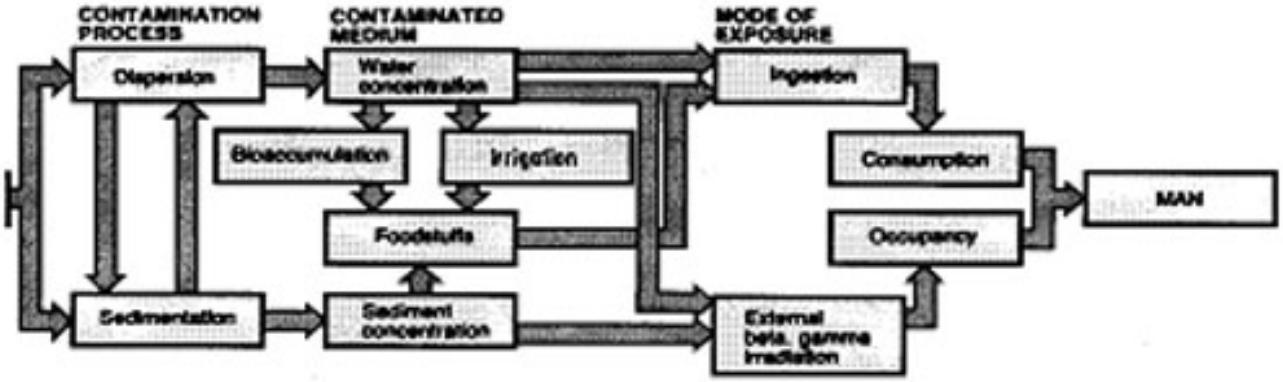
2 Power Reactors of CANDU type (230 MWe) of Indian design

7• Kaiga

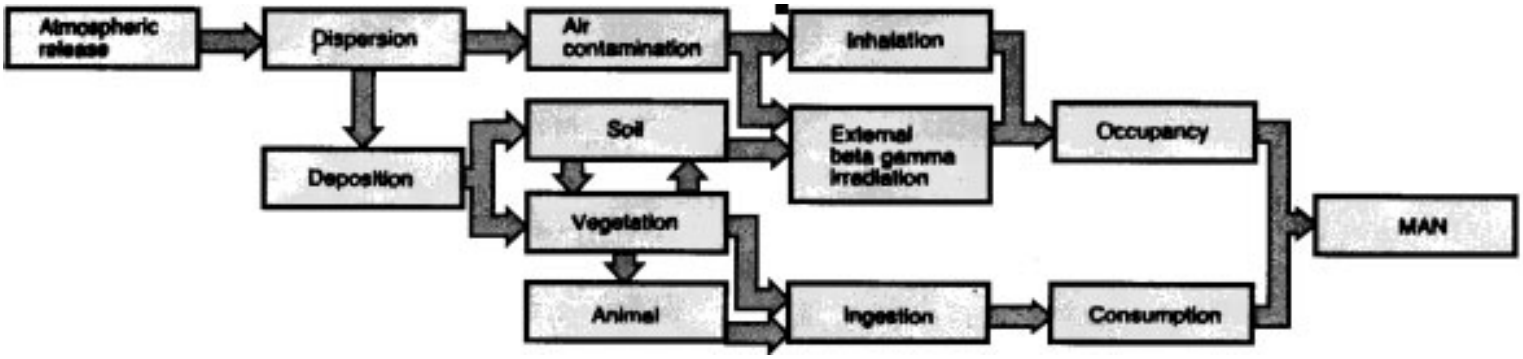
2 Power Reactors of CANDU type (230 MWe) of Indian design

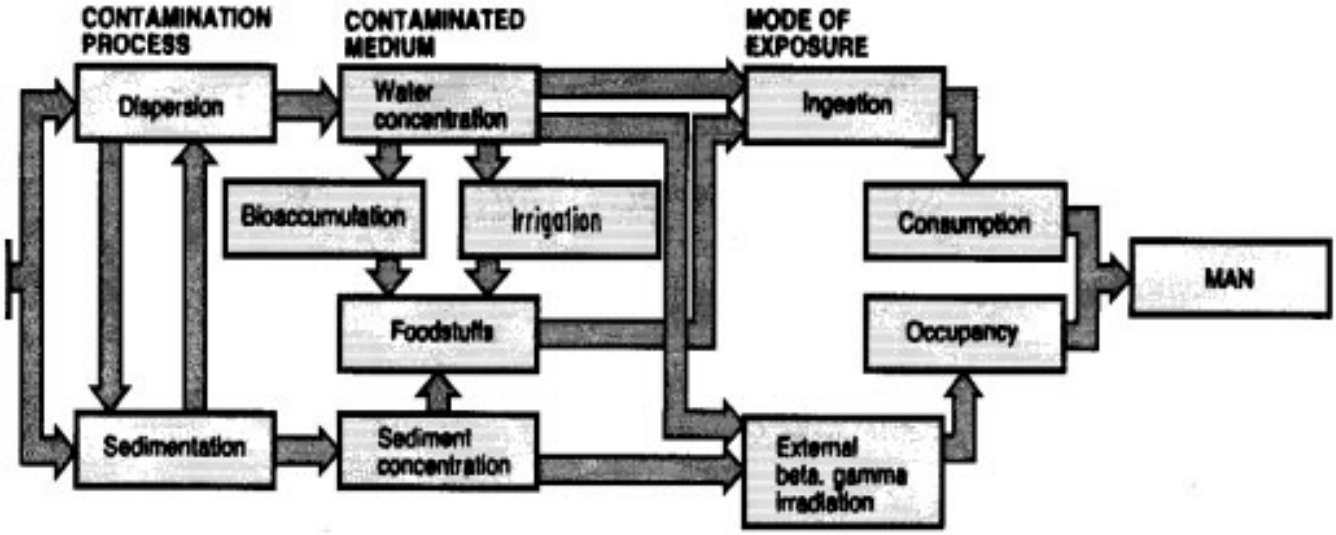
7.3 Pathways

Source : Health, Safety & Environment Programme
Bhabha Atomic Research Centre
Mumbai,India
1999



Liquid release





Atmospheric release

7.4 Dose assessment

7.4.1 Special Features of Indian Programme

• At site selection stage, it is ensured that the site is having a low population density so that in the event of evacuation, very few persons need to be moved out. This is in addition to the other requirements of availability of water supply, infra-structure, demand for power etc.

• A zoning criteria is strictly followed for Nuclear Power Plants. Under this, the Nuclear Power Corporation of India (Agency responsible for designing, building and operating Nuclear Power Plants)

acquires 1.5 km around the proposed plant site. In addition, 5 km around this first zone called exclusion zone is also treated as restricted area. This is called sterilized zone. A third zone called emergency planning zone of 15 km around the Power Station is routinely monitored and is covered in all off-site or general emergency exercises. With this zoning concept, regular monitoring is done for about 15 km around the nuclear facility. Most countries do not have such zoning criteria.

• The most important part of the programme is the establishment of an environmental surveillance laboratory much before the plant goes into operation to collect background data on radioactivity levels in food items, air, water, soil etc so that the impact of the plant can be assessed. The data collected by these laboratories is submitted to Atomic Energy Regulatory Board (AERB) of India for their assessment. The dose limits stipulated by them are given in the table below. These laboratories are located at all the 6 Power Reactor sites.

Table 7.4.1 : Dose Limits Stipulated By Atomic Energy Regulatory Board for India

Category	Effective Dose Limit (mSv)	Annual Equivalent Dose Limit (mSv)
Radiation Worker	Annual 30* 5 years 100 Lifetime 1000	Eye Lens 150 Skin and Extremities 500
Trainees	Annual 6	Eye Lens 50 Skin and Extremities 100
Temporary Workers	Annual 15	Eye Lens 75 Skin and Extremities 250
Members of Public	Annual 1	Eye Lens 15

• For Pregnant Women, 2 mSv to Abdomen for the remainder of Pregnancy.

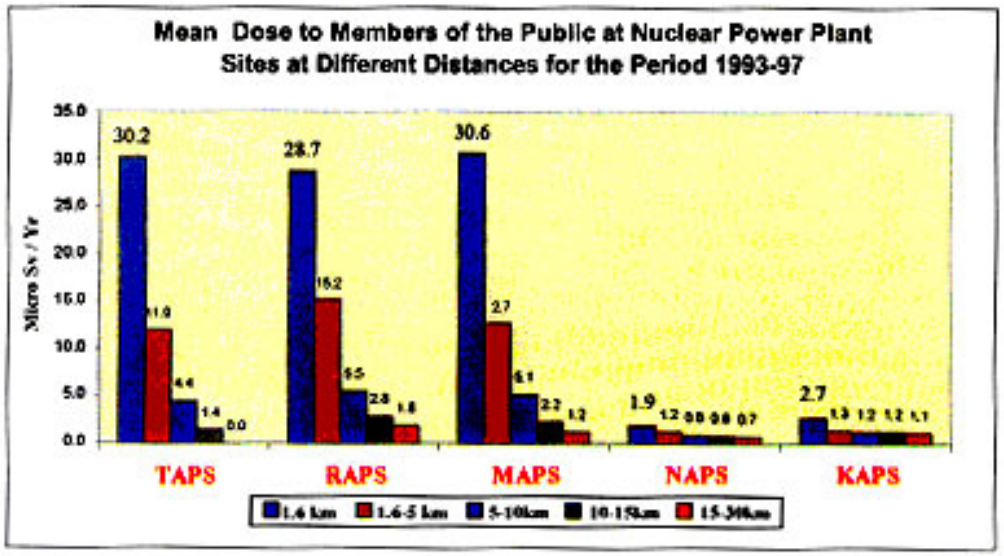
At places, other than Nuclear Power Plant sites, Health Physics Laboratories carry out the above jobs. However their area of work is confined to plants and site boundary as no general emergency is expected. BARC, Mumbai comes under this category. The data collected at these places is also submitted to AERB for their assessment.

7.4.2 Additional Features For Sensitive Sites

For sensitive areas from ecological viewpoint like Kaiga, it has been ensured that bio-diversity existing at the site is maintained through plantation.

7.4.3 Environmental Monitoring

Author had presented data from uranium and thorium mining and milling sites at the earlier meeting of RADSITE (Mishra,1998). All the data from the four Nuclear Power Plant Environmental Surveillance Laboratories existing in early 90's were published in 1995 (Hegde et al.,1995;Gurg et al,1995; Iyengar et al,1995; Sharma et al,1995;). Thereafter, every year annual data is published, Typical reports for 1999 for four sites are given in references(Hegde et al ,2000; Verma et al ,2000; Rajan et al,2000; Sharma et al,2000;)- The sites of Kakrapar and Kaiga, which came later is also compiled and published, annually (Sebestian et al,2000; Ravi et al,2000;). Similar data from BARC, Mumbai is also brought out as Annual reports for submission to AERB (Gurg et al,2000). A Summary of past five years data for different Power Station sites is given in Figure 7.4.3.1..



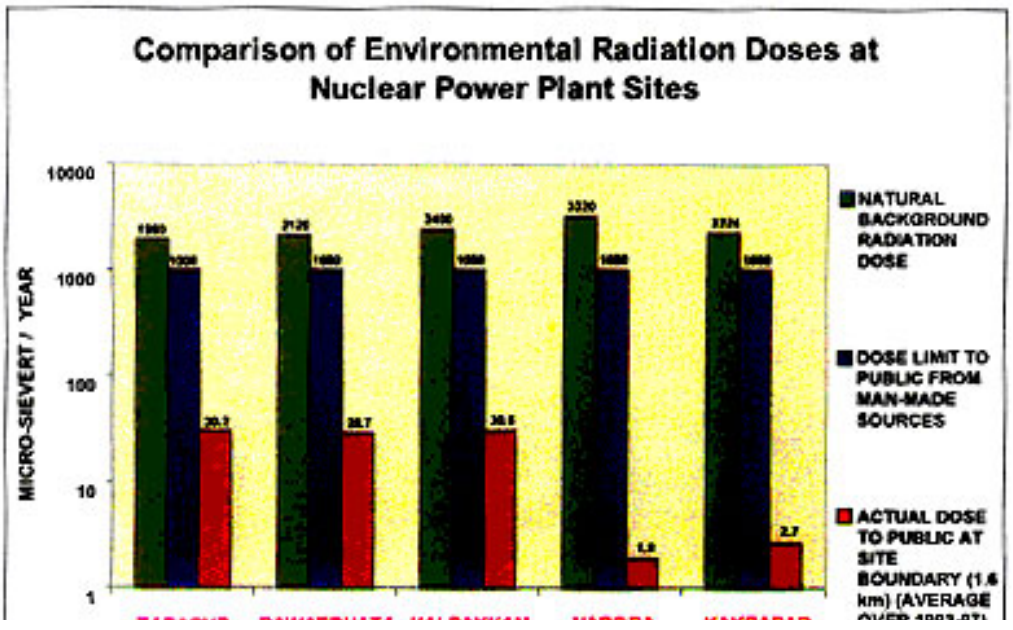


FIGURE 7.4.3.1. environmental monitoring around NPP in India

7.5 Impact on population health

From Dr. U. Mishra (India). "Population exposure and environmental impact of nuclear fuel cycle facilities in India" (RADSITE Meeting, Brussels,12-14Nov 1998) .

India has embarked on a very ambitious programme of nuclear energy applications which includes electricity generation, isotope and radiation sources production, etc. Nuclear power programme is particularly innovative being based on utilisation of nationally available fissile and fissionable materials. Ten NPP's are now in operation at five sites in the country.

The environmental and population radiation protection is of special concern at operation of nuclear facilities. Environmental and Radiological Laboratories have been set up at each major nuclear site. Mining, milling and purification of uranium and thorium and fabrication of fuel assemblies is accompanied with strict control and treatment of effluents from tailings. Most radiologically significant radionuclides are 230Th, 226Ra, 222Rn and 210Po. Their concentrations in surface waters near production sites does not exceed permissible levels. Tailing ponds are local sources of external exposure and inhalation but they are located in non-inhabited sites. NPP's operating in normal conditions create very low doses to local populations: 2 to 30 µSv per year at the plant fence, 1 to 5 µSv per year at the distance of 5 km and about 1 µSv per year at the distance 15 to 30 km. Reprocessing of the spent nuclear fuel is planned after at least 10 years of interim storage. Up to now there was no accidents in the Indian nuclear programme accompanied with environmental releases of radionuclides. Neither there were no indications of deterioration of the environment in the vicinity of Indian nuclear plants.

Conclusion

The above mentioned approach has ensured that there is no contamination requiring remediation at any of the nuclear sites in India and all radiation and radioactivity levels are being routinely and regularly monitored for quick detection of any contamination so that immediate corrective measures can be taken.

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KRASNOYARSK-26

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8.1 Generalities

8.1.1. Historical background(Zhidkov et al., 2000; Mikheev et al., 1995; Egorov et al., 2000)

In the beginning of the 1950's, at the height of the Cold War, on the right bank of the great Siberian Enisey River about 60 kilometers downstream of the city of Krasnoyarsk, at the place where the Atamanovo chain of hills meets the river, a super-secret underground nuclear industrial complex arose with a settlement 10 km to the south of the main production site.

The decision to create the Krasnoyarsk Mining & Chemical Combine (MCC), initially named Combine No.815, was made by the CPSU Central Committee and the Council of Ministers of the USSR on February 26, 1950 (No. 826/302 SS/OP). In accordance with the Decree of Presidium of the Supreme Soviet of the USSR of March 17, 1954, “the settlement of the Combine No.815” was renamed as the town of Zheleznogorsk.. The facility became widely known as the nuclear complex “Krasnoyarsk-26”.

The MCC territory is about 360 km^2 . Southwesterly winds predominate. The observation zone dimensions are: 15 km toward the predominating winds bearing to the North-East, 9 km of the windward site from the South-West, and 2-8 km toward other directions. Settlements in the area controlled by the MCC include the town of Zheleznogorsk with a population of more than 80,000; about 600 people in the village of Dodonovo; about 400 people in the village of Bolshoi Balchug; and about 5,000 people in the Atamanovo settlement.

The river flowing close to the MCC territory is a controlled, non-freezing stream from the hydroelectric power plant.

The first production nuclear reactor, AD, for plutonium generation was started-up on August 25, 1958. The second similar reactor, ADE-1, was started-up on July 20,1961. Both are thermal, uranium-graphite, water-cooled channel-type reactors. The reactors worked in single-pass mode, disposing cooling water into the Enisey River. The AD and ADE-1 reactors were finally shut down on June 20, 1992 and September 29, 1992, respectively.

The start-up of the third reactor, ADE-2, was carried out in 1964. The reactor had a closed primary cooling circuit and was dual-purposed (plutonium generation as well as heat and electricity production). In 1964 a radiochemical plant for reprocessing of irradiated uranium was also put into operation. The industrial complex also includes a reactor water preparation plant and numerous auxiliary facilities.

The ADE-2 reactor and the radiochemical plant are still operating. The reactor is supplying the town of Zheleznogorsk and some neighbouring settlements with heat and electric power, and it is not possible to decommission it until substituting power capacities are introduced. The radiochemical plant is now engaged in radioactive waste processing.

In accordance with a unique design, the main objects of MCC were accommodated inside a mountainous massif at a depth of about 200 meters from the surface. This insured great stability and viability of the nuclear complex under conditions of an military conflict.

In 1977. the construction of RT-2 plant for spent nuclear fuel (SNF) reprocessing was started. The plant's design capacity of 1500 tons of irradiated uranium per year was destined for reprocessing of spent fuel assemblies from VVER-1000 power reactors. Construction stopped in 1989.

In 1984, a “wet” SNF storage facility was put into operation as a part of the future RT-2 plant's first stage. Its design capacity is 6,000 tons of VVER-1000 reactors' SNF. For the present the repository is filled to roughly 60 %, and its capacity is expected to be sufficient until 2007.

8.1.2. Geography, climate, hydrology and sediment transport

Enisey is the largest river in Russia with respect to water flow and is located on the border between Eastern and Western Siberia. The total length of the river is 4,092 km and the catchment area extends over a territory of 2,580,000 km^2 .The annual average discharge into the Kara sea is 564-630 km^3 (AMAP, 1997; CACAR, 1997; Chernogaeva, 1989). About 50 % of the water masses in Enisey originate from winter precipitation, about 37 % from rain and the rest from groundwater. Almost 80 % of the discharges occur in the summer period from June to September (Pavlov and Pfirman, 1995). The climate and geography extend the same variations as described for the Ob river system. The Enisey river bottom is mostly covered with coarse sand, pebble and gravel. Soft silty sediments are quite rare.

8.1.3. History of investigations

Data on the character and scope of radioactive contamination of the environment caused by the operation of the Krasnoyarsk Mining and Chemical Combine (MCC) began to occur in press only in the recent years.

8.1.3.1. Radiation monitoring in the sanitary and supervision zones

Areas nearby the Combine (like any other radiation hazardous facility in Russia) are divided into two zones:

(1) the sanitary zone – the territory around the Combine, where exposure may be above the dose limits for the population. The regime of restrictions and radiation control is introduced in this zone.

(2) the supervision zone – the territory of possible influence of the nuclear facility where exposure may be close to the dose limits for the population. A specific radiation monitoring program is introduced there.

The structure of the state administration of the radiation monitoring in the region of the MCC is presented in Fig. 8.1.

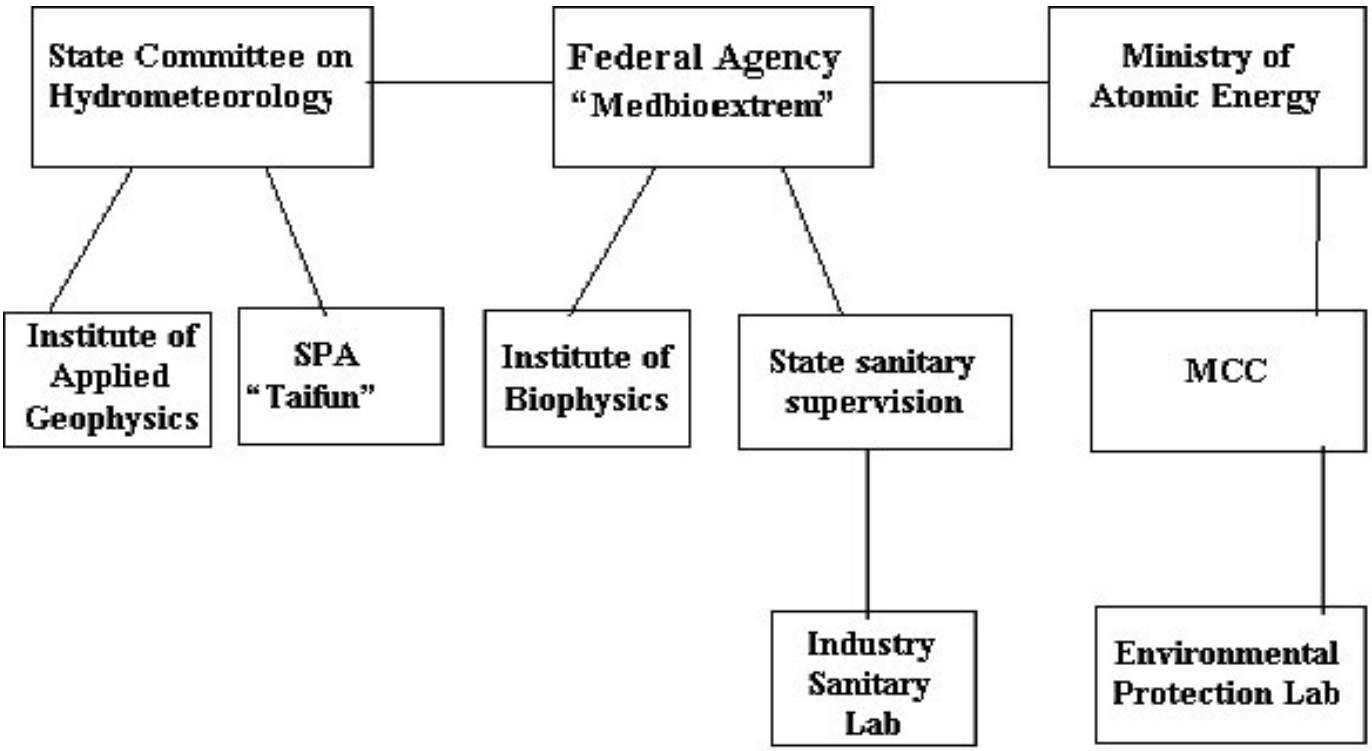

Fig.8.1. The structure of state administration of the radiation monitoring in the MCC area

The State Committee on Hydrometeorology of the USSR was in charge of environmental measurements outside the sanitary and the supervision zones (now the duties are the responsibilities of the Roshydromet – RF State Committee on Hydrometeorology). The other bodies and institutions involved in the activities have carried out radiation measurements inside these zones. Routine monitoring was provided by the practical industrial and sanitary services. Annual reports of observation and analysis were sent to the corresponding authorities. Research institutions worked according to their research programs, in particular, aimed at unification of monitoring system and techniques.

8.1.3.2. Investigations outside the sanitary and supervision zones

In the past years additional independent radioecological studies along the Enisey river were carried out by the missions, which were not related to the system described above.

The first investigations of the radionuclide contamination of the Enisey river were carried out in the early 1970s by the State Committee on Hydrometeorology of the USSR (Vakulovski et al.1994; Vakulovski et al., 1995). Data of this period show a considerable contamination of the bottom sediments and of the river biota near the MCC. Detailed investigations of radionuclide contamination of the river and river-side ecosystems begun in the 1990s (Nosov et al.,1993; Nosov et al.,1996; Kvasnikova et al.,2000; Sukhorukov et al.,2000a; Linnik et al.,2000; Bolsunovsky et al.1998;). Data were obtained during radioecological expeditions organized by the institutions of the Hydrometeorological Service of Russia (SPA "Typhoon", Obninsk; Institute of applied Geophysics, Moscow), and the Siberian Branch of the Russian Academy of Sciences. The airborne-gamma-spectrum data were received during the State radiation monitoring program (a leading institution – Institute of Global Climate and Ecology) [Kontarovich et al.,1993]. The interesting data were generated in the framework of some international projects by the Kurchatov Institute and the Vernadski Institute (NATO/CCMS ; Linnik et al.,2000, . Sukhorukov et al.2000b, Sukhorukov et al.2000c, Kuznetzov et al.1999; Vakulovski et al.1995). Some results were summarized in the reports of the ISTC-project "Radiation Legacy" (RADLEG).

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8.2 Source term

8.2.1. The MCC radiation legacies: an overall characterization

The Combine's production reactors and radiochemical plant have been the main sources of environmental contamination due to radionuclide gas and aerosol releases and wastewater discharges. The many-years discharges into the Enisey river led to radioactive contamination of the water, bottom sediments and soil in a number of sections of the floodplain, including some islands and plots **,** mainly on the river's right bank.

The MCC industrial site and sanitary & protective zone (SPZ) has a total area of 55 km^2 and is partly contaminated with radionuclides (the contaminated area is about 4.3 km^2). In the observation zone, 3.5 km^2 are contaminated.

During the MCC operation period, large amounts of high-, medium- and low-level radioactive wastes, both liquid (LRW) and solid (SRW) were accumulated as a result of weapons-grade plutonium production. The MCC radiation legacy includes several hundred units of contaminated process equipment with unique large dimension facilities (shut down production reactors), hundreds of kilometers of pipelines, and various industrial compartments. Radioactive wastes are kept in storage facilities and water basins and contain a total activity of more than 110 MCi [1-3].

8.2.2. Liquid radioactive wastes

Liquid Radioactive Wastes (LRW) resulting from production operations are sent, depending on the activity level, either to cleaning facilities, or collected in special tanks and in open storage reservoirs. After corresponding treatment and cleaning they are sent to an underground disposal site (Severnyi). Decontaminated waters are discharged into the Enisey River.

In storage tanks of the radiochemical plant about 7000 m^3 of process sludges have been accumulated with about 593.3 kg of total calculated amount of plutonium, about 531.1 kg of uranium and about 143 MCi total activity. Each storage tank in sections 83, 84 and 86 is a 3200 m^3 cylindrical iron-concrete reservoir (12 m in diameter and 30 m in height), lined with stainless steel. Storage tanks of the section 59/1 are used for storage of highly active nitric acid solutions. Each of them, made of stainless steel and with a 315 m^3 volume is 9 m in diameter and 5 m in height. All the tanks are placed in iron-concrete canyons lined with stainless steel to the height of 4 m.

As a result of many years' compression, under conditions of elevated temperatures and radiation, the sludges have lost their fluidity.

There are also four open basins (Nos. 354, 354a, 365, 366) at the MCC production site for low-level liquid radwaste storage with a total volume of about 1 million m^3 . They contain about 50,000 m^3 of deposits with total activity about 40,000 Ci.

Basins 354 and 354a are open-pit-type engineered water-storage reservoirs built in practically waterproof rocks. Basin 354 was designated to receive and store regeneration solutions and hydroxide sludges from ion-exchange

cleaning facilities. Basin 354a is 100 m from basin 354 and was designated to receive, balance and temporarily store low-level wastes and condensate after evaporation of the radiochemical plant's process wastes, before sending it to an underground disposal site.

Basins 365 and 366 are also open-type engineered water-storage reservoirs, constructed on the first flood-plain terrace of the Enisey River. Basin 365 was designated to receive and temporarily store the reactors' emergency waters and off-grade non-processed waste-waters of the radiochemical plant before sending them to cleaning facilities. Liquid radwastes in the basin are isolated from ground-waters with an anti-filtering shield of clay, two asphalt layers on the bottom and slopes, as well as a bottom and bank draining system for interception and collection of leakages in case of damage to waterproofing. Basin 366 was built by hydraulic deposition of soil. It is designated to receive decontaminated waters from the MCC's cleaning facilities and the ADE-2 reactor's control and protection system cooling waters for holding, settling and filtration before discharge into a stream, and then into the Enisey River [1-3].

Water-storage reservoirs still remain serious sources of radiation hazard.

Exposure rates in the areas adjacent to the basins are as follows:

- basins 354, 354a – at the distance of 600 m from the shore line – 50-1000 m R/h;
- basin 365 – at the shore line level – 0.15 R/h; at the distance of 600 m from the shore line – 300-1000 m R/h;
- basin 366 – at the distance of 100 m from the shore line – 200 m R/h.

Soil contamination at the distance of 1 km from the basins' S&PZ is 6.7×10^{-8} Ci/kg for basins 354 and 354a, 2.0×10^{-8} Ci/kg for basins 365 and 366. Natural growth contamination at the same distance is 3.5×10^{-7} Ci/kg and 8.2×10^{-7} Ci/kg, correspondingly[4].

8.2.3. The underground LRW disposal site

The Severnyi site is situated 12 km from the MCC main production works within the limits of the Combine's sanitary & protective zone. It has been operating since 1967. The site occupies about 6.5 km^2 and is surrounded by an exclusion zone of 52 km^2 , which, at its closest point, lies 1.0-1.5 km from the Enisey River. The disposal site itself is located approximately 2.5 km from the Enisey River, 12 km north of the reprocessing plant

Two sandy aquifers (horizons I and II) are used for MCC liquid radwaste disposal. Low-level liquid radwastes (up-to 800 m^3 /day) are disposed into the horizon II (180-280 m below ground), and medium-level liquid radwastes (up-to 500 m^3 /day) are disposed into the horizon II (355-500 m below the ground). Earlier experimental disposal of some portions of wastes, conditionally attributed to high-level ones, was carried out into the horizon I.

The disposed wastes contain radionuclides of uranium fission products, including cesium, strontium, zirconium, niobium, ruthenium, cerium, and trace amounts of uranium and transuranium elements, that are unrecoverable in the solutions' processing. Before underground disposal, LRW treatment is carried out at the MCC cleaning facilities and at the radiochemical plant to provide compatibility of the wastes with the geological medium, as well as additional recovery of long-lived transuranium elements.

The wastes are transferred by pipelines. The pumping is carried out through a system of 12 injection wells, using an injection pressure of about 2 MPa. Within and outside the disposal site about 20 wells are used to control the state of the geological medium and the wastes migration.

The horizons are underspread, separated , and covered by loam floors, isolating the strata, containing LRW from surface and shallow underground waters. The natural speed of water movement is 5-6 m/y in horizon I and 10-12 m/y in horizon II.

Special geological prospecting works and explorations preceded creation of the Severnyi underground disposal site. The works substantiated the feasibility of LRW injection and the safety of disposal. The disposal is licensed.

Between 1967 and 2000, 1,893.5 thousand m^3 of medium-level liquid radwaste with a total activity of 149MCi have been injected into horizon I.

Between 1969 and 2000, 3,305 thousand m^3 of low-level liquid radwastes, with a total activity of 15.3 kCi, were disposed into horizon II.

The underground disposal of liquid radwastes eliminated the impact of huge amounts of radionuclides on the population and on the environment. The state of the wastes and the geological formations used to contain them are continuously controlled. Probable complications and emergency situations while carrying out the disposal will not lead to disastrous consequences connected with large-scale effects on the environmental systems [46].

8.2.4. MCC radioactive releases and discharges

A monitoring program included measurements of releases and discharges as well as measurements of environmental contamination and exposure due to these sources.

Annual radionuclide releases that occurred from 1982 to 1991, under operation of the MCC, are presented in Figures 2, 6,7 and 9 [7].

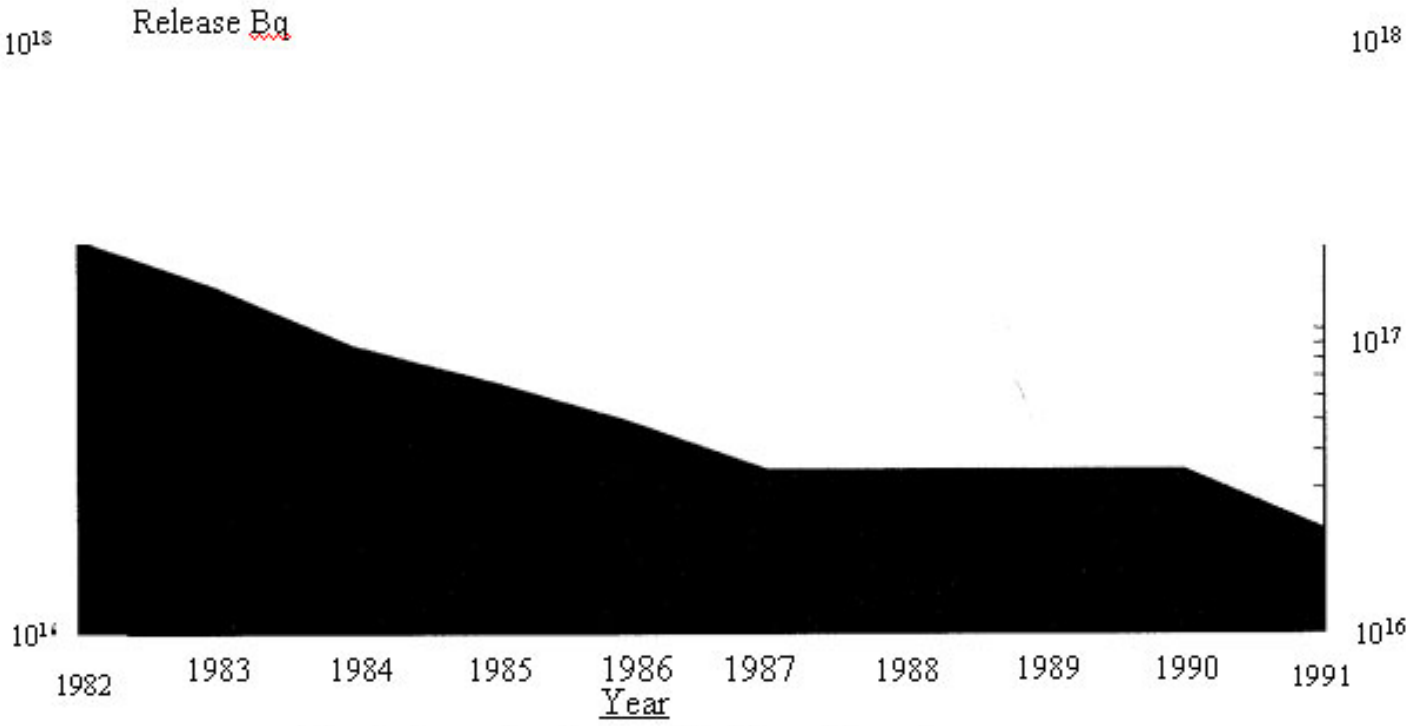


Fig. 2. Annual releases of noble radioactive gases.

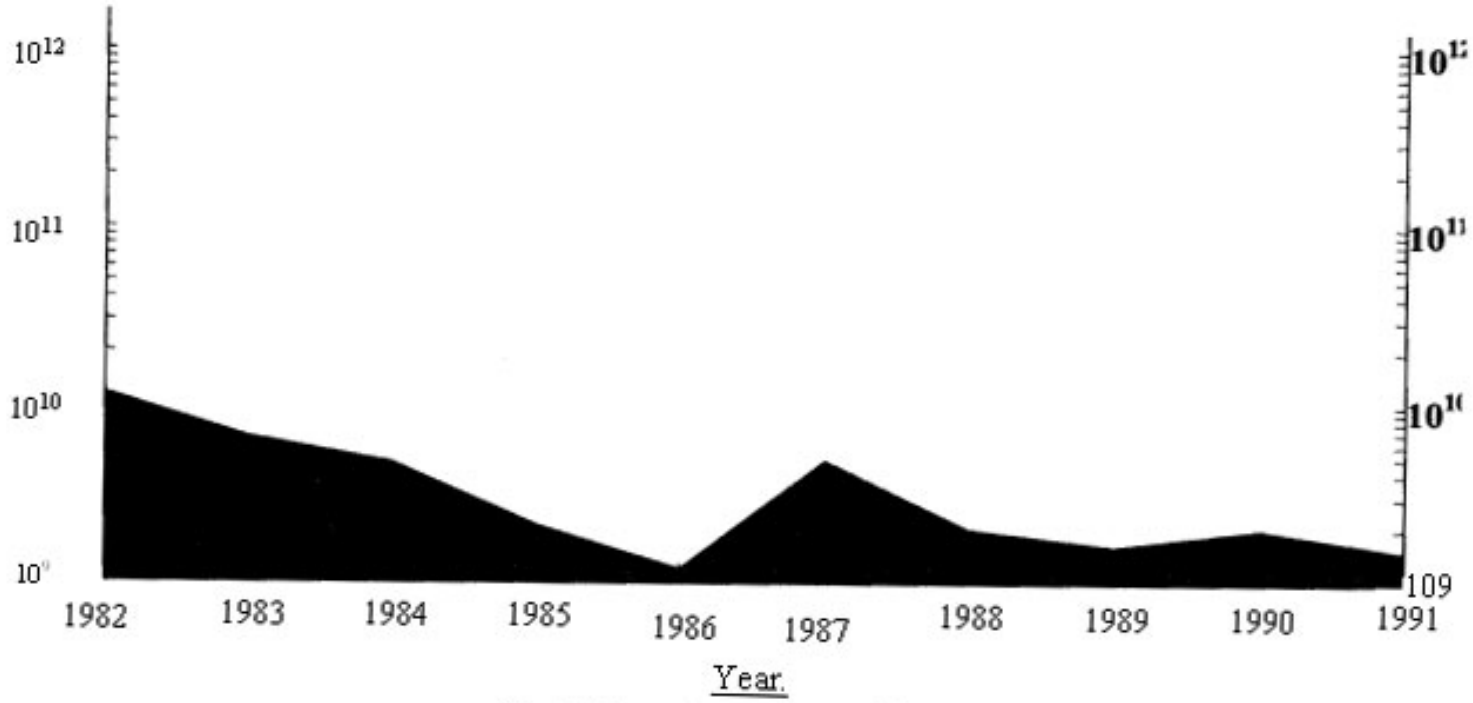


Fig. 6. Annual releases of ^{137}Cs.

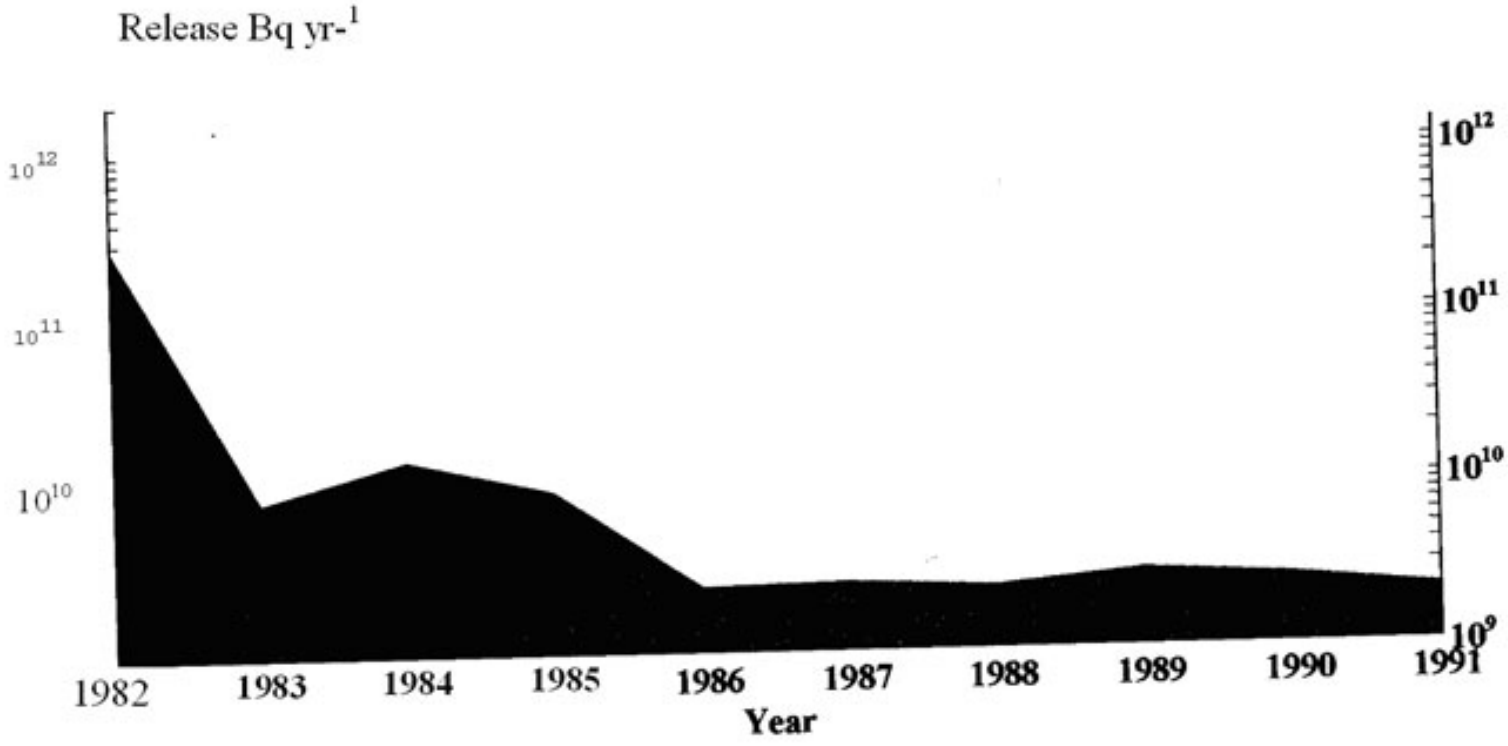
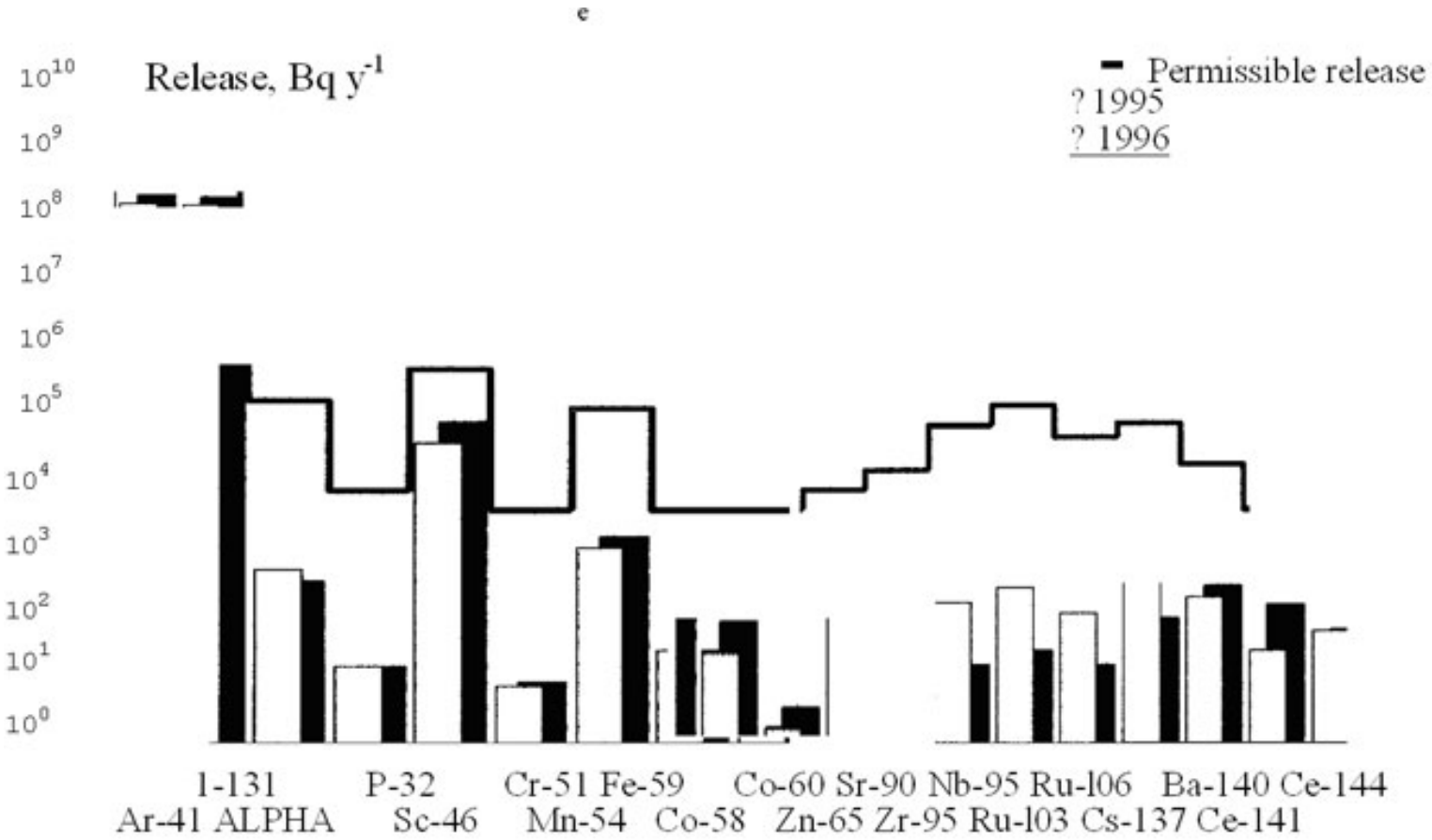


Fig. 7. Annual releases of ^{90}Sr.



Fig;9. Comparison of actual releases and permissible levels in 1995-1996

MCC air releases now do not exceed the standard levels by any components. Releases of noble gas radionuclides have been reduced 44-fold since 1991. Gamma exposure rate in the near-surface layer of the atmosphere in the MCC sanitary & protective zone is 8-15 m R/h and never exceeds the permissible value (60 m R/h) [8].

8.2.5. Radioactive contamination of the Enisey river valley and catchment

The impact of MCC 50 years of operation can be traced along the whole length of the Enisey River down to the Kara Sea. The radioecological situation in the floodplain of the Enisey River is mainly determined by the formerly conducted discharge of the single-pass AD and ADE-1 reactors' cooling waters. At the same time natural radioactive anomalies and global fallout resulting from atmospheric nuclear tests should also be taken into account.

Within the limits of 100 km around the MCC 290 gamma-anomalies of natural origin have been revealed [9]. The uranium, thorium or radon anomalies from a few meters to 2-3 km long have areas within the range from several square meters to 0.2-0.3 km^2 with gamma-exposure rates varying fro²0-30 to 2,200 m R/h. Of the total number of the recorded natural radioactive anomalies 15 have gamma-exposure rate above 400 m R/h, 34 – within the range of 150-400 m R/h, and 241 – less than 150 m R/h. Most of the anomalies are of uranium and thorium nature. They are linked with outcrops of granitoids, ancient crystalline complexes and karst formations mainly within the limits of difficult of access mountainous & taiga systems of the East Sayan and Enisey mountain ridge. As to radon anomalies, they are usually revealed in settlements, being a result of radon accumulation in non-well ventilated compartments.

Global fallout of radionuclides happen in the Northern hemisphere mostly during 1954-1970 period with maximums in 1959, 1963 and 1964. Spatial distribution of radionuclides was mostly connected with interrelation between air masses and relief.

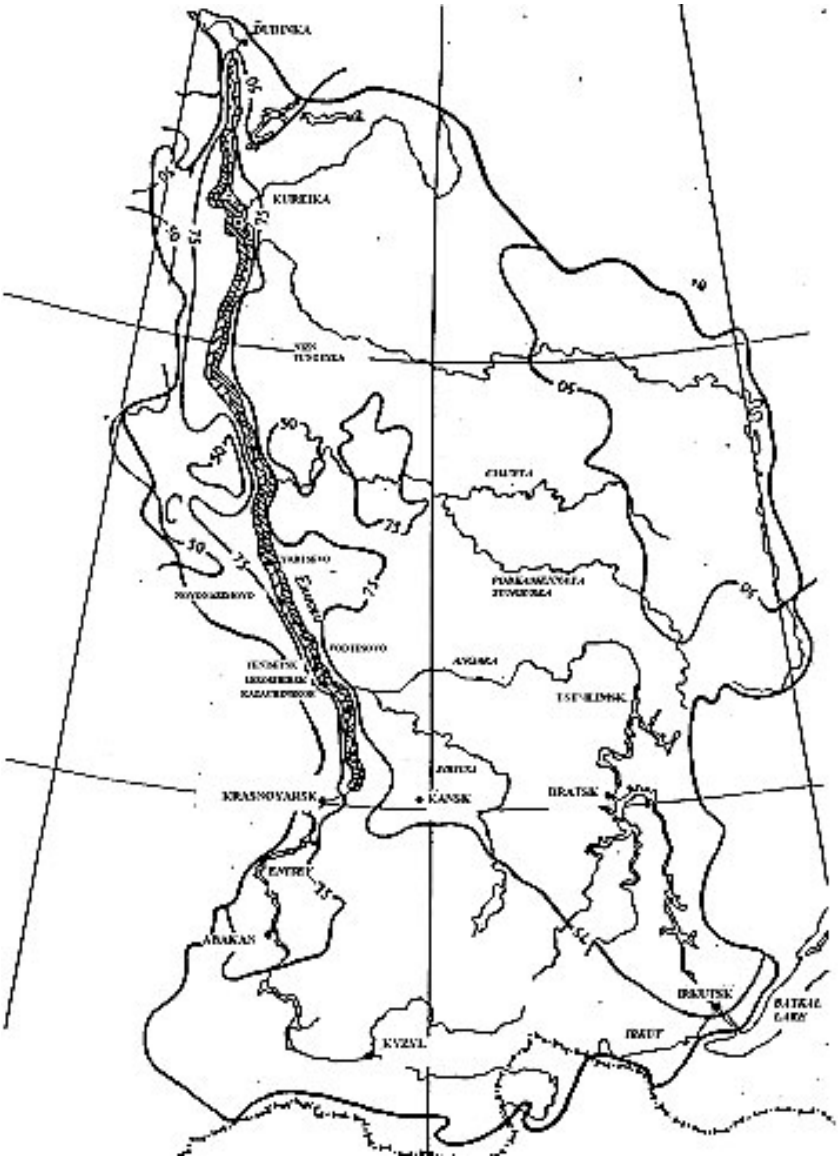
Airborne gamma spectrum survey was carried out a) in the valley and catchment of the Enisey River in 1962, i.e.

during the initial period of the discharge of effluents from straight-through reactors of the MCC into the Enisey River, b) in the valley and catchment of the Enisey River in 1970 after the termination of the main global fallouts from the nuclear tests in the atmosphere and c) in the valley and partially in catchment of Enisey River in 1993, i.e. immediately after the decommissioning of straight-through reactors at the MCC.

Survey carried out by the Institute of Applied Geophysics in 1962 indicated the presence of 95 Zr+ 95 Nb, 103 Ru+ 103 Rh, 140 Ba+ 140 La in the contamination pertaining to global and tropospheric fallouts after one of the most intensive periods of nuclear tests in atmosphere. Contamination with 137 Cs during that period played a subordinate role in comparison to 95 Zr+ 95 Nb. Average level of 137 Cs contamination density was about 2.5 kBq/m^2 . The survey did not confirm an increase in contamination of the Ye nisei valley with this radionuclide, nor presence of short-lived radionuclides discharged by the MCC, because of rather sparse survey grid (step 100 km) and meridian direction of the routes (the survey was aimed mostly at the study of area surface contamination resulting from the fallouts after nuclear tests). Methodological aspects and features of the equipment of this and subsequent surveys are described elsewhere [10-12].

The peculiarities of the contamination field in the Enisey river basin were given in [13]. The survey carried by the Institute of Applied Geophysics in 1970 provided virtually unique information on the contamination of the larger part of the Enisey catchment (about 1/5 of the catchment area was surveyed again after the Chernobyl accident under the direction of the Institute of Global Climate and Ecology). The survey established that in the lower reaches of the Enisey (in the belt 65-70 degrees northern latitude) there exists a latitudinal distribution of 137 Cs contamination characteristic of the whole northern hemisphere. The contamination reflects specifics of the stratospheric fallout of the nuclear explosion products: contamination gradually decreases from south to north from 4.6 to 1.8 kBq/m^2 (**fig. 8.2.2.1.)** . Levels of contamination in the middle and upper flow of the Enisey river are probably governed by factors of relief, which influenced the structure of the field of fallouts and levels of contamination. Increased levels of the global background, 4.6 – 5.6 kBq/m^2 , are found on the right bank of the Enisey River. In several regions (e.g., in the Baikal Lake area) contamination reaches up 7.5 kBq/m^2 . This is explained by the total increase in the relief of the Middle Siberian plateau in comparison to the West Siberian depression, and by complexity of the highland relief in the upper Enisey flow. The levels of contamination at the left bank are, on the average, 3.7-4.6 kBq/m^2 , decreasing in some places to 2.5 kBq/m^2 . The Enisey valley is found in the map only in the middle flow by a sharp increase in the global background over the high right bank of the river. Cesium anomalies were not revealed in the valley by the survey to the scale 1:10,000,000 – 1:50,000,000. This information is important for understanding that the enormous area of the Enisey catchment (2600 thousand km^2) and complexity of the relief (especially the most contaminated areas in the upper reaches and the river tributaries) could cause very noticeable wash-out of the global 137 Cs contaminantion, together with water and soil particles into the hydrological network during snow-melting period. Such wash-out could transport bomb-derived fallout over large distances from south to north, re-deposit it in accumulative landscapes of the valleys , and, possibly, be partially entrained in the Enisey estuary or transported further on into the Kara sea.

Fig.8.2.2.1. 137 Cs contamination of the Enisey catchment as of 1999. Area contamination of the catchment is shown in surface contamination density isolines, in mCi/k² (100 mCi/km^2 = 3.7 kBq/m^2). Contamination along the River Enisey is shown as a linear diagram. (Enisey1.jpg)



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In 1993, a survey was carried out in the Enisey valley's area 15 km wide and 500 km long downstream of the MCC. In addition two routes, each 1760 km long, were made along the river's left and right banks from Zheleznogorsk to Dudinka (where Enisey is flowing into the Arctic Ocean). Main results of the 1993 air-gamma survey are presented in Table 1.

Table 1. Results of the air-gamma survey of the Enisey River valley, 1993 [13].

Distance from the discharge location, km	137 Cs, kBq/m^2 , mean		137 Cs, kBq/m^2 , max	
Left bank	Right bank	Left bank	Right bank	
0-160	6.29	35.9	18.1	122
160-320	9.62	5.55	74	121
320-480	8.51	4.07	66.1	45.1

480-640	8.14	5.55	144	107
640-800	7.03	4.44	100	28.1
800-960	8.51	3.33	36	16.3
960-1120	7.77	4.44	45.5	23.3
1120-1280	7.03	4.07	33.3	24.1
1280-1440	6.66	2.96	27.8	13
140-1600	5.55	2.96	18.5	11.1
1600-1760	5.92	2.59	17	15.2

As it can be seen from the Table 1, the Enisey valley contamination levels change little with distance from the source. Maximums of 100 kBq/$m^2$and more are observed at distances of 640-800 km from the source, exceeding the maximum values observed at closeer distances. Anomalies on islands and the riverside are of local nature with areas up to several hundreds of m^2 .

For the first time, the air-gamma survey data for radionuclides other than 137 Cs were considered in the soil of Enisey floodplain. In the beginning of the 1990's, the 60 Co/ 137 Cs ratio for the whole of Enisey valley was estimated to be 0.7 ± 0.32, varying little along the valley. At the same time, 152 Eu/ 137 Cs and 154 Eu/ 137 Cs ratios noticeably changed with distance from the source, but remained essentially constant at distances exceeding 20 km. At a distance of 0-5 km from the discharge location europium radionuclides generally exceed cesium in activity, within a rather broad range: 152 Eu/ 137 Cs = 1.8-7.5; 154 Eu/ 137 Cs = 1-3. At a distance of 5-20 km from the source 152 Eu/ 137 Cs = 1.8 ± 0.53; 154 Eu/ 137 Cs = 0.5 ± 0.06. At distances more than 20 km 152 Eu/ 137 Cs = 0.6 ± 0.17; 154 Eu/ 137 Cs = 0.12 ± 0.07. Such changes in the ratio of europium radionuclides to cesium may indicate that europium is associated with “hot particles”, whereas cesium more easily migrates in the form of suspended matter and in dissolved state.

Some landscape-depending features of radionuclide distribution in the near zone of Enisey River floodplain were investigated by Linnik et al. [14]. They discovered definite dependence of 137 Cs contamination density on the floodplain landscape characteristics, varying in hydrodynamic conditions of alluvial sediments precipitation. Because 137 Cs migrates mainly in firmly fixed forms making a part of suspended matter, the floodplain landscape analysis can be used to reveal zones with different 137 Cs contamination densities. For 60 Co and 152,154 Eu nuclides, an association of contamination density with the nature of alluvial sediments was not found, and this, most likely, should be explained by another geochemical conditions of the nuclides' precipitation.

The most contaminated areas of the Enisey River floodplain are located in tailings of islands [15] and stagnant zones [16] where 137 Cs density may reach 350 kBq/² and more. Maximum 137 Cs concentrations in soil and bottom sediments are found at the depth of 10-30 cm [15], evidence of high MCC discharges in the past, as well as of ongoing processes of radionuclide burial after the single-pass reactors' shutdown. It was established [15,16], that up to 40-60 % of 137 Cs are transferred in the form of a suspended matter, and the rest is in a dissolved state.

Radionuclides present in water are accumulated in the river's bottom sediments. 137 Cs concentrations in the bottom sediments at distances up to 15 km from the discharge location are within the range of 50-500 Bq/kg. Even at significantly greater distances 137 Cs global background is exceeded by tens times. The bottom sediments are the main source of radioactive contamination of the river's floodplain [17].

In the 300 km zone the radioactive contamination of the floodplain of the Enisey River was caused by two intense floodings in 1966 and 1988 that dispersed bottom sediments, containing radionuclides, to islands and floodplain areas. At present in that zone there are some areas with gamma-exposure rates ranging from³0 to 200 m R/h [2]. The contaminated belts are 15-50 m wide with the silt thickness up to 1m. Maximum contamination levels on the right bank of Enisey reach 7 MBq/km^2 , at the distance of 500 km – 0.8 MBq/km^2 [15].

A Novosibirsk group, which had studied distribution of man-made radionuclides in alluvial soils and in bottom sediments of Enisey River in the neighborhood of the MCC (“Taiwan” spit, Atamanovo island) came to a conclusion that radionuclide contamination in the MCC near zone took place over a long period of time and was non-uniform, and this led to very changeable distribution of the contaminants in soils and bottom sediments, reflecting the dynamics of the MCC discharges, including those resulting from emergency situations [18]. The radionuclide migration processes in different forms (dissolved, adsorbed on various carrier-particles, and “hot particles”) have led to their non-uniform distribution in soils. A clearly expressed peculiarity of radionuclide vertical distribution in soils and bottom sediments is the activity decrease in upper (5 cm and 3 cm, respectively) intervals, that can be considered as an evidence of decrease of radioactive products entering into Enisey River. Continuous radionuclides washing out of the soils' upper layers during floodings makes for that, too, as well as covering of contaminated sediments with fresh clean or insignificantly contaminated material. Still, total gamma-emitting radionuclides' stocks in the explored sites remain high enough (126 Ci/k² in the Atamanovo island's spit), thus presenting certain hazard to the health of people, visiting the islands.

As of January 1, 1966, at the MCC about 7.8 k² were contaminated, mainly with 137 Cs and 90 Sr radionuclides. The data on the contaminated lands are presented in Table 2.

Table 2. Contaminated lands at the M&CC [2]

Distribution of the contaminated land areas by	Contaminated lands area, km 2			
Exposure rate level, m R/h	Including the territories of			
Production site	S&PZ	Observation zone	Total	
Up to 60	0.005	0.666	0.106	0.777
60-120	-	0.149	-	0.149
120-240	3.297	0.060	3.394	6.751
240-1,000	-	0.050	-	0.050
> 1,000	-	0.062	-	0.062
Total	3.302	0.987	3.500	7.789

137 Cs soil contamination densities at a distance up to 15 km downstream from the discharge location are within the range of 50- 130 mCi/k² . Contaminated areas of the MCC production site and S&PZ are mainly located in the underground disposal site territory as well as at the open water-storage reservoirs. The exposure rates at the areas are mainly within the range of 20-300 m R/h, there are only a few small local spots (several square meters) with contamination densities up to several hundreds m R/h [1].

Plutonium specific activities in soil in the Enisey River flood plain at distances up to 1500 km from the discharge location do not exceed 20 Bq/kg [1], but still 2-10 times that of global background levels [19].

Elevated gamma-exposure levels at some spots can be in some cases explained by the presence of “hot particles”, which are found at distances up to 400 km from the discharge location [13-15,20].

To estimate the present levels of contamination, mostly of global origin, we used 7 samples taken by the survey team of the Severtsov Institute of Ecology and Evolution during the 1997 field season. These samples were taken along the transverse profile through the Enisey valley at a distance of 500 km from the point of discharge of

radioactive waste from the Krasnoyarsk MCC, part of the samples were taken layer by layer with respect to the position of genetic soil horizons. The average level of the 137 Cs global fallouts in the surveyed area, as of the time of the sample measurement (1999), was estimated as 2-3 kBq/² . Distribution of 137 Cs in fine podzol sandy soil on the first terrace above the floodplain of the Enisey right bank under the birch and Siberian pine forest with horsetail-moss-bilberry cover is shown in **Fig.8.2.2.2.**

Vertical distribution of 137 Cs in soil demonstrates prevalence of this radio-nuclide in the upper 5-10 cm of soil, with the exception of soil from marshlands and peats where a sufficiently uniform profile of 137 Cs in the upper 10-20 cm of soil is formed.

Moreover, the data show the changes in average levels of the global contamination of 137 Cs under the influence of landscape factors with the increase in the content of this radionuclide in the accumulative fascias. For example, one finds an activity of 3.9 kBq/m2 in the slope of the terrace floodplain in alluvial marshland humus-gley soil; the activity of 6.1 kBq/² in the sphagnum bushy swamp of the first terrace above the floodland in the upper marshland peat soil; 2.1 kBq/² in the transit part of the periodically flooded central floodplain in alluvial meadow light loam soil; and 2.2 kBq/² at the flat top of the terrace above the floodplain without signs of wash-off or material accumulation in the fine podzol sandy soil.

It is absolutely clear that global contamination is characterized by spatial redistribution in the Enisey valley, and the formation of global anomalies in accumulative fascias can result in areas having more than twice the average global background levels.

The contribution of different sources to the modern 137 Cs contamination of the Enisey-river basin was estimated [21].

Table 3. 137 Cs in the Enisey river valley and catchment (2000), PBq

	Global fallout	Chernobyl deposition	Discharge and release of Krasnoyarsk-26	Total
Catchment	5.6	0.236	0.126	5.962
Valley	0.095	0.0047	0.126	0.226

Global fallout, with a small Chernobyl contribution, makes up 98 % of the total amount of 137 Cs in the catchment territory, and not more than 44% of the total amount of 137 Cs in the river-valley.

8.3. PATHWAYS

8.3.1 Radionuclide composition of the water of Enisey river

The two decommissioned reactors were the main source of the radioactive discharge into the water of Enisey river. In table 8.3.1.1 from [Nosov et al.,1993;] radionuclide composition of the water of Enisey river downstream of the source of discharge is presented. These are 1992 data, from an expedition of the Institute of Global Climate and Ecology, before the decommissioning of reactors. Discharges have been significantly reduced since decommissioning of the two straight-through cooled reactors. The 24 Na concentrations have been reduced 3000 times, 51 Cr concentration - 800 times, 76 As concentration - 230 times, and 239 Np - 650 times. However, the concentrations of long-lived 137 Cs and 60 Co are now practically the same as before 1992 (Nosov et al.,1996).

Table 8.3. 1.1.
Radionuclide concentration in the water of Enisey river, Bq/l (including the suspension), 1992, [Nosov et al.,1993]

Distance from the source of discharge, km	24 Na	32 P	51 Cr	56 Mn	76 As	137 Cs, 10 -3	239 Np
Source, 0	9600	110	410	7800	140	110	260
Atamanovo, 6	810	11	96	110	12	12	23
Bolshoi Balchug, 16	270	7.4	24	26	6.3	3.6	11
Kononovo, 25	130	5.9	11	12	2.2	3.5	2.2
Predivinsk, 100	56	2.6	7.8	-	1.4	3.3	3.7
Kazachinskoe, 180	13	2.2	4.1	-	0.6	3.1	1.5
Strelka, 250	3.7	1.9	4.1	-	0.2	5.6	1
Lesosibirsk, 290	2.2	1.1	3.3	-	0.2	3.7	0.7
Podtesovo, 350	0.2	-	3.7	-	0.1	3.3	0.9
Bor, 850	0.1	-	1.5	-	0.04	2.3	0.2
Permissible level	1010	700	56000	3700	700	560	2600

8.3.2. Spatial redistribution and accumulation of radionuclides in the estuary zone of the Enisey-river

An investigation of the Khlopin Radium Institute (St-Petersburg, Russia) gave some new data on the accumulation of 137 Cs and 239,240 Pu in the bottom sediments of the estuary of Enisey-river. An increase of 137 Cs and 239,240 Pu concentrations in the bottom samples was found in the zone of mixing between the sea- and river-water. This zone can be considered as a geochemical barrier to radionuclide migration from the Krasnoyarsk MCC to the Kara sea. The mean velocity of 137 Cs and 239,240 Pu accumulation was estimated (Legin et al.,2001) for the southern part of the estuary (i.e. for low part of the bed of the river) as 44-163 Bq/m² per year of 137 Cs and 0,4-4,9 Bq/m² per year of 239,240 Pu; and for the central zone of estuary – 720 Bq/m² per year of 137 Cs and 8,4 Bq/m² per year of 239,240 Pu. These data show that a 16-20-fold increase in accumulation of the poorly soluble radionuclides occurs at the geochemical barrier of the estuary. In the northern part of the estuary (opening to the Kara sea) the velocity of accumulation decrease to 3,3-21,4 Bq/m² per year of 137 Cs and to 0,15-1,4 Bq/m² per year of 239,240 Pu. These data demonstrate the considerable decrease of radioecological risk for the fish and animals in the Arctic ocean region.

8.3.3. Data on the fish contamination

Table 8.3.3.1 from [Vakulovski et al.,1994] contains data on fish contamination in 1972, and Table 8.3.3.2 contains data from [Nosov et al.,1993] from 1992, just before the shut-down of the two reactors. The main dose-forming radionuclide was 32 P. The maximal concentration 10000 Bq/kg was measured in the muscles of grayling in 1992. Note that the permissible dose levels for humans of 5×10^{-3} Sv/year will be reached if someone were to eat 65 kg of fish contaminated at these levels [Nosov et al.,1993]. This is an extreme event, but still possible.

Table 8.3.3.1.
Radionuclide concentrations, Bq/kg fresh weight, in fish from Enisey river in 1973 [Vakulovski et al.,1994]

Distance from the source of discharge, km	Species of fish	32 P	65 Zn	137 Cs
190	Dace	2800	26	4
190	Soroga	3600	37	11
190	Perch	2200	22	7
330	Perch	600	4	7
600	Dace	2800	33	7

600	Soroga	1040	56	4
1230	Pike	600	-	15
1230	Soroga	600	-	7
1230	Dace	740	-	4
1460	Dace	270	11	48
1460	Soroga	20	-	4

Table 8.3.3.2. The radionuclide concentration in the fish muscles, Bq/kg, 1992 [3]

Place	Species of fish	24 Na	32 P	65 Zn	137 Cs
Krasnoyarsk	Sig	5,9	560	1,7 10 2	19
40 km	Grayling	4,1	37	10	4,8
Bolshoi Balchug, 16 km	Sig	160	810	67	8,1
Predivinsk, 100 km	Grayling	440	10000	2,6 10 2	8,1
Strelka, 250 km	Sturgeon	0,7	370	8,5	5,1
	Burbot	29	440	30	13
	Ruff	100	2000	92	6,7
	Grayling	81	4800	2,2 10 2	10

8.3.4. Contamination of the bottom materials and of the soil of the flood-plain

The direct discharge into the water of the Enisey-river for a long time caused by the contamination of the bottom materials and of the soil of the flood-plain of the Enisey-river.

The long-lived radionuclide composition in 1992 of the bottom materials is shown in the table 8.3.4.1. from [Nosov et al.,1993], and the radionuclide content in 1992 of the soil contamination of the flood-plain of the Enisey-river is shown in Table 8.3.4.2 [Nosov et al.,1993]. The radionuclide composition of the bottom and flood-plain soils have changed now, after the decay of the short-lived radionuclides as 54 Mn and 65 Zn.

Table 8.3.4.1
Radionuclide concentration in the bottom accumilative material in the more contaminated parts of Enisey river-bed, Bq/kg (dry weight), 1992 [Nosov et al.,1993]

Distance from the effluence, km	51 Cr	54 Mn	60 Co	65 Zn	137 Cs	152 Eu	154 Eu
Atamanovo, 6	2442	148	1813	444	1443	814	185
Bolshoi Balchug, 16	1110	148	925	444	163	480	100
Kononovo, 25	126	9	37	11	355	41	11
Predivinsk, 100	322	27	407	74	218	211	96
Kazachinskoe, 180	111	18	241	48	255	181	33

Strelka, 250	444	78	237	74	300	126	28
Lesosibirsk, 290	31	1	1	4	8	9	5
Podtesovo, 350	29	3	6	5	27	2	3
Bor, 850	52	9	21	8	27	2	4

Table 8.3.4.2 Long-lived radionuclides in the soil of flood-plain of Enisey river, kBq/m² , 1992 [Nosov et al.,1993]

Site of soil sampling	60 Co	137 Cs	152 Eu	154 Eu
Island Atamanovski	200-311	256-350	460-2630	167-1155
Island Berezovski	33-118	23-200	59-310	13-100
Bolshoi Balchug	30-70	20-70	30-110	10-30
Tarygin	30-70	121-204	0-130	0-25
Predivinsk	3-9	7-13	5-11	1-2
Island Predivinski	9-67	13-100	11-66	1-26
Momotova	0-50	38-74	0-27	0-6
Lopatin	1-85	10-155	4-63	0-7
Cheriomukhov	48-64	63-117	26-70	3-9
Tungusski	0-67	19-115	9-74	5-8
Bolshoi Kekurski	1	7	-	-
Belyi	20-63	53-78	11-50	4-6
Sumarokov	1-3	1-7	0	0

Many years of discharges of long-lived radionuclides, including 137 Cs, into the Enisey river contaminated the flood-plain with these nuclides. Therefore, the large-scale survey of 1993 clearly registered an increase in contamination levels in the Enisey valley, which is evident from Fig.8.2.2.1.

The 1993 survey [Kontarovich et al.,1993] was carried out at the part of the valley 15 km wide and 500 km long downstream of Krasnoyarsk-26. Two sample routes were laid along the left and right banks of the Enisey river from Krasnoyarsk-26 to Dudinka (i.e. to the mouth of the river at the Arctic Ocean), the length of each route was 1760 km. The specific features of the methodology and technical equipment of the survey performed using an airborne gamma spectrometry system “Makfar-2” (Canada) are described in [Vakulovski et al.,19].

Note,that the first 20 km downstream of the place of discharge is regulated by the dam of the Krasnoyarsk electro-station, so the river processes are very weak and redistribution of the long-lived radionuclides is not expected to be considerable in the future.

Results of the airborne-gamma-spectrum survey along the valley of the Enisey-river are summarised in Table 8.3.4.3. The number of spectra was about 800000 [Kontarovich et al.,1993]. The mean levels of 137 Cs decreased very slowly. High values can be observed at great distances from the source (i.e., 144 kBq/² on the left river-side, 500 km from the source). This is due to the peculiarities of migration and accumulation of the soil materials along the river-valley. The geosystems with the high levels have (as a rule) a small area - not more than some sq.m.

Table 8.3.4.3.
Results of airborn-gamma-spectrum survey of the valey of the Enisey-river, 1993 [Kontarovich et al.,1993]

Distance from the source of discharge,	137 Cs, kBq/m² mean		137 Cs, kBq/m² max	
km	Left bank	Right bank	Left bank	Right bank
0-160	6.29	35.9	18.1	122
160-320	9.62	5.55	74	121
320-480	8.51	4.07	66.6	45.1
480-640	8.14	5.55	144	107
640-800	7.03	4.44	100	28.1
800-960	8.51	3.33	36	16.3
960-1120	7.77	4.44	45.5	23.3
1120-1280	7.03	4.07	33.3	24.1
1280-1440	6.66	2.96	27.8	13
1440-1600	5.55	2.96	18.5	11.1
1600-1760	5.92	2.59	17	15.2

These geosystems are situated the flood-plain, where the silt particles areaccumulated [Leontiev,1979]. These geosystems become a good natural collector of the radioactive contamination, and the founding of its geographical situation can be a good help to the establishment of the countermeasures.

8.3.5. Redistribution and v ertical distribution of radionuclides in the soils of the flood-plain

The stream crosses the floodplain during periods of high-water and washes away its foothold. A part of the soil material from this flooding accumulates on the surface of the floodplain, while other portions are transported along the side of floodplain by the river. Highest accumulations occur on the floodplain near the river, where the velocity of the current from the flooding river diminish quickly due to the change of the river depth and an increase in roughness of the bottom surface. In the central part of the floodplain the accumulation of sediments decrease, and the sediments become more fine. Only finest particles (silt and clay particles) can be transport to the back part of the flood plain.

Ace drift and wind are two other migration factors on the floodplain.

Radionuclides, participating in the various transport processes can be distributed with depth in the sediments. Thus, radionuclide inventories increase in the accumulative zones, but burying of radionuclides by newly deposited material decrease the external dose-rate.

A graph of 137 Cs and other gamma-emitting radionuclide distributions in the sediment of the flood-plain of the Island Beliy show [Nosov et al.,1993] that the maximum 137 Cs content occurs at a depth of 30 cm. More than 90 % of the contribution in the dose-rate produced by gamma-emitting radionuclides is due to their accumulation in the 0-10 cm soil layer. The figure shows, that the Europium isotopes are the main dose-forming elements, they migrate very poorly along the valley and within the soil depth profile.

Many scientists think [Makhonko,1998 ; Vakulovski et al.,1994, Nosov et al.,1993; Nosov et al.,1996] that these geosystems-collectors present the main danger for the forming of the external dose-rate. Data on the depth distribution of radionuclides in the sediment of the flood-plain present an opposite argument. We can see that the 137 Cs maximum occurs at 32 cm deep, only 60 Co and 152 Eu can contribute significantly to dose. The spatial redistribution of Eu, however, occurs in the first 20 km downstream of the source.

8.3.6. Behaviour of radionuclides in the forest landscapes of the Krasnoyarsk region

The Krasnoyarsk region is covered by coniferous forests (larch, abies, fir, pine); agricultural lands are not widespread. Forests are an ecosystem with a high holding capacity for radionuclides and other microelements. Biogeochemistry of radionuclides in the forest landscapes was described in numerous publications of Russian scientists (Alexakhin et al., 1976; Alexakhin and Naryshkin, 1977; Klyashtorin et al., 1999; Tikhomirov, 1972; Tikhomirov, 1993), but we have not found articles or data, specifically directed to the investigation of the Krasnoyarsk region. The reason is not only the peculiarities of the scientific investigations near the military sites, but also the absence of the high levels of contamination. So, we can made only some general observations on the environmental impact. The relatively high migration of 90 Sr to all elements of the forest ecosystem is established in all publications. This observation is true for Krasnoyarsk region forests.

8.4 Dose assessment

Dose assessment to the population from the main pathways was carried out according to established methods on the basis of the following data:

- routine control of the parameters of radiation condition in sanitary and supervision zones provided by the Environmental Protection Lab of the MCC and Industrial-Sanitary Lab of Medical-Sanitary Division;

- research control carried out by specialists of different research institutes in the area of possible impact from the MCC [1-3].

The concept of critical organ and critical group has been the basis for control of the exposures to the population. That is why the available official records were written, as a rule, in the form of maximum dose equivalent to a critical organ (tissue) for the most exposed group of populations. In order to provide a clearer understanding in this chapter of dose impact from the MCC, all dose estimates have been re-calculated in the form of effective doses.

EXTERNAL EXPOSURE

The input data for assessment of external exposure were as follows:

- measurements of gamma-exposure rate;

- measurements of radionuclide ground deposition density;

- residence histories (fraction of time spent at typical contaminated locations).

The radiation dose was accumulated mainly during spring-summer-autumn seasons because in winter time the level of exposure rate decreased greatly due to weakening of gamma-radiation by snow cover.

It is important to note that after the straight-through reactors had been shut down there was no substantial change in exposure rates measured in the vicinities of the settlements [3,5]. With respect to external exposure to the critical group of the population living up to 50 km downstream from the place of discharge, exposure from radionuclides in river water and bottom sediments is second in importance. After stopping of straight-through reactors, exposure to the population at the river substantially decreased. For example, in the place of mixture of sewage and river water the value of exposure rate measured at depth 1 meter from water surface in autumn 1994 was about 30 times lower than that in 1991 [3].

To assess external effective dose it was assumed for all population that the average time spent on the bank (in summer) was equal to 300 hours per year and for the critical group of fishermen - 600 hours

per year, including 300 hours per year on the near islets and in the boats on the river. The results of external dose

assessment during the period of time when the reactors were in operation are presented in Table 8.4.1.

Table 8.4.1. Average annual external effective doses to the populations in 1962-1991.

Distance from the place of discharge, km	Location of the settlement	Average external effective dose (to the whole populations / critical group), m Sv y^{-1}
5-10	left bank	44 / 350
10-25	right bank	33 / 90
	left bank	17 / 80
50-250	-	15 / 60
850-1500	-	10 / 30

During the time period when the first reactor was in operation up to 1962 the radiation doses were assessed to be not higher than 20 % of the values presented in Table 8.4.1

.INTERNAL EXPOSURE

Ingestion intake is the main radionuclide pathway for internal exposure to the populations living in the settlements located on the banks of the Enisey River. The following radionuclides entered the body:

- 32 P, 24 Na, 65 Zn, and 137 Cs with fish from the Enisey River;

- 32 P, 137 Cs, and 90 Sr with milk from cows, pastured on submerged meadows and consuming water from the Enisey River and hay from contaminated areas.

The role of drinking water regarding internal exposure to the populations is negligible. Because ground water is used as drinking water, the water from the Enisey River is not used even in agricultural purposes. However, only the two settlements located 250 km (Strelka) and 290 km (Lesosibirsk) downstream are the exception. In this settlements the water from the Enisey River is used for agricultural and drinking purposes [5, 6].

The fraction of activity transferred by sediments does not exceed (10-15)% for all the radionuclides. Fraction of 137 Cs in sediments is assessed to be about (20-50)% of its total activity in water [3].

Two L/day consumption of water results in an annual effective dose averaged over population of 8 m Sv y^{-1}, with range from 5 m Sv y^{-1} to 40 m Sv y^{-1} depending upon the age-group exposed (highest exposure is estimated for children of 1-2 y, and the lowest exposure is to adults).

After stopping of the straight-through reactors in 1992 and use of closed loop, the concentration of 24 Na, 32 P, 51 Cr, and 239 Np decreased greatly up to 2-3 orders of magnitude in a river water [3].

The input data to assess internal exposure from ingestion intake were: (1) the values of radionuclide specific activity in foods locally produced (river fish, milk et al.) and (2) annual rate of foods consumption for different age-groups.

When the reactors were in operation the highest contribution to the internal exposure was provided by intake of 32 P with fresh fish and milk. The highest specific activity of 32 P was found in fish caught at distances of 18-60 km from the place of discharge (Table 8.3.1.1.). On a whole, the specific activity of 32 P and other radionuclides in fish muscles depends upon the type of fish. It results in the major contribution in uncertainty in dose estimate.

Average annual internal effective doses to the populations from ingestion intake with river fish during commission

of the reactors are presented in Table 8.4.2. The main contribution to that dose (up to 82%) is due to ingestion intake of 32 P.

Table 8.4.2. The doses to the populations living in settlements located on the river banks from consumption of river fish.

Distance from the place of discharge, km	Average effective dose, m Sv y^{-1}	Range of average effective doses to different groups of population, m Sv y^{-1}
5-15	290	80 – 630
15-20	590	160 – 1280
50-60	780	220 – 1700
100-150	260	75 – 580
150-250	75	20 – 160

The highest doses were received by a critical group of population (fishermen) and the lowest doses were received by children aged 1-2 y.

Following decommission of the straight-through reactors, the level of contamination of river fish is determined by 137 Cs, its specific activity in fish muscles in the range (2.3-15) Bq kg^{-1} at the distances up to 25 km from the place of discharge [3, 6]. That activity decreased about twice compared to the time period when the reactors were in operation (Fig. 8.?). Average internal dose from consumption of fish contaminated by 137 Cs to the residents of the settlements located on the river banks within 30 km from the place of discharge is estimated to be equal to 4 m Sv y^{-1} , with range from 0.15 m Sv y^{-1} to 10 m Sv y^{-1} depending upon age-group.

In 1976-1978 the measured specific activity of 32 P in milk produced in the settlements located on the river banks within 50 km from the place of discharge was, on average, equal to

37 Bq L^{-1} [4]. Average annual internal effective dose from intake of 32 P with milk was estimated to be 60 m Sv y^{-1} with range from 30 m Sv y^{-1} to 420 m Sv y^{-1} depending upon age-group (the highest exposure was estimated for the children of 1-2 y and the lowest exposure – to the adults).

Specific activities of 137 Cs and 90 Sr in milk, potato, other vegetables, and meat in various period of time did not differ from corresponding activities in the other settlements, which were not affected by the releases from the MCC [4, 5, 6].

Exposure to the populations living in the settlements located in supervision zone from intake of 137 Cs and 90 Sr with foods locally produced was estimated to be in the range of 15 to 30 m Sv y^{-1} [4, 6]. Exposures were within the variation of doses from global fallout typical for the region.

Inhalation intake of the radionuclides released from the MCC was not an important factor with respect to internal exposure to the populations. According to the estimation based on monitoring data on radionuclide concentration in a ground-level air in supervision zone, average effective dose from inhalation intake in supervision zone in 1990 and in 1999 was tenths of 1 m Sv y^{-1} [5, 6]. During the time period when the reactors were in operation that dose did not exceed a few m Sv y^{-1} .

ACCUMULATED EFFECTIVE DOSES

The values of average total effective doses and collective doses to the populations living in the settlements located

on the river banks which were accumulated during the period of time when the reactors were in operation are presented in Table 8.4.3.

Table 8.4.3. The values of average total effective doses and collective doses to the populations living in the settlements located on the river banks which were accumulated during the period of time when the reactors were in operation.

Distance from the place of discharge, km	Population	Average accumulated dose, mSv		Collective dose, man Sv
1959-1991	1992-2001			
5-15	2,500	11	0.4	28.5
15-25	2,000	21	0.25	42.5
50-65	1,700	27	0.15	46.2
65-75	700	17	0.15	12.0
90-150	8,000	8.8	0.15	70.8
150-250	10,000	2.9	0.15	30.5

Total collective dose to the populations living in the settlements located on the river banks which were accumulated during the period of time when the reactors were in operation is estimated to be equal to 230.5 man Sv, more than 98% of that dose falls in the period of time from 1959 to 1991.

As a whole, the presented estimates of exposures to the populations do not contradict with the estimates received earlier [1, 3, 7].

It should be noted that available estimates of internal exposure from intake of 32 P based on biological dosimetry (measurements of 32 P in urine [4]) suggests a possible overestimation of internal dose exposure from that radionuclide when estimated on the basis of consumption of locally produced foods. Such overestimation might be due to an incorrect accounting of different types of fish preparation and consumption (some fish are consumed immediately, whereas other parts are processed for storage and later consumption).

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The “hot particles” of 0.01 to 0.2 mm in size with exposure rates within the range of 500-9,000 m R/h are found with contamination densities up to 68 particles per k² . They may include radionuclides of transuranium elements, cesium, europium, etc.

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Chap.9 - MARCOULE

Arrigo A. CIGNA

9.1 Generalities

CEA built three large metal-fuelled plutonium production reactors at the complex in Marcoule, Gard, along the Rhône River. Designed G1 (38 MWth), G2 (150 MWth), and G 3(150 MWth), these gas-cooled graphite-moderated reactors operated from 1956 to 1968, 1958 to 1980, and 1959 to 1984, respectively. Although designed primarily for plutonium production (they produced an estimated 2.5 to 2.8 metric tons of Pu altogether), they all were eventually connected to the grid of EdF and generated some electricity. Their graphite-gas design also became the model for EdF's first civilian power reactors (Kirchmann, 2000).

To obtain tritium for thermonuclear weapons, the CEA built and still operates two heavy-water reactors at Marcoule, Célestin I and II. Rated at 190 MWth each, they came on line in 1967 and 1968, respectively. COGEMA began operating a tritium extraction plant in November 1967. It extracts tritium from the lithium-6 alloy targets that are irradiated in the Célestin I and II reactors.

France began reprocessing in 1949, when it separated the first milligrams of Pu from the spent fuel of the Zoé reactor. A pilot plant was commissioned in 1954, followed by France's first full-scale reprocessing plant, the UP1, which was completed at Marcoule in 1958. It was designed to extract Pu from the spent metal fuel of the new G reactors being constructed on the same site. Its capacity is estimated at 400 metric tons per year.

The COGEMA facility of Marcoule was opened in 1955. Its purpose is threefold:

- . the production of plutonium and tritium;
- . the reprocessing of fuel from French and Spanish gas-cooled reactors;
- support for the CEA facilities in the Rhône valley.

Many aspects of military and civilian radioactive waste disposal in France- from selecting, constructing, and operating sites to the rules governing waste classification, packaging, and transportation- are the responsibility of ANDRA, (acronym for the National Agency for the Management of Radioactive Wastes), established within the CEA in 1979.

After reprocessing, the leftover high-level liquid wastes (defined as Category C) are stored in double-walled, stainless steel, refrigerated tanks at Marcoule and La Hague until they can be vitrified. A pilot plant for vitrifying Category C wastes, Piver 1, operated in Marcoule between 1969 and 1980. From 1969 to 1973 it vitrified about 185 PBq of fission products, mostly derived from the reprocessing of graphite-gas reactor fuel. Piver 1 was dismantled between 1982 and 1991, and was replaced by Piver 2. COGEMA also built the world's first commercial-scale vitrification plant **(** AVM **)** for high-level

liquid wastes, which opened at Marcoule in 1978.

In addition to the facilities above mentioned, Marcoule also hosted the Phénix breeder reactor and the pilot plant for reprocessing breeder fuel. This breeder reactor is an industrial prototype of a fast-breeder type (233MWe) belonging to the CEA and EdF. It has not been the object of any specific ruling authorising it to release liquid effluents. In fact, the reactor's liquid releases are taken into account with those of the Marcoule complex.

9.2 Source term

9.2.1 The waste production

The reprocessing operations generated about 4.8 EBq of combined 90 Sr and 137 Cs wastes through 1990 (figures not decay corrected). The fission products are stored in liquid form in electrically cooled, double-walled, stainless steel tanks until vitrified in glass. Marcoule's pilot vitrification plant, Piver 1, operated from 1969 to 1980 and vitrified 185 PBq in 12 metric tons of glass. Its commercial-scale vitrification plant (AVM) began operation in 1978, and through the end of 1985 it had produced about 400 metric tons of glass conditioned in 150 l stainless steel containers, which are stored on-site in more than 1,100 air-cooled holes. In 1998 AVM was stopped for maintenance works but resumed in 1999 for vitrification of the most radioactive effluent arising from the works of final dismantling of UP1.

Sludges precipitated out from UP1's effluent treatment facility are packaged in drums with bitumen for final disposal. Other UP1 radioactive wastes include the spent fuel cladding that is stripped off prior to reprocessing and the noble gases (primarily 85 Kr) and 3 H released during reprocessing. There have been three incinerators at Marcoule: one for low-level waste, one for wastes high in alpha activity, and a pilot plant. All have experienced problems with clogging or corrosion of their filters due to the acidity of the wastes being burned.

Decommissioning activities at Marcoule also have generated solid wastes. The plant's oldest Pu-purification workshops, known as Room 82 and Room 100, shut down in 1963 and 1973 respectively, were completely dismantled in 1985.The operation took four years of planning. It required the removal of 1,000 cubic meters of solid wastes, all contaminated with alpha-emitting radionuclides (principally Pu). Almost 300 containers were transferred to ANDRA; 200 drums of the most contaminated Pu wastes remained at Marcoule. Also recovered and recycled were 150 metric tons of lead and 20,000 metric tons of barium sulphate. To complete the decommissioning of larger facilities at Marcoule, COGEMA announced in 1992 that it was building a waste treatment facility specifically for processing mildly contaminated steel; some 4,000 metric tons from decommissioning the G1 and G3 reactors are to be treated.

9.2.2 Solid Wastes Storage

On 31/12/1998 the situation, according to ANDRA National Inventory, was the following at Marcoule:

Solid Wastes	QUANTITIES	a Total Activity	ß g Total Activity
Vitrified	2,728 containers	27 PBq	6,000 PBq
Bitumen	61,181 drums (200l)	0.47 PBq	41.5 PBq
Fuel Structure Mat	2,710 tons	0.51 PBq	154.3 PBq

It is worth knowing that the bitumen start to be radiosensitive from an integrated dose of 1MGy (beta gamma) through production of radiolysis gases and an increase of the drum volume. Still, no volume increase has been observed at Marcoule where more that 25,000 drums are stored since 1966. Yet, activity in some drums exceeded 37 GBq/l beta gamma in 1967.

9.2.3 Trends in discharges over the period 1980-1991 (Cigna et al., 1994)

9.2.3.1 General

By far the main sources of radionuclide releases into the Mediterranean sea are the discharges from the Marcoule complex (Table 9.2.3.1). These releases account for 76.7 % of the total beta-gamma discharges and more than 99.9 % for the total alpha discharges in the Mediterranean sea (total Beta +Gamma discharges = the sum of beta-gamma emitters identified in Table 9.2.3.1.

Table 9.2.3.1 - Summary of liquid discharges (1980-1991).

Discharge	Marcoule	Other	Total
Beta and Gamma without 3 H	0.533 PBq	0.013 PBq	0.546 PBq
3 H	4.87 PBq	1.63 PBq	6.50 PBq
Alpha	894 GBq	0.26 GBq	894.26 GBq

The main contributor to total beta-gamma discharges is 3 H (92.26%). Letting aside 3 H, the most important contributor is 106 Ru+ 106 Rh (79.69%), followed by decreasing contributions by 90 Sr+ 90 Y (7%), 137 Cs (5.63%), 134 Cs (1.1%), 58 Co (0.93%) and 54 Mn (0.8%). The main contributors for total alpha discharges are: 241 Am (31.4%), 239+240 Pu (27.87%) and Nat U (24.79%).

9.2.3.2 Marcoule fuel reprocessing plant

As reported in the preceding paragraph, from 1980 to 1991 the Marcoule complex discharged about 0.5 PBq of beta-gamma activity (excluding tritium), 4.87 PBq of 3 H and 894 GBq of alpha activity. By excluding tritium, 106 Ru+ 106 Rh accounts for 81.42% of the total beta-gamma activity, while 90 Sr+ 90 Y and 137 Cs contribute 6.88% and 5.57% respectively, the other radionuclides representing contributions of less than 1%.

It must be underlined here that there is a clear decrease of the releases in 1991 due to new treatment process set up since 1990. Such a decrease is continuing also in the following years.

9.2.3.3 Nuclear power plants

While the releases from Marcoule (Table 9.2.3.1) are characterised by 106 Ru+ 106 Rh, the releases from nuclear power plants when excluding 3 H are characterised by a number of elements such as 58 Co (39.75%), 90 Sr+ 90 Y (11.98), 60 Co (10.6%) and 137 Cs (7.99%).

Over the period 1980-1991 the nuclear power plants released a total amount of 1.64 PBq of beta-gamma activity represented mainly by 3 H releases (99.2%). When excluding 3 H the total beta-gamma activity is 0.013 PBq. As underlined in the paragraph above mentioned, the total alpha activity released by the nuclear power stations is negligible compared to the releases from Marcoule, i.e. 0.26 GBq (239+240 Pu are the only radionuclides reported).

Table 9.2.3.3.1. - Technical specifications of the nuclear power plants in operation in the Rhône valley

Reactor type/ Name	Number of units	Net capacity (MWe)
PWR/ Bugey	(4)	2x880, 2x920
UNGG/ Bugey	(1)	540
FBR/ Creys-Malville	(1)	1200 (temporarily shutdown?)
PWR/ Cruas-Meysse	(4)	2x880, 2x915
FBR/ Phenix	(1)	233
PWR/ St Alban	(2)	2x1335
PWR/ Tricastin	(4)	4x915

Table 9.2.3.3.2.- Technical specifications of the definitively shutdown nuclear power plants in Marcoule

Reactor type/Name of the unit	Net capacity (MWe)	Shutdown date
UNGG/ Marcoule G1, G2, G3	2, 38, 38	Shutdown dates 1968/1982/1984

9.3 Pathways

9.3.1 Liquid Effluents

All liquid radioactive effluents produced by all facilities of the site are processed at the «Station de Traitement des Effluents Liquides» (STEL), improved in 1990. The effluents are analysed before discharge and are only released if the Rhône flow-rate is adequate (debit measured in the 1965-1968 period was 2,260 $m^3 s^{-1}$ in February and 1,140 $m^3 s^{-1}$ in July).

The regulatory limits set for Marcoule allow total alpha releases into the Rhône up to 150 GBq per year, the «objectif de progrès» determined by OPRI (Office Protection contre les Radiations

Ionisantes) is fixed at 52.5 GBq. Other permitted yearly releases into the Rhône include 2,500 TBq of 3 H (Objective of progress: 500 TBq) and 6 TBq each 90 Sr and 137 Cs (Objective of progress fixed respectively at 1.5 and 1.2 TBq).

No data are actually available on the volume of liquid effluents produced in the first years of operation but according to G.Rodier, in 1963, the STEL received 100,000 m³ of effluents containing about 740 TBq. These effluents were sorted out in three categories: high level of activity (37 to 925 GBq /m³) , medium activity (7 MBq to 37 GBq/m³) and low level (37 kBq to 37 MBq /m³) . The effluents of low activity represented about 50% of the volume received. In 1983, the liquid effluents with an activity lower than 925 GBq/m³ reached a yearly volume of 130,000 m³ .

9.3.2 Chronology of Liquid Discharges

Based on the MARINA-MED and the "Rapports Environnement" for the years 1997 & 1998 published by the COGEMA-Marcoule the quantities of radioactivity released between 1980 and 1998 are shown in Tables 9.3.1. and 9.3.2. and the graph shows the evolution in time. It must be pointed out that sometimes data have minor differences according their origin (Cigna et al., 1994, Kirchmann, 2000).

Table 9.3.1.- Radionuclides (GBq) in liquid discharges from Marcoule, 1980-1991

Radionuclides	1980	1981	1982	1983	1984	1985	1986
Mn54	2,60E+02	1,30E+02	4,40E+02	3,00E+02	4,00E+02	7,70E+02	2,30E+02
Co58	3,00E+00	3,00E+00	4,00E+00	4,00E+00	1,00E+01	1,00E+01	7,50E-01
Co60	7,00E+01	1,00E+02	8,00E+01	6,00E+01	9,00E+01	1,00E+02	5,00E+01
Sr90+Y90	1,60E+03	1,00E+03	2,42E+03	8,60E+02	2,00E+03	3,94E+03	5,46E+03
Zr95+Nb95	5,00E+01	3,00E+01	4,00E+01	2,00E+02	3,00E+01	4,10E+01	3,70E+00
Ru103	5,00E+01	4,00E+01	1,90E+02	4,10E+02	1,20E+02	2,30E+02	6,80E-01
Ru106+Rh106	2,51E+04	2,69E+04	3,66E+04	5,34E+04	2,80E+04	3,43E+04	3,31E+04
Sb125	6,00E+02	8,00E+02	1,90E+03	1,00E+03	3,61E+03	1,84E+03	1,38E+03
Cs134	8,00E+02	8,00E+02	1,30E+03	3,00E+02	3,40E+02	4,50E+02	4,30E+02
Cs137	3,80E+03	3,80E+03	5,55E+03	1,66E+03	2,10E+03	2,35E+03	2,47E+03
Ce144+Pr144	5,00E+02	3,00E+02	9,00E+02	5,00E+02	3,00E+02	4,40E+02	5,30E+02

H3	4,14E+05	3,30E+05	3,48E+05	2,05E+05	4,06E+05	5,21E+05	5,36E+05
U (nat.)	2,04E+01	8,90E+00	6,00E+00	2,06E+01	2,60E+01	2,43E+01	3,03E+01
Pu239+240	2,34E+01	1,87E+01	1,37E+01	1,20E+01	2,57E+01	2,66E+01	2,48E+01
Pu238 +Am241	4,08E+01	1,68E+01	3,52E+01	2,17E+01	4,01E+01	2,17E+01	3,47E+01
Cm242+244	3,90E+00	1,90E+00	1,20E+01	3,20E+00	2,40E+00	3,80E+00	1,04E+01
Am241	3,30E+01	1,06E+01	3,07E+01	1,77E+01	3,16E+01	1,29E+01	2,65E+01

Radionuclides	1987	1988	1989	1990	1991
Mn54	1,40E+02	6,30E+02	6,90E+02	1,70E+02	2,00E+01
Co58	2,00E+00	7,00E-01	2,00E+00		1,00E-01
Co60	7,80E+01	5,20E+01	6,30E+01	3,70E+01	5,50E+01
Sr90+Y90	5,30E+03	4,92E+03	4,50E+03	2,72E+03	1,92E+03
Zr95+Nb95	2,70E+00	2,70E+01	8,10E+01	4,40E+01	3,00E+00
Ru103	2,10E+00	2,30E+00	8,40E+01	3,00E+01	1,60E+01
Ru106+Rh106	3,22E+04	5,05E+04	4,76E+04	4,88E+04	1,74E+04
Sb125	5,70E+02	7,60E+02	9,20E+02	1,25E+03	4,20E+02
Cs134	2,70E+02	1,90E+02	1,50E+02	3,90E+02	1,00E+02
Cs137	2,42E+03	1,95E+03	1,13E+03	1,67E+03	7,60E+02
Ce144+Pr144	3,90E+02	3,10E+02	4,50E+02	5,30E+02	1,90E+02
H3	4,37E+05	3,76E+05	4,57E+05	4,63E+05	3,76E+05
U (nat.)	2,59E+01	2,01E+01	1,57E+01	1,63E+01	7,15E+00
Pu239+240	2,41E+01	2,88E+01	1,74E+01	2,11E+01	1,26E+01
Pu238+Am241	5,74E+01	4,00E+01	2,02E+01	2,07E+01	1,36E+01
Cm242+244	6,30E+00	6,60E+00	3,90E+00	3,90E+00	2,02E+00
Am241	4,95E+01	3,05E+01	1,45E+01	1,37E+01	9,44E+00

Table 9.3.2. - Liquid discharges (GBq) from 1980 to 1998.

Year	Alpha	Sr90+Y90	Cs134+Cs137	H3	Others
1980	1,2E+02	1,6E+03	4,6E+03	4,1E+05	2,7E+04
1981	5,7E+01	1,0E+03	4,6E+03	3,3E+05	2,8E+04
1982	9,8E+01	2,4E+03	6,9E+03	3,5E+05	4,0E+04

1983	7,5E+01	8,6E+02	2,0E+03	2,1E+05	5,6E+04
1984	1,3E+02	2,0E+03	2,4E+03	4,1E+05	3,3E+04
1985	8,9E+01	3,9E+03	2,8E+03	5,2E+05	3,8E+04
1986	1,3E+02	5,5E+03	2,9E+03	5,4E+05	3,5E+04
1987	1,6E+02	5,3E+03	2,7E+03	4,4E+05	3,3E+04
1988	1,3E+02	4,9E+03	2,1E+03	3,8E+05	5,2E+04
1989	7,2E+01	4,5E+03	1,3E+03	4,6E+05	5,0E+04
1990	4,5E+01	2,7E+03	8,6E+02	4,6E+05	1,8E+04
1991	3,6E+01	1,9E+03	9,3E+02	3,8E+05	2,4E+04
1992	1,4E+01	3,0E+02	2,3E+02	3,5E+05	1,1E+04
1993	7,1E+00	4,0E+02	1,2E+02	3,5E+05	6,1E+03
1994	1,0E+01	4,0E+02	2,3E+02	3,2E+05	3,0E+03
1995	1,1E+01	3,0E+02	1,2E+02	2,6E+05	6,7E+03
1996	1,2E+01	4,0E+02	1,2E+02	2,7E+05	7,2E+03
1997	1,2E+01	3,0E+02	9,3E+01	1,6E+05	7,2E+03
1998	4,1E+00	2,0E+02	3,5E+01	1,9E+04	1,2E+03

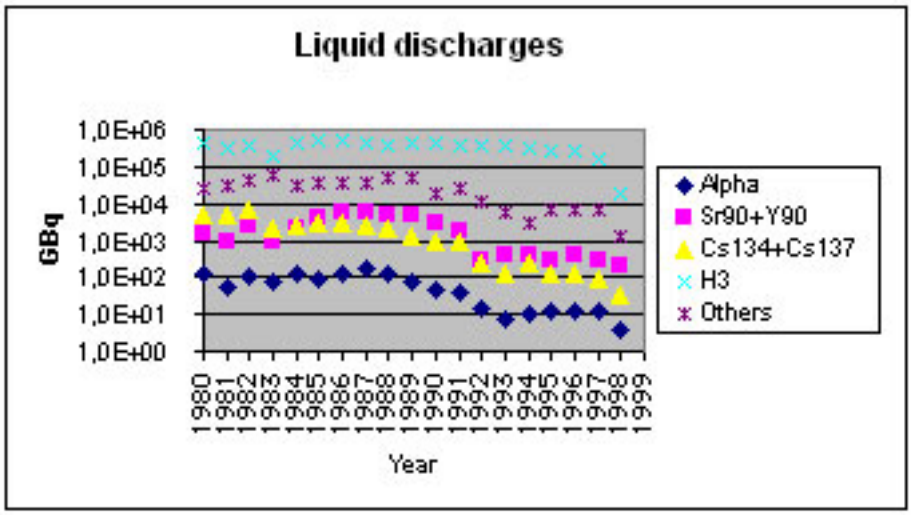

Fig. 9.3.1 - Liquid discharges from 1980 to 1998

9.3.3 Atmospheric Discharges

According to the Rapport Environnement 1997 published by COGEMA-Marcoule, most of the radionuclides present in gaseous effluents are removed by the Very High Efficiency (VHE) filters and Iodine traps.

All the stacks are equipped with a continuous sampling system in order to analyse and compute the releases. Furthermore the atmosphere is monitored through 2 stations on-site and 4 located in a 10-km radius around the nuclear installation.

9.3.4 Chronology of Atmospheric Discharges

Based on the Rapports Environnement for the years 1997 & 1998 published by the COGEMA-Marcoule the quantities of radioactivity released between 1988 and 1998 are shown in Table 9.3.3. and the graph shows the evolution in time.

Table 9.3.3. - Atmospheric discharges from 1988 to 1998

Year	Alpha	Halogens	Beta +Gamma	Tritium	Rare Gases
1988	1,3E-02	5,5E+01	1,4E+01	1,2E+00	
1989	1,3E-02	7,0E+01	1,7E+01	7,3E-01	
1990	1,4E-02	8,0E+01	1,2E+01	5,6E-01	
1991	1,8E-02	5,1E+01	4,0E+00	6,4E-01	
1992	2,0E-02	2,5E+01	3,0E+00	6,0E-01	
1993	2,0E-02	3,4E+01	3,5E+00	6,9E-01	
1994	2,1E-02	2,5E+01	2,2E+00	5,2E-01	1,3E+04
1995	2,4E-02	4,4E+01	3,3E+00	4,7E-01	1,5E+04
1996	2,5E-02	4,9E+01	1,7E+00	7,5E-01	1,6E+04
1997	7,2E-03	1,5E+01	5,4E-01	7,9E-01	5,7E+03

1998	7,3E-03	2,2E+00	7,0E-02	3,3E-01	5,0E+02

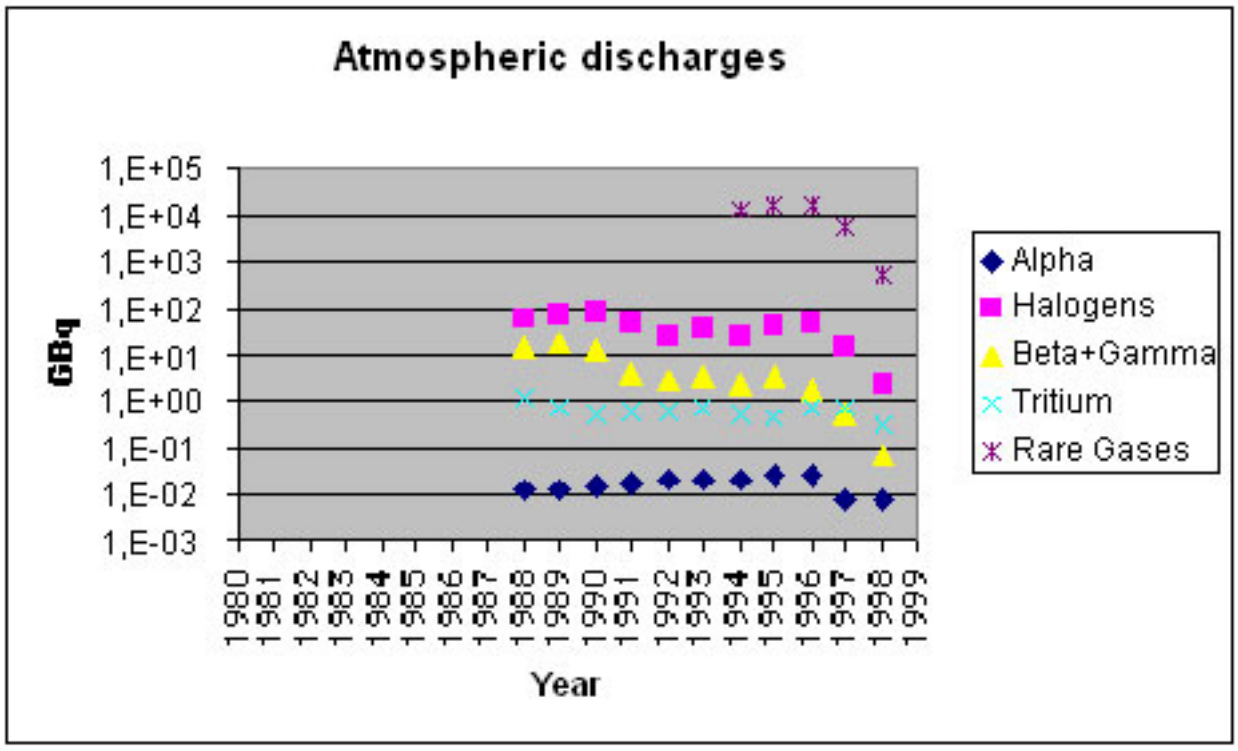

Fig. 9.3.2 - Atmospheric discharges from 1988 to 1998

9.3.5 Accidental Releases

In normal operation ATM (workshop for tritium extraction) discharged 26 GBq daily, in 1981, which represented 9.4 PBq per year; the authorised limit of tritium release being 10 PBq. Some accidental releases also occurred:

- 9 June 1976: release of 1 PBq of tritium in 20 hours, probably from ATM ;
- June 1981: release of 0.3 PBq from ATM ;
- 23 October 1981: release of 0.7 PBq of tritium in 4 hours from ATM.
- Between October 1956 and December 1960, 22 cladding failures occurred in G1. On 26 Oct.1956 the failures released fission products in the atmosphere.
- Several other incidents/accidents occurred between 1960 and 1992 in the Marcoule installations and resulted in workers' radiological exposure.

9.4 Dose assessment

The collective radiological impact on the population of the member states of the European Community (EC) due to liquid discharges released from Marcoule nuclear during normal operations into the Mediterranean waters in the period 1980 - 1991 has been estimated for the MARINA-MED

Project (Cigna *et al.*, 1994). The present note is mainly based on the Working Group 4 Report for MARINA-MED Project.

A mathematical model, ATOMED (Simmonds *et al.* , 1995) was developed to predict the dispersion of radionuclides in the Mediterranean Sea and to estimate the exposure of the population of the European Community. A model for the Rhône river was also used to model the dispersion of the radionuclides discharged by the Marcoule plant in a more accurate way.

The model ATOMED was developed for the updating of the CEC project *Methodology for evaluating the radiological consequences of radioactive effluents released in normal operations* (NRPB-CEA, 1979). It is mainly based on the REJMAR code developed by CEA/IPSN (Chartier, 1987; Chartier *et al.* , 1988) to assess the radiological consequences of radioactive releases into the marine environment and includes the sedimentation model developed at NRPB. The NRPB model was adopted because it describes in more detail the transfers of radioactivity from the water column to the deep sediment.

Collective doses and collective dose rates give the measure of the health detriment to the EC population induced by the radioactivity discharged into the Mediterranean Sea. The following simplifications were adopted in the assessment of doses:

- the radiological impact of the liquid releases due to freshwater exposure pathways was not taken into account;

- only the impact of Mediterranean Sea was assessed, although part of the radioactive wastes discharged into the Mediterranean Sea can contaminate European Atlantic waters; the levels of radioactivity in the Atlantic waters which originate in the Mediterranean Sea are negligible compared to the levels of radioactivity in the Atlantic waters due to direct discharges into the Atlantic Ocean;

- the impact on non-EC countries has not been assessed;

Collective doses and collective dose rates were calculated using the dosimetry outlined in the ICRP Publication 26 (ICRP, 1977). The term "dose" is therefore used in this report to indicate the effective dose equivalent, while the term "collective dose" indicates the collective dose commitments truncated at 500 years. The effective dose equivalent is the sum of the weighted committed dose equivalents in specific organs from the intake of activity into the body and from external irradiation. The collective dose is the total dose received by an exposed population. The integral of the collective dose rate over all time is called the collective dose commitment. When the time of integration is less than infinity, the quantity is called the truncated collective dose commitment.

9.4.1 Predictive models and associated input

9.4.1.1 The ATOMED-3 Model

In the ATOMED-3 Model the Mediterranean Sea is represented by a number of compartments which simulate the horizontal and vertical structure of the sea. Instantaneous uniform mixing within the

compartments is assumed and the movement of water masses between various sea areas is modelled using rates of transfer between adjacent compartments, which simplify the various physical, chemical and biological processes of the marine environment. The detailed structure of the model is reported in Cigna *et al.* (1994).

The horizontal structure was designed to take into account the general circulation of the Mediterranean Sea and to include observations of currents in the straits. The seasonal variability of the general circulation was not taken into account, although it is rather significant in some parts of the Mediterranean Sea. This was due to the lack of data necessary to quantify the seasonal variations of water fluxes, biological parameters and seafood catches.

The Mediterranean Sea is a deep sea for the largest part of its area and the Mediterranean dynamics is, in many places, highly baroclinic. Therefore, a vertical structure has been adopted in the dispersion model. A 100 m deep upper layer represents an annual thermocline. Two deep lower compartments represent the Eastern and Western Mediterranean Levantine intermediate and deep waters. These water masses could not be distinguished because of the lack of relevant data. Separate compartments representing the bottom boundary layer (BBL) have been included to model in detail the processes at the water column-bottom sediments interface.

For some radionuclides, their adsorption by sediments can lead to a large depletion from the water phase, due to the partitioning between the liquid phase and the suspended sediments and the subsequent removal of activity from the water column to the bottom sediments. In ATOMED, this partitioning is modelled using distribution coefficients, usually called Kd. Open ocean Kd, rather than coastal Kd were used for this work because the coastal shelf is rather narrow throughout most of the Mediterranean Sea. The values of the sediment distribution coefficients were taken from Charles *et al.* (1990).

The movement of radionuclides within the seabed following their deposition from the overlying water and the possible return of radionuclides to the water column was modelled by means of a multilayered structure of the seabed (Charles *et al.* , 1990) in which transfer rates between different layers are used to represent the physico-chemical (pore-water diffusion, sediment-water partitioning and physical burial) and biological (bioturbation) processes taking place at the interface between the water column and the bed of the sea.

As the Mediterranean Sea is a deep sea, the activity concentrations in beach sediments were not calculated from the activity concentrations predicted by the dispersion model in the top layer of the sea bed, as it is done for shallower tidal seas. Activity concentrations in beach sediments were calculated using activity concentrations in filtered seawater around the beaches and assuming an instantaneous equilibrium partitioning between the beach sand and the water. Available coastal Kd for silt were used These silt Kd values were divided by a factor of 10 to take into account the composition of sand and gravel of the Mediterranean beaches.

9.4.1.2 The Rhône river model

A simplified model for the Rhône river was implemented in addition to the ATOMED model to

improve the simulation of the dispension of liquid radioactive effluents released from the Marcoule plant .

The Rhône river model was derived from the river model described in the NRPB-CEA report (NRPB-CEA, 1979) and in the recent updating prepared by (Simmonds *et al.* (1995). This model was developed by Schaeffer (1975) and parameters for the Rhône river are given in the above references.

The model assumes that activity in water downstream of nuclear installations decreases exponentially with distance from the discharging point. The value of the exponential factor for a particular radionuclide depends on its radioactive half-life, the velocity of the river water and the extent of any sedimentation effect.

For the Marcoule plant, the river water takes only a few days to reach the sea from the point of discharge therefore the radioactive decay of the nuclides discharged was ignored. The effect of sedimentation is given by the product of the length of the river and a factor which depends on the riverine sediment distribution coefficient Kd of the radionuclide. This factor can assume the following values:

0 (m^{-1})	If Kd < 10^3 (m^3 t^{-1})
2 •10^{-6} (m^{-1})	If 10^3 (m^3 t^{-1}) < Kd <10 4 (m^3 t^{-1})
10^{-5} (m^{-1})	if Kd > 10^4 (m^3 t^{-1})

The riverine Kd used in the model were taken from NRPB-CEA (1979) and (Simmonds *et al.* , (1995). The unconsolidated river bed sediments, containing the adsorbed radionuclides, act as a fluid under the influence of the shear force exerted by the river flow and, to a lesser extent, gravity. The timescale involved in the transport of sediment from Marcoule to the Mediterranean Sea is of the order of 30 years. This slow motion leads to a considerable decrease in the activity concentrations of the short and medium lived radionuclides absorbed onto the bed sediments before they reach the sea due to radioactive decay. For discharges from the Marcoule nuclear installation a simplified conservative approach was adopted. The radioactive decay of the radionuclides absorbed onto the river bed sediments was ignored and it was assumed that these radionuclides contaminate instantaneously the upper sediment layer of the Gulf of Lions. Part of the activity in the seabed sediments is then transferred to the BBL compartments through the processes taking place at the seabed-BBL interface and thence to the Mediterranean Sea general circulation. In this approach the considerable effect of the burial of the Rhône river delta, as well as the remobilization processes due to Mistral wind pulses and the sediment redistribution near the shelf canyons have not been explicitly taken into account because of the scarce information on the long term effects of these phenomena. It is nonetheless believed that the long term effects on the water circulation in the Gulf of Lions and in the Liguro-Provençal Basin are negligible.

9.4.2 Methodology

Very short lived radionuclides (half life less than 0.1 year) were not considered in the dose assessment. For these radionuclides the accuracy of results obtained using compartmental models is not very high. The basic assumption of compartmental models is that the activity concentration of the

radionuclide is uniform in each box. For short lived radionuclides this assumption is not consistent with what happens in reality, because the half life of the radionuclides is much shorter than the time it takes the seawater to reach the boundaries of the compartments.

The implementation of the dispersion model for these short lived radionuclides would therefore lead to the prediction of activity concentrations in areas where the radionuclides are not actually present. Decay products of the discharged radionuclides were not taken into account. The residence times of the surface water compartments are too short for the decay products to contribute significantly to the doses due to the parent radionuclide.

For the undistinguishable radionuclides: 95 Zr+ 95 Nb, 106 Ru+ 106 Rh, 144 Ce+ 144 Pr and 239 +240 Pu it was assumed that total amount of 95 Zr, 106 Ru, 144 Ce, and 239 Pu were released. Dosimetric data used for 95 Zr, 106 Ru and 144 Ce included that of their short lived decay products. A list of the radionulides considered in the assessment is given in Table 9.4.2.1.

Table 9.4.2.1- Radionuclide environmental parameters (Charles et al., 1990)

Nuclide	Sediment Kd (m3/t)				Conc. Factor (m3/t)	
	Coastal	Ocean	River	Fish	Crustaceans	Molluscs
3H	1,00E+00	1,00E+00	1,00E+00	1,00E+00	1,00E+00	1,00E+00
54Mn	2,00E+05	2,00E+08	1,00E+04	4,00E+02	5,00E+02	5,00E+03
58Co	2,00E+05	1,00E+07	1,00E+03	1,00E+03	5,00E+03	5,00E+03
60Co	2,00E+05	1,00E+07	1,00E+03	1,00E+03	5,00E+03	5,00E+03
65Zn	2,00E+04	2,00E+05	1,00E+03	1,00E+03	5,00E+04	3,00E+04
90Sr	1,00E+03	2,00E+02	2,00E+03	2,00E+00	2,00E+00	1,00E+00
95Zr	1,00E+06	5,00E+05	6,00E+04	2,00E+01	2,00E+02	5,00E+03
99Tc	1,00E+02	1,00E+02	2,00E+02	3,00E+01	1,00E+03	1,00E+03
103Ru	3,00E+02	1,00E+03	1,00E+03	2,00E+00	1,00E+02	2,00E+03
106Ru	3,00E+02	1,00E+03	1,00E+03	2,00E+00	1,00E+02	2,00E+03
110Ag	1,00E+03	1,00E+04	2,00E+02	5,00E+02	5,00E+03	1,00E+04
124Sb	1,00E+03	5,00E+02	1,00E+03	4,00E+02	4,00E+02	2,00E+02
125Sb	1,00E+03	5,00E+02	1,00E+03	4,00E+02	4,00E+02	2,00E+02
133Ba	5,00E+03	1,00E+04	0,00E+00	1,00E+01	1,00E+00	2,00E+01
134Cs	3,00E+03	2,00E+03	3,00E+04	1,00E+02	3,00E+01	3,00E+01
137Cs	3,00E+03	2,00E+03	3,00E+04	1,00E+02	3,00E+01	3,00E+01
144Ce	2,00E+06	1,00E+08	1,00E+04	5,00E+01	1,00E+03	5,00E+03
239U	1,00E+03	5,00E+02	1,00E+03	1,00E+00	1,01E+02	3,00E+01
238Pu	1,00E+05	1,00E+05	1,00E+05	4,00E+01	3,00E+02	3,00E+03
239Pu	1,00E+05	1,00E+05	1,00E+05	4,00E+01	3,00E+02	3,00E+03

241 Am	2,00E+06	2,00E+06	4,00E+05	5,00E+01	5,00E+02	2,00E+04
244Cm	2,00E+06	2,00E+06	4,00E+05	5,00E+01	5,00E+02	3,00E+04

Collective doses were calculated for four exposure pathways: consumption of fish, crustaceans and molluscs and external exposure from contaminated beach sediments.

Doses due to ingestion of seafood were calculated using activity concentration in marine biota, amounts of seafood consumed in the European Community, edible fractions of each type of seafood and committed effective dose equivalents per unit intake of each radionuclide.

Radionuclide concentrations in seafood were calculated using activity concentrations in filtered seawater in the compartments representing the upper layer of the water column, predicted by ATOMED and transfer factors from seawater to seafood taken from Charles *et al.* (1990. Seafood catch statistics, in the form of annual net amounts of fish, crustaceans and molluscs available for human consumption in the European Community were used (Cigna *et al* ., 1995) It was assumed that these amounts do not vary with time. This is a reasonable assumption because the largest fraction of the dose is delivered within a few years from the last year of discharge and the assessment of the collective doses is not very sensitive to variation in ingestion rates of seafood.

Collective doses resulting from external exposure to radioactivity deposited in beach sediments were calculated using activity concentrations in beach sediments predicted by ATOMED model and Hunt's equation for external exposure to contaminated sandy beaches (Hunt, 1984). A beach occupancy rate of 75 h m^{-1} y^{-1} (hour per meter per year) was assumed in the calculations. The length of the beaches in each regional compartment was assumed to be equal to the coastline length divided by 2. This factor was calculated by Anselmi *et al.* (1979) for the Italian coasts but was assumed to be representative for the Spanish, French and Greek coasts as well. The exposure of the skin to beta radiation was considered to be negligible and therefore was not included in the calculations. Mean effective gamma energies and dose per unit intake for ingestion were taken from Charles *et al.* . (1990).

9.4.3 Results

9.4.3.1 Radiological impact of liquid effluents by radionuclide and pathway.

The Marcoule nuclear plant is by far the main contributor to the collective dose arising from man-made radioactivity released routinely into the Mediterranean Sea. The total collective dose associated with the discharges from Marcoule was 1.6 man Sv which is 82 % of the total collective dose delivered by all EC nuclear plants discharging into the Mediterranean Sea. Collective doses predicted by the model for this installation are at least an order of magnitude higher than those calculated for all the other nuclear plants. This result shows that the use of the Rhône river model only for the discharges from Marcoule does not affect the overall result of the assessment, even though doses calculated for all the other installations are probably overestimated. The main radionuclides contributors to the collective dose are 106 Ru (0.76 man Sv, 95% of which is due to ingestion of molluscs), 241 Am (0.26 man Sv, 97% is due to ingestion of molluscs), 90 Sr (0.21 man Sv, almost entirely due to ingestion of fish), 239 Pu (0.14 man Sv, ingestion of molluscs account for 89% of this

dose), 137 Cs (0.13 man Sv, almost entirely due to ingestion of fish). Other minor contributors with less than 2% of the total collective dose are 244 Cm, 134 Cs, 238 Pu and 95 Zr.

The total collective dose commitment truncated at 500 years delivered to the EC population following the discharge of liquid radioactive effluents from EC nuclear installations in the period 1980 - 1991 is 1.96 man Sv.

For all nuclides, the maximum collective dose rate was calculated during the time of release considered. Collective dose rates decrease rapidly after the end of the discharges. This result implies that the largest fraction of the collective dose is delivered within few years after the discharges occur and justifies the assumption that current parameter values, used in the assessment, will not vary in the future.

Collective dose rates reach two maxima during the period of release: 0.18 man Sv y^{-1} in 1984 (mainly due to 106 Ru) and 0.13 man Sv y^{-1} in 1987 (mainly due to 241 Am and 90 Sr). In 1992, at the end of the period of releases taken into account, the total collective dose rate is 0.079 man Sv y^{-1} ; in year 2000 it is $4 \cdot 10^{-3}$man Sv y^{-1} , while 500 year later, at the end of the integration period adopted for the calculation of the collective doses, the total collective dose is less than $3 \cdot 10^{6}$ man Sv y^{-1} (Table 9.4.3.1. and Fig. 9.4.3.1.).

Breakdowns by pathway of the collective doses and collective dose have been evaluated. Ingestion of molluscs is the dominant pathway (60% of the total collective dose). 106 Ru (62%) and to a lesser extent 241 Am (22%) and 239 Pu (10%) are the main contributors to the total collective dose due to ingestion of molluscs. Ingestion of fish (20% of the total collective dose) and external exposure to radioactivity in beach sediments (18% of the total collective dose) are also significant pathways. 90 Sr and 137 Cs are the most important contributors to the collective dose associated with the ingestion of fish. They account for 51% and 31% of the total collective dose due to this pathway; 134 Cs (4.5%) and 239 Pu (2.8%) also contribute to the collective dose due to consumption of fish. 60 Co (27%), 58 Co (27%) and 106 Ru (13%) are the most significant radionuclides contributing to the collective dose due to external irradiation from beach sediments. Minor contributors to this pathway are 95 Zr (9.6%), 54 Mn (7.8%) and 144 Ce (5.7%). Ingestion of crustaceans (less than 2% of the total collective dose) is negligible.

The variation with time of the collective dose rates due to ingestion of molluscs is correlated to the variation of the releases. Mediterranean molluscs consumed by the EC population are, in fact, mainly caught in the Adriatic Sea, in the Liguro-Provençal Basin and the Gulf of Lions into which discharges from all the nuclear plants are released. Collective dose rates due to external exposure to radioactivity in beach sediment decrease rapidly with time. This is due to the relatively short half lives of the main contributing radionuclides for this pathway.

Radionuclide	FISH	CRUSTACEANS	MOLLUSCS	BEACH
Am241	6,30E-03	2,40E-03	2,50E-01	2,90E-04
Ce144	4,00E-04	2,80E-04	3,80E-03	5,90E-03
Cm244	4,30E-04	1,60E-04	2,50E-02	3,40E-06

Co58	9,60E-06	1,70E-06	4,70E-06	7,30E-05
Co60	2,00E-03	3,50E-04	9,60E-04	5,30E-03
Cs134	1,70E-02	2,00E-04	5,20E-04	1,50E-03
Cs137	1,20E-01	1,70E-03	4,80E-03	4,80E-03
H3	2,60E-04	1,20E-05	3,20E-05	0
Mn54	3,30E-04	1,40E-05	4,00E-04	7,20E-03
Pu238	1,70E-03	6,10E-04	1,70E-02	4,90E-07
Pu239	1,10E-02	4,10E-03	1,20E-01	7,50E-07
Ru103	1,10E-06	2,00E-06	1,10E-04	4,00E-05
Ru106	7,30E-03	1,40E-02	7,20E-01	1,40E-02
Sb125	3,10E-03	1,30E-04	1,60E-04	1,60E-04
Sr90	2,00E-01	3,00E-03	8,20E-03	2,90E-08
U238	7,20E-05	4,00E-05	3,60E-04	9,20E-07
Zr 95	4,90E-06	1,70E-06	1,20E-04	1,00E-02

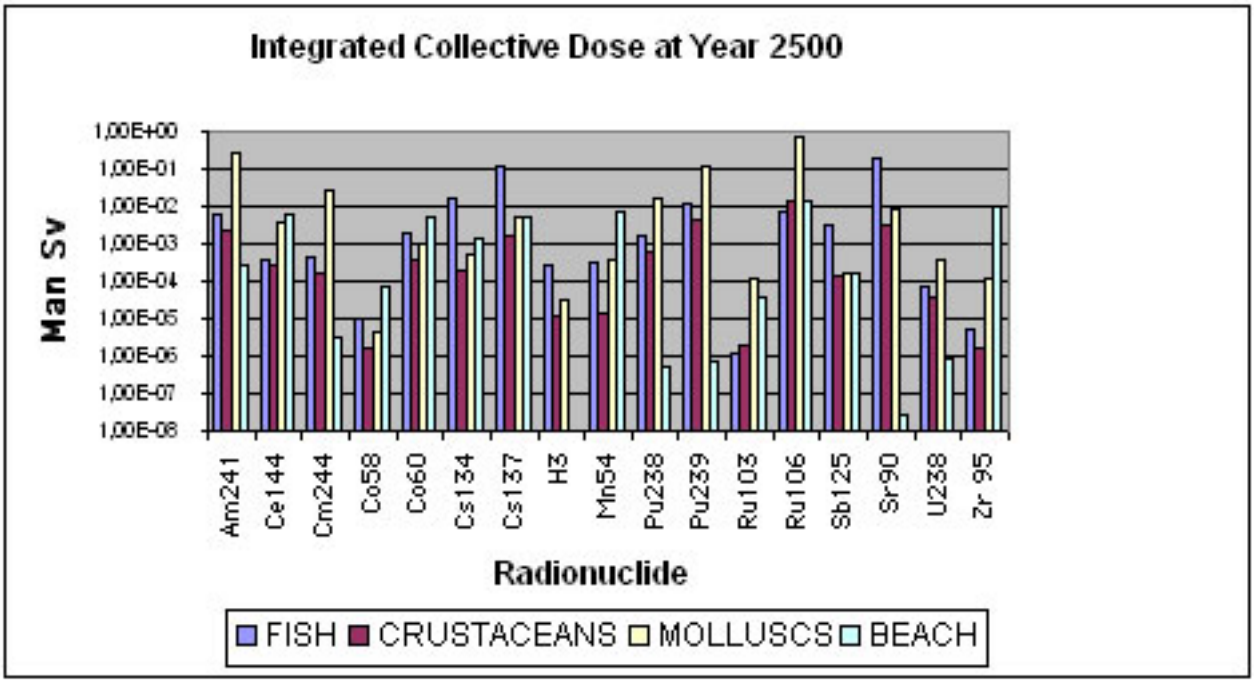

Fig. 9.4.3.1 - European Community integrated collective dose from Marcoule discharges by exposure pathway (Man Sv).

9.4.3.2 Contribution of EC member states to the collective dose and collective dose rates

The highest collective dose rates were calculated for France in 1982 and 1984 (0.083 man Sv y^{-1}), for Italy in 1987 (0.05 man Sv y^{-1}) and for Spain in the same year (0.046 man Sv y^{-1} . The highest collective doses are delivered to the populations of the Mediterranean countries except Greece (France 0.78 man Sv, Italy 0.6 man Sv and Spain 0.46 man Sv). The populations of the EC countries which import a great quantity of seafood from the Mediterranean region and Greece are exposed to collective doses of the order of few hundredth of man Sv (Greece 0.02 man Sv, Germany 0.02 man Sv and Portugal 0.017 man Sv). Collective doses delivered to the populations of all the other EC

nations contribute less than 0.5% to the total collective dose (Belgium and Luxembourg $9.4 \cdot 10^{-3}$ man Sv, the Netherlands $6.5 \cdot 10^{-3}$ man Sv, United Kingdom³.5 $\cdot 10^{-3}$ man Sv, Denmark $8.3 \cdot 10^{-4}$ man Sv and Ireland $2.2 \cdot 10^{-5}$ man Sv).

The lower doses received by the Greek population compared to the doses delivered to other Mediterranean countries can be explained by the fact that the Greek annual seafood catches are smaller than those of the other countries and that seafood consumed by the population of Greece is mostly caught in the Aegean Sea, which is far from the release sites. Collective doses are also correlated to the population size and the Greek population is smaller than the populations of the other Mediterranean EC countries.

Table 9.4.3.2. - European Community collective dose rate by compartments (Man Sv y^{-1})

YEAR	ALBORAN SEA	ALGERIAN BASIN	LIGURO-PROVENCAL BASIN	GULF OF LIONS
1981	1,10E-06	8,70E-04	3,40E-02	7,80E-02
1982	3,80E-06	1,30E-03	4,80E-02	1,00E-01
1983	6,60E-06	1,40E-03	5,00E-02	7,90E-02
1984	9,20E-06	1,50E-03	6,10E-02	1,00E-01
1985	1,10E-05	1,20E-03	4,30E-02	6,20E-02
1986	1,30E-05	1,40E-03	5,40E-02	8,60E-02
1987	1,50E-05	1,60E-03	6,10E-02	9,10E-02
1988	1,80E-05	1,50E-03	5,70E-02	7,90E-02
1989	2,00E-05	1,60E-03	5,90E-02	8,30E-02
1990	2,20E-05	1,60E-03	5,80E-02	8,30E-02
1991	2,30E-05	1,40E-03	5,30E-02	7,40E-02
1992	2,30E-05	9,30E-04	2,90E-02	3,20E-02
1993	2,20E-05	3,90E-04	7,70E-03	2,20E-03
1994	2,00E-05	1,90E-04	3,20E-03	8,80E-04
1995	1,80E-05	1,20E-04	1,90E-03	5,10E-04
1996	1,70E-05	9,40E-05	1,40E-03	3,70E-04
1997	1,50E-05	8,10E-05	1,20E-03	3,10E-04
1998	1,40E-05	7,20E-05	1,00E-03	2,80E-04
1999	1,30E-05	6,60E-05	9,40E-04	2,50E-04
2000	1,20E-05	6,10E-05	8,60E-04	2,30E-04
2050	1,50E-06	4,70E-06	6,60E-05	1,90E-05
2100	5,20E-07	1,10E-06	1,60E-05	4,80E-06
2200	1,20E-07	1,50E-07	2,60E-06	8,80E-07
2300	5,50E-08	5,00E-08	8,50E-07	3,40E-07
2400	3,80E-08	3,00E-08	5,10E-07	2,40E-07
2500	3,00E-08	2,30E-08	3,90E-07	1,90E-07

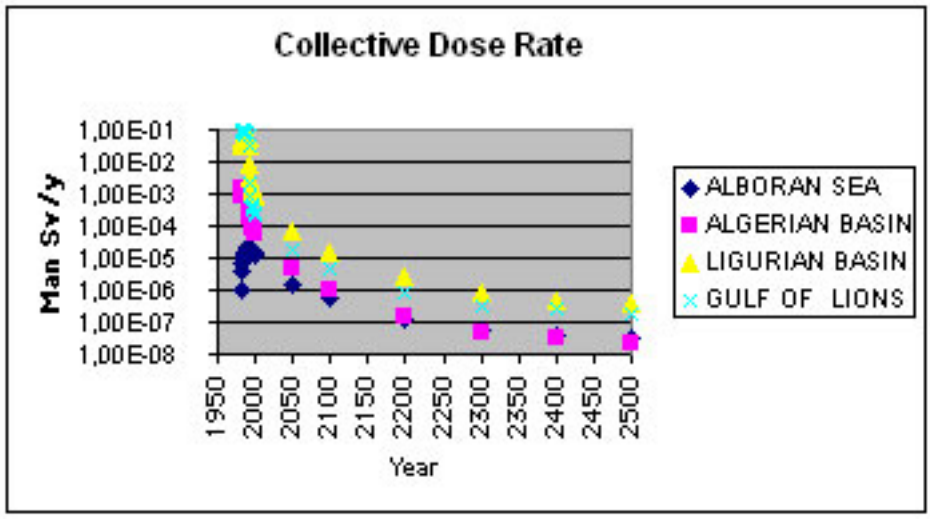

Fig. 9.4.3.2. - Collective dose rate by compartments (Man Sv y^{-1})

9.4.3.3 Contribution of different geographical areas to the total collective dose

The contribution to the collective dose and collective dose rates delivered to the EC population from individual surface seawater compartments was calculated and the results referring to the compartments close to the mouth of the Rhône river are reported in Table 9.4.3.2. and Fig. 9.4.3.2. The most important contribution to the total collective dose (49%) is due to the Gulf of Lions, into which liquid discharges from the French nuclear plants are released. The Liguro-Provençal Basin, which communicates directly with the Gulf of Lions and receives liquid discharges from the Spanish installations accounts for 32% of the total collective dose. The results of collective dose rates show that the predominant influence of the Gulf of Lions decreases with time.

9.4.3.4 Comparison between observations and predictions of activity concentrations of 137 Cs

A comparison between activity concentrations of 137 Cs measured in the Mediterranean Sea and activity concentrations of the same nuclide calculated using the marine dispersion model was carried out for MARINA-MED Project (Cigna *et al.*, 1994). This comparison cannot be considered a real validation exercise but gives an indication of the correctness of the marine dispersion model. Only the Gulf of Lions and the Liguro-Provençal Basin were considered in the exercise, because these compartments are the closest to the discharge point. Predicted activity concentrations in other parts of the Mediterranean Sea would be too small compared to the contribution from Chernobyl and from fallout for the comparison to have any validity.

Observed activity concentrations of 137 Cs in the surface waters in the years 1981 to 1988 are in the range 2 Bq m^{-3} to 5 Bq m^{-3} for the Gulf of Lions and in the range 5 Bq m^{-3} to 6 Bq m^{-3} for the Liguro-Provençal Basin. Activity concentrations of 137 Cs in the surface water predicted by the ATOMED model for the discharges from Marcoule vary from 0.025 Bq m^{-3} (1992) to 0.14 Bq m^{-3} (1983) for the Gulf of Lions and from 0.01 Bq m^{-3} (1992) to 0.039 Bq m^{-3} (1983) for the Liguro-Provençal Basin. Measured activity concentrations of 137 Cs in the sediments are between 15 Bq kg^{-1} and 20 Bq kg^{-1} for the Gulf of Lions (for the period 1986 to 1990) and between 4 Bq kg^{-1} and 15 Bq kg^{-1} for the Liguro-Provençal Basin (for the period 1983 to 1990). The highest activity

concentrations of 137 Cs in sediments calculated for discharges from Marcoule were 35 Bq kg^{-1} (1992) for the Gulf of Lions and $4.9 \cdot 10^{-5}$ Bq kg^{-1} (1992) for the Western Mediterranean Basin. The good agreement between observations and predictions for the sediments of the Gulf of Lions may be a coincidence due to the use of a simplified Rhône river model, but these results show that the model does not generally overestimate activity concentrations in the Mediterranean Sea.

9.5 Impact on population health

• 9.5.1 Impact on a critical group

In 1996 IPSN (Institut de Protection et de Sûreté Nucléaire) published a report (DPHD/96-01) on the impacts of the radioactive releases from the nuclear site of MARCOULE on a critical group of population (inhabitants of Codolet).

In 1997, two regional authorities (CLI, DRIRE) gave a mandate to the company SENES Consultants Ltd in order to make a qualitative evaluation of the IPSN report entitled " *Contribution méthodologique à l'évaluation de l'impact dosimétrique du fonctionnement du site de Marcoule"*.

It is outside the scope of the present report to analyse this qualitative evaluation but SENES estimates ,as a perspective, that the increase of the dose to the Codolet inhabitants is about 60 to 70 µSv a^{-1} with a peak value of about 170 µSv a^{-1} .In the IPSN report these values are respectively about 5 to 23 µSv a^{-1} (peak value 41 µSv a^{-1}).

It is also underlined that the contribution of C-14 as well as those of the transuranic elements and noble gases were not taken into account .because of the lack of information.

9.5.2. Epidemiological study

A survey was performed by the " laboratoire de Santé Publique et d'Epidémiologie de l'Université de Montpellier 1" in 1996 on the occurrence of acute leukaemias, lymphomes and thyroid cancers observed between 1985 and 1995 in children 0-14 years old and living at less than 35 km of the reprocessing plant.

The results shown no excess of leukaemias or lymphomas among this young population group which seems exposed to the same risk as other western European populations

9.5.3. Impact on Mediterranean basin populations

The overall impact of the releases from the EC nuclear installations into the Mediterranean Sea in the period 1980-1991 was assessed in the MARINA-MED Project (Cigna *et al.*, 1994) by calculating the collective dose truncated at 500 years and collective dose rates to the EC population. A simplified version of the Rhône river model was implemented only for discharges from Marcoule. The impact of liquid effluents discharged into the Mediterranean Sea by EC nuclear plants was found to be close to that due to 137 Cs present in the same sea as a result of nuclear bomb fallout and the Chernobyl

accident. The total collective dose predicted by the Mediterranean dispersion model, ATOMED, was 1.96 man Sv, while the maximum collective dose rate was calculated to be around 0.18 man Sv y⁻¹ . The contribution of the nuclear bomb fallout and the Chernobyl accident to the collective dose was estimated to be 3.7 man Sv.

The main contributing plant to the collective dose was found to be the Marcoule reprocessing plant (95% of the total collective dose). Bugey (4.5%) is the next most important contributor. 106 Ru is the main contributing radionuclide (39% of the total collective dose), while the predominant pathway was found to be ingestion of molluscs, which accounts for 60% of the total collective dose. Finally, the Gulf of Lions is the main contributing sea area to the total collective dose (49%).

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ENQUETE EPIDEMIOLOGIQUE D'INCIDENCE DES HEMOPATHIES

MALIGNES & CANCERS THYROÏDIENS CHEZ LES ENFANTS DE

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Chap.10 SELLAFIELD

Sect.10.1;10.3:Luis León Vintró, Peter I. Mitchell and Kilian J. Smith
Sect.10.2: René Kirchmann
Sect.10.4: Michael Savkin
Sect.10.5: Fourth COMARE Rpt (chap.9)

10.1 Generalities

The site at Sellafield (formerly known as Windscale), located on the Western coast of England, represents the largest nuclear complex in the United Kingdom. The site, containing a number of nuclear reactors, storage plants, and spent nuclear fuel reprocessing facilities, has been operational since 1951 and was, at first, used for the production and reprocessing of plutonium for military purposes. From the late 1950's, operations have been dominated by reprocessing of fuel from commercial nuclear power programmes. As a result of these operations, authorised discharges of radioactive effluents from the site to the environment have routinely taken place, either in the form of low-level liquid waste discharges to the north-eastern Irish Sea or as aerial discharges via a number of individual discharge points.

From the beginning of the operations at the Sellafield site, the Ministry of Agriculture, Fisheries and Food (MAFF) Directorate of Fisheries Research Laboratory in the U.K., along with other Government Departments and agencies, has conducted extensive monitoring programmes throughout the United Kingdom, the Irish Sea and other coastal waters of the British Isles with the twin objectives of verifying the satisfactory control of liquid and atmospheric discharges and ensuring that the resulting public radiation exposure is within nationally-accepted limits. This monitoring is independent of similar programmes carried out by nuclear site operators as a condition of their authorisations to discharge radioactive wastes. In the aquatic environment, a wide range of seafood and indicator materials are regularly assayed for radionuclide contents, and areas of known or suspected contamination and where public occupation occurs monitored for external dosimetry purposes. The types of material sampled and the locations from which samples are taken are chosen to be representative of the main exposure pathways, as determined from local habits surveys and other sources.

In the terrestrial environment, a wide range of foodstuffs are sampled, together with indicator materials such as grass and soil. Samples are obtained from different locations around the site in order to encompass the possible variations in activity levels due to the influence of meteorological conditions on the dispersal of gaseous effluents. The results of these programmes have been published in a series of comprehensive annual reports titled ' *Aquatic Environment Monitoring Report: Radioactivity in Surface and Coastal Waters of the British Isles* ' (AEMR, 1967-95) and ' *Terrestrial Radioactivity Monitoring Programme Report: Radioactivity in Food and Agricultural Products in England and Wales* ' (TRAMP, 1989-95), combined since 1995 in a single report titled ' *Radioactivity in Food and the Environment* ' (RIFE, 1996-2000).

Similar monitoring programmes have also been conducted by the statutory authorities charged with the responsibility to monitor radioactive levels in the marine and terrestrial environments in other countries affected by the Sellafield discharges. In the Republic of Ireland, the authority charged with this task is the Radiological Protection Institute of Ireland, who publishes regular reports on their results (Cunningham and O'Grady, 1986; Cunningham *et al.* , 1988; O'Grady and Currivan, 1989; O'Grady *et al.* , 1991; McGarry *et al.* , 1994; Pollard *et al.* , 1996; Long *et al.* , 1998; Ryan *et al.* , 2000).

The results of these monitoring programmes, together with research on the environmental behaviour of important radionuclides, their budgets in environmental compartments and their residence times in particular zones, have enabled the statutory authorities to assess the impact of effluent discharges from this site, establish radionuclide pathways to man and determine realistic dose commitments to critical groups. In this chapter, a review of the existing literature on radiological exposure pathways to man resulting from the Sellafield discharges is presented, with emphasis on those pathways that, over the years, have been identified as the most important routes of exposure of the general population.

10.2 Source term (R.Kirchmann)

The site at Sellafield (formerly Windscale) on the west coast of Cumbria comprises the largest nuclear complex in the UK, associated since the inception of the UK nuclear program with spent fuel reprocessing, associated waste management operations and nuclear electricity operation.

Discharges of radioactive effluents from the site to the environment have taken place since commencement of operations at the site in 1951.Throughout the history of the site, the operators have conducted monitoring of the main effluents streams as well as

monitoring of environmental materials and foodstuffs to establish the impact of discharges on members of the public.

The Sellafield site has evolved in size and complexity over the period since operations began. Chronologies of radioactive discharges from the site have previously been compiled for the Windscale Inquiry and for the studies undertaken by the NRPB on behalf of the Independent Advisory Group chaired by Sir Douglas Black in conjunction with the investigation of childhood leukemia in the nearby village of Seascale (Stather et al 1984).After publication of this study it became apparent that the discharge chronology was incomplete. Subsequently, an extensive historic research and review of archived documentation was undertaken by BNFL, together with technical assessments of some plant operations and environmental monitoring data, in order to assemble a more reliable chronology of discharge data. This was provided to NRPB for a reassessment of doses to the population of Seascale (Stather et al 1986).

10.2.1 Operations at Sellafield

During the Second World War, the Sellafield site had been used as a munitions factory .Construction work on nuclear facilities started in 1947 with construction of two air cooled reactors **,** known as the Windscale Piles, which were used for irradiation of uranium and the subsequent production of plutonium **.** Pile I went critical in October 1950 reaching normal operating power in April 1951 ; Pile II went critical in June 1951. Both Piles were closed following a fire in Pile I in October 1957.Prior to the closure of the Windscale Piles, construction had started on the Magnox reactors at Calder Hall. The first of these reactors became operational in 1956 and all four reactors are still in operation.

Irradiated fuel discharged from the Piles was stored in an open water filled pond and was subsequently reprocessed in the Primary Separation Plant (B204) which went fully active in February 1952. The first Plutonium Purification Plant (B209S) was commissioned in February 1952 and was closed in September 1954.Operation of the second Plutonium Purification Plant (B203) began in October 1954. The separation and plutonium purification functions were transferred to a new integrated separation and purification plant (B205) in 1964 which has continued in operation until the present day (1995).

A prototype Advanced Gas Cooled Reactor, constructed on site, reached full power in 1963 and was operated until 1981.The original reprocessing plant (B204) was modified and a new facility for the shearing and dissolution of oxide fuel was constructed within this building and brought into operation between 1969 and 1973.Operation of the plant ceased following an incident involving the escape of a ruthenium-106 aerosol from a shielded cell into the operating area of the plant.

Oxide fuel from both gas cooled and water cooled reactors has been stored in a number of specially constructed storage ponds pending the start up in 1994 of the Thermal Oxide Reprocessing Plant (THORP). This new plant has been designed to very stringent effluent standards taking advantage of new technology, so as to minimize its contribution to discharges of the more radiologically important isotopes.

In the 1980s, BNFL has undertaken a substantial program of waste treatment plant construction at Sellafield. Most notable, from the point of view of discharges to the environment, has been the Company's achievement in reducing radioactivity in liquid discharges to the Irish Sea by the introduction of a number of effluent treatment plants costing about £750 million : the Site Ion Exchange Effluent Plant (SIXEP) and Salt Evaporato **r** , which both commenced operation in 1985 ; and the Enhanced Actinide Removal Plant (EARP) and Segregated Effluent Treatment Plant (SETP) which commenced active commissioning in 1994 (EARP in March and SETP in July). As a consequence the discharges of the principal radionuclides to the Irish Sea from Sellafield are since 1995 only 1% of the peak levels in the 1970s. Nevertheless it must underlined that, as a result of the commissioning of EARP, discharges of technetium-99 and strontium-90 both increased in 1994. Discharges of carbon-14 to sea also increased, due to a diversion of carbon-14 from the aerial to the liquid effluent stream, with a consequent reduction in the amount of carbon-14 discharged to atmosphere.

10.2.2. Liquid effluents

Low level liquid effluents arising from a number of sources on the Sellafield site are discharged to the Irish Sea via pipelines which extend about 2.5 km from the water mark. The first two such pipelines were laid in 1950.

10.2.2.1 **Sources of liquid effluent**

The major liquid effluent streams comprise process liquors from reprocessing operations and purge water used in the fuel storage ponds.The majority of the extracted fission products are concentrated into an aqueous acid effluent stream for evaporation and storage. This material is now being converted into vitrified form in the Waste Vitrification Plant.

Subsequent extraction stages involve separation of plutonium from uranium, and further purification of these streams, giving rise to medium active liquors , containing, in particular, Ru-106 and a smaller proportion of actinides. During the operation of the first reprocessing plant (B204), medium active liquors were subject to chemical treatment and delay storage (to allow Ru-106 to decay) prior to discharge to sea. These liquors were the most important source of radioactive discharges to sea in that period, with the Ru-106 content being a significant fraction of the overall activity discharged.

With the commencement of the second reprocessing plant (B205) in 1964, facilities for the concentration of medium active liquor by evaporation were introduced permitting longer delay storage of concentrates prior to discharge. The discharge of medium active concentrate to sea was terminated in 1980 ; the EARP treats after 1994 the backing of stored concentrates together with continuous arising of these and other reprocessing effluents.

The other major effluent stream, fuel storage pond water , was discharged to sea without treatment until the late 1970s. During the early to mid 1970s, the radioactivity content of this stream increased significantly due to the increased storage time and consequent corrosion of Magnox fuel. Temporary measures for removal of radioactivity from pond purge water were introduced in the late 1970s pending operation from May 1985 of the site ion exchange effluent plant (SIXEP), whereby pond water is continually purged and then treated by passing through an array of sand filters and clinoptilolite ion exchangers. These measures proved successful in reducing discharges of Sr-90, Cs-134 and 137Cs.

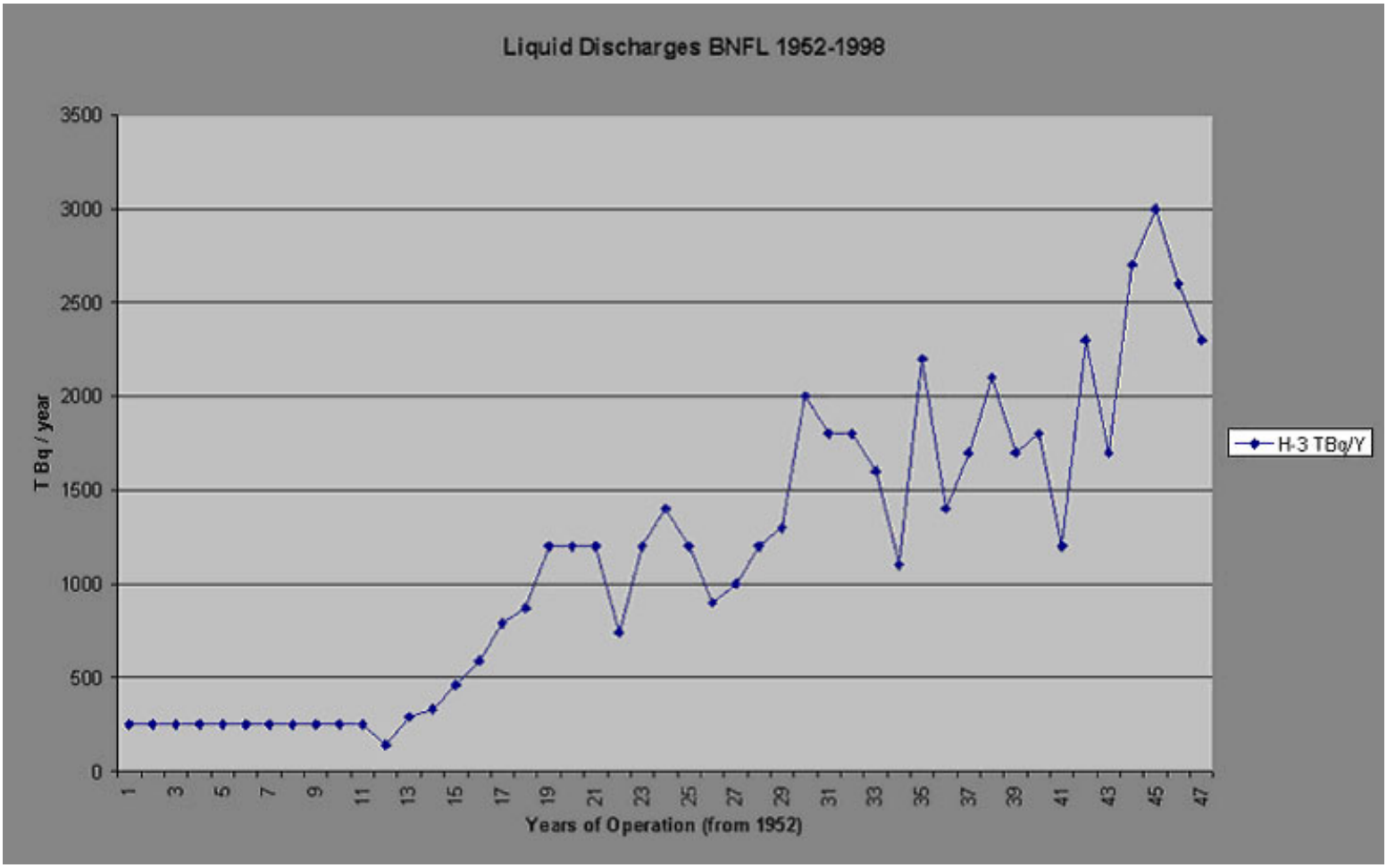
Discharges from Pu and Am during the early to mid 1970's due to increased throughputs and processing of residues. Discharges of these nuclides decreased following operation of a floculation precipitation treatment facility from the mid 1970's, the termination of discharges concentrates to sea in 1980 , and the commissioning of the Salt Evaporator.

Another stream of liquid effluent, operational since 1988, is the pond water from the storage of oxide fuel in the THORP Receipt and Storage area. This stream is monitored and discharge directly to sea ; it contains only a small proportion of the overall activity currently discharged to sea from the site.

In addition to the above there have been a number of other waste streams for example, from surface drainage water, laundry effluent and sewage, which although high in liquid volume have been minor streams in terms of radioactivity content.

10.2.2.2. Chronology of liquid discharges

Records of discharges of radioactivity to sea have been made since 1952.The analytical schedule became progressively more comprehensive with time and improved technology, gamma spectrometric methods being introduced in 1962. Determination of additional specific nuclides in liquid effluent were made : 241Am from 1968 ; 241Pu from 1972 ; and 3H from 1963.



In 1978, BNFL expanded the analytical schedule significantly to include a number of specific nuclides, from S-35 to Cm-243/244. In that year, separate determination of the plutonium isotopes 238Pu and 239/240Pu began (previously these nuclides had been included in the plutonium alpha determinations).

Uncertainties in the liquid discharge chronology arise in two areas :

· First due to possible systematic bias in sampling of liquid effluent streams

· Second due to incomplete analysis of all component nuclides in liquid discharges during the earlier years.

Investigations shown that any major systematic bias which would markedly affect the validity of the recorded discharge chronology could not be identified. It was concluded that it was unnecessary to apply any correction to the recorded data.

Confirmation in the liquid discharge chronology:

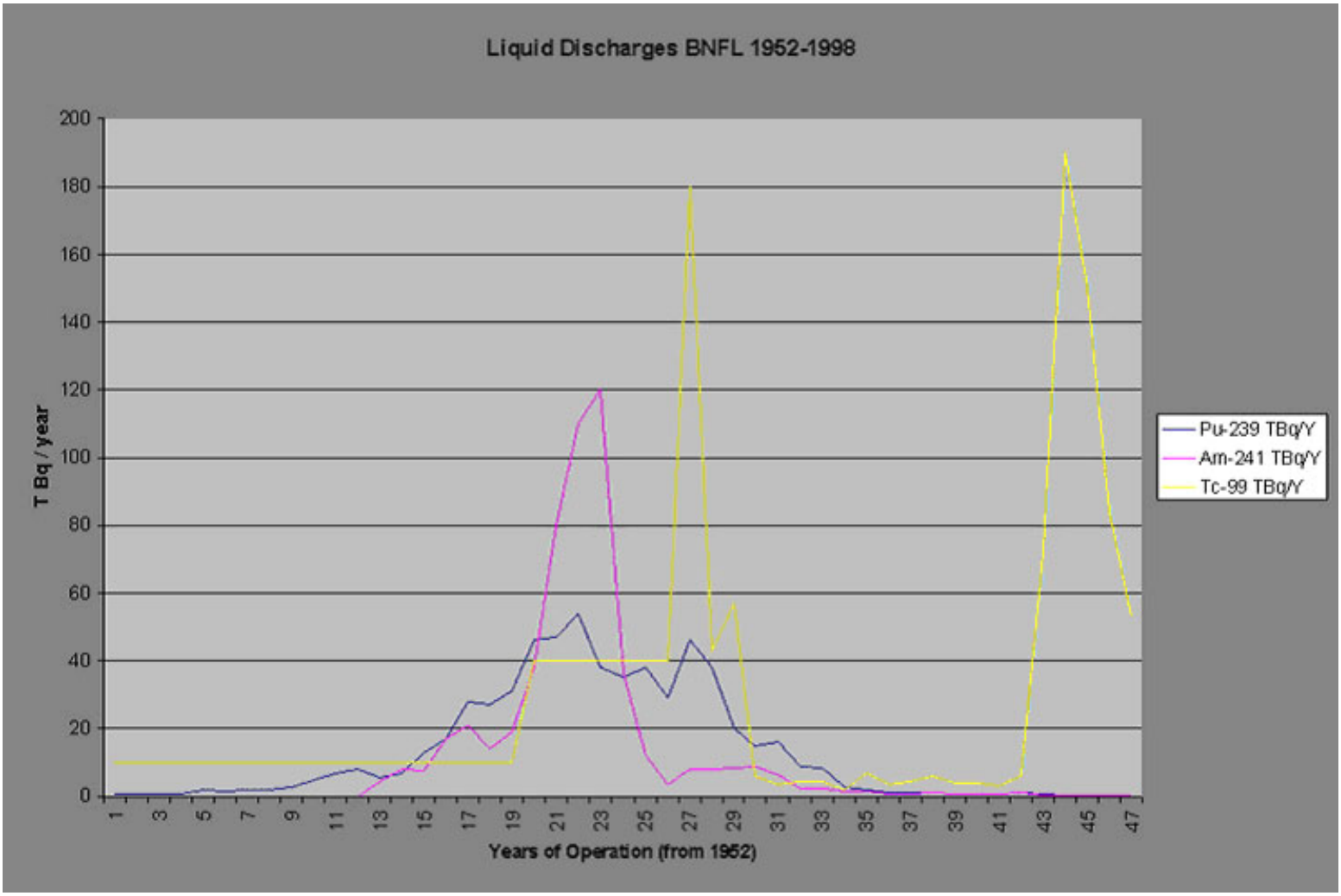
In principle, environmental measurements should permit the confirmation of the discharge chronology if they can be related to discharge levels by means of a suitable environmental model. The Sellafield Environmental Assessment Model (SEAM) was used to correlate the discharge rates with available environmental data. There are two main sources of environmental monitoring data for the Sellafield area :

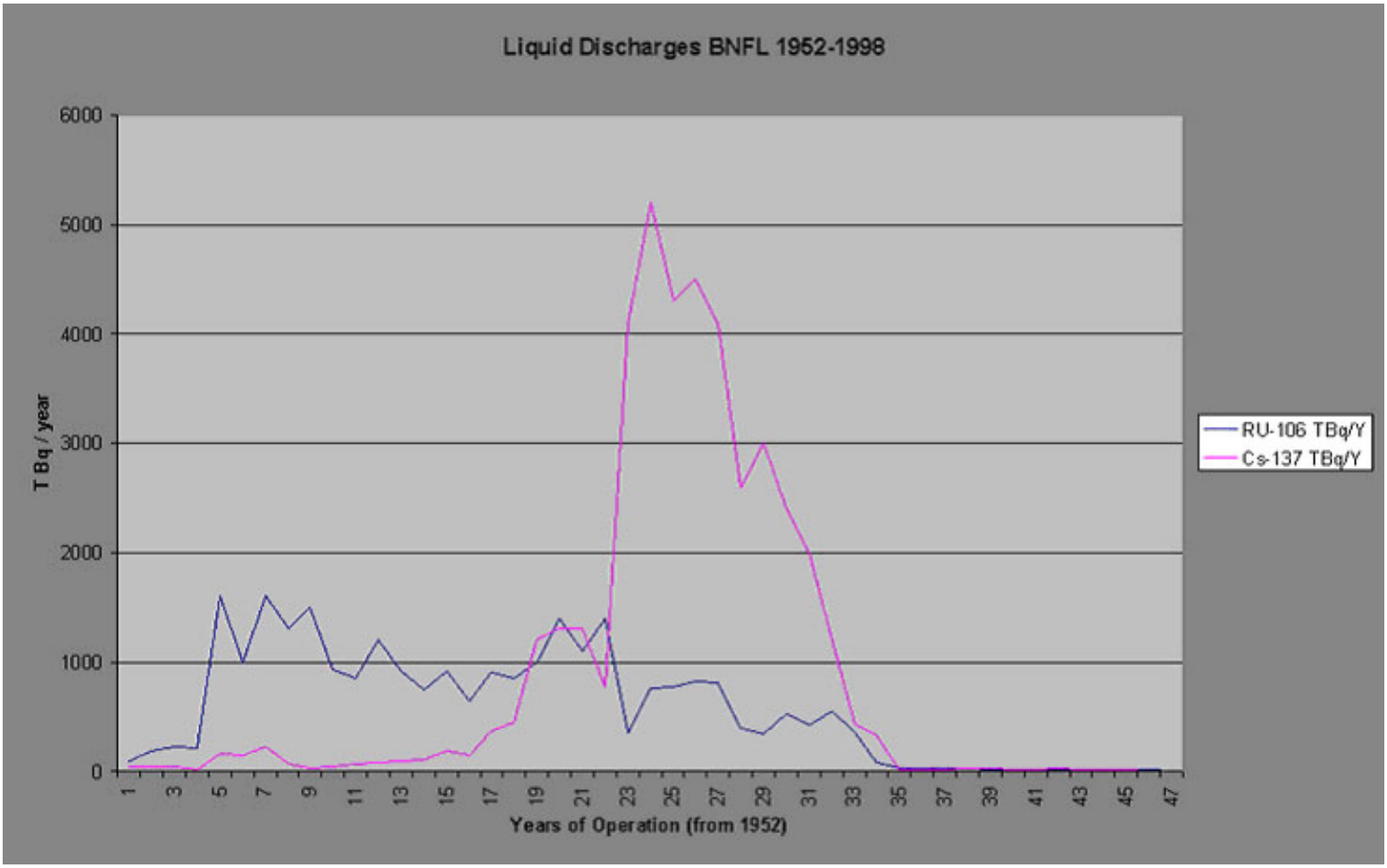
· The routine program operated by BNFL (BNFL 1971-1992) and previously UKAEA (UKAEA unpublished) ;

· The program operated by MAFF (MAFF 1967-1992).

In addition, analysis of sediment cores obtained from a disused dock basin in Maryport Harbour (about 40 km north of Sellafield) contains a chronology of radionuclide concentrations in suspended sediment extending back to the 1950's (Kershaw et al 1990). Concentrations of 239/240Pu and 241Am in suspended sediments were calculated using the SEAM model, assuming distribution coefficient (Kd) values of 3×10^5 and 2×10^6 , respectively. The results gave confidence in the 239/240Pu and 241Am discharge chronologies, again in term of both absolute concentrations in sediments and their temporal pattern .In particular the quantity of 238Pu discharged during the period 1959-1977 was estimated at 94+/- 8 TBq which represents 18% of the Pu(**a**) discharges

reported during this period.





10.2.3. Atmospheric discharges

Before commencement of operations, consideration was given to the significant sources of atmospheric effluent. Studies on stack dispersion characteristics were conducted using models of chimneys in wind tunnel experiments.

The Pile chimneys were identified as giving rise, potentially, to the greatest exposure to the members of the public ; mainly due to external dose from argon-41 discharges formed by neutron activation of naturally occurring argon-40 in the cooling air . Consideration was also given to likely discharges of radioactive species arising in the Piles from surface contamination of fuel cartridges and burst cartridges. Three detection systems were present in the Piles to give early warning of a burst' cartridge occurring in the reactor cores.

Assessment of arising of specific radionuclides from the B204 Primary Separation Plant was made. Gamma radiation monitoring equipment was installed on a number of inputs to the stack before the end of 1952.

Thus, the pathway receiving most attention in the early years for doses to members of public was external irradiation from the effluent plume, with maximum dose rate predicted (from Gaussian plume type models) at about 5 km downwind.

10.2.3.1. Sources of atmospheric discharges

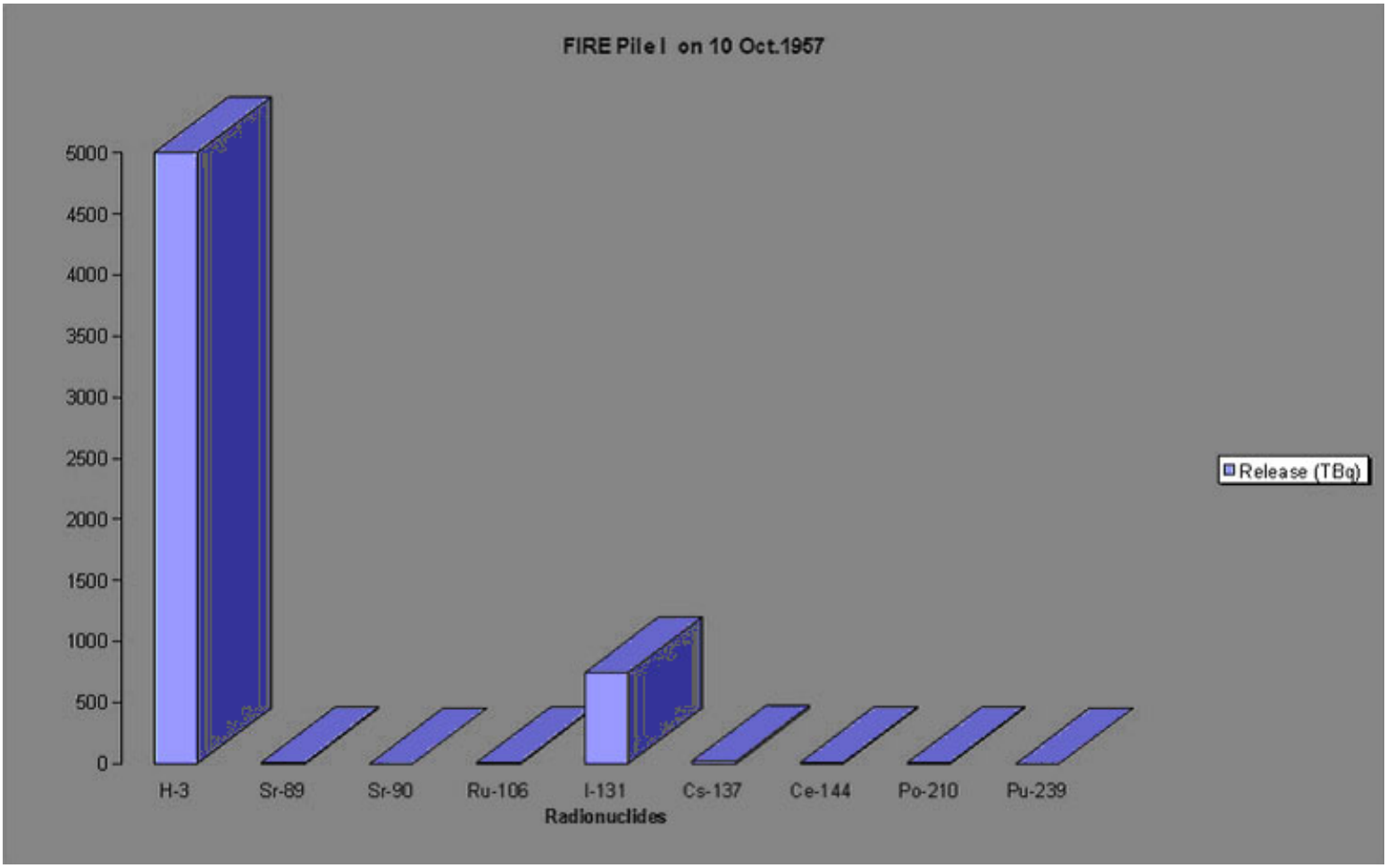
Radioactive effluents are discharged from the Site *via a number of individual discharge points with different release heights.* During the period of operation of the site, the most significant release sources have been associated with plants and processes described above. It must be underlined that a major release of iodine and volatile fission products occurred during the fire in Pile I on 10 October 1957, as shown in table 10.2.1.

Table 10.2.1.

Nuclide Release (Bq)

3H	5.00 E +15
Sr-89	3.00 E+12
Sr-90	7.40 E+10
Ru-106	3.00 E+12
131 I	7.40 E+14
137Cs	2.20 E+13
Ce-144	3.00 E+12
Po-210	8.80 E+12
Pu-239	1.60 E+09

(Crick and Linsley 1981/83, Stather et al 1984)



10.2.3.2 Chronology of atmospheric discharges

Based on information provided by BNFL, Stather et al (1986) gave a chronology of discharges for high and low release heights, nominally at 100 m and ground level respectively, attributable to operations associated with reprocessing and the Windscale Piles, and fuel storage in the ponds. Subsequent to the Stather's publication, further studies have been carried out in relation to aerial effluents from Sellafield which also require the discharge chronology to be reconsidered

As well as routine releases, the chronology included other releases where these were considered significant (including the uranium oxide release) ; an exception being the discharge from the 1957 fire (see table 10.2.1).

Uncertainties in the atmospheric discharge chronology.

Inevitably, there is some uncertainty in applying SEFS (Sampling Efficiency Factors) determined during 1987-88 to stack monitoring results measured many years ago. However, the most important sampling systems examined have retained the same essential features.

· Discharges of plutonium from the most significant stack (B204) operating during the pre-1964 period, have now been established from stack monitoring data, moreover, the assumption that all alpha activity determined on filter papers during this period is attributed to Pu represents a degree of conservatism since radon progeny (and uranium) may contribute materially to the measured alpha counts.

· For fission products, the agreement to within a factor of 2 to 3 between the measured stack results and those estimated for the pre-1964 period gives reassurance.

· Ar-41 discharges from the Windscale Piles contributed significantly to dose to local residents during the 1950s.The calculation of Ar-41 discharges is dependent on the following parameters : the neutron flux within the reactor cores; the neutron activation cross-section of Ar-40 ; and the air void within the pile reactor cores. From this review, it is concluded that the uncertainty in the calculated discharge of Ar-41 from the piles is of the order of + - 25%.

• *Confirmation of the atmospheric discharge chronology*

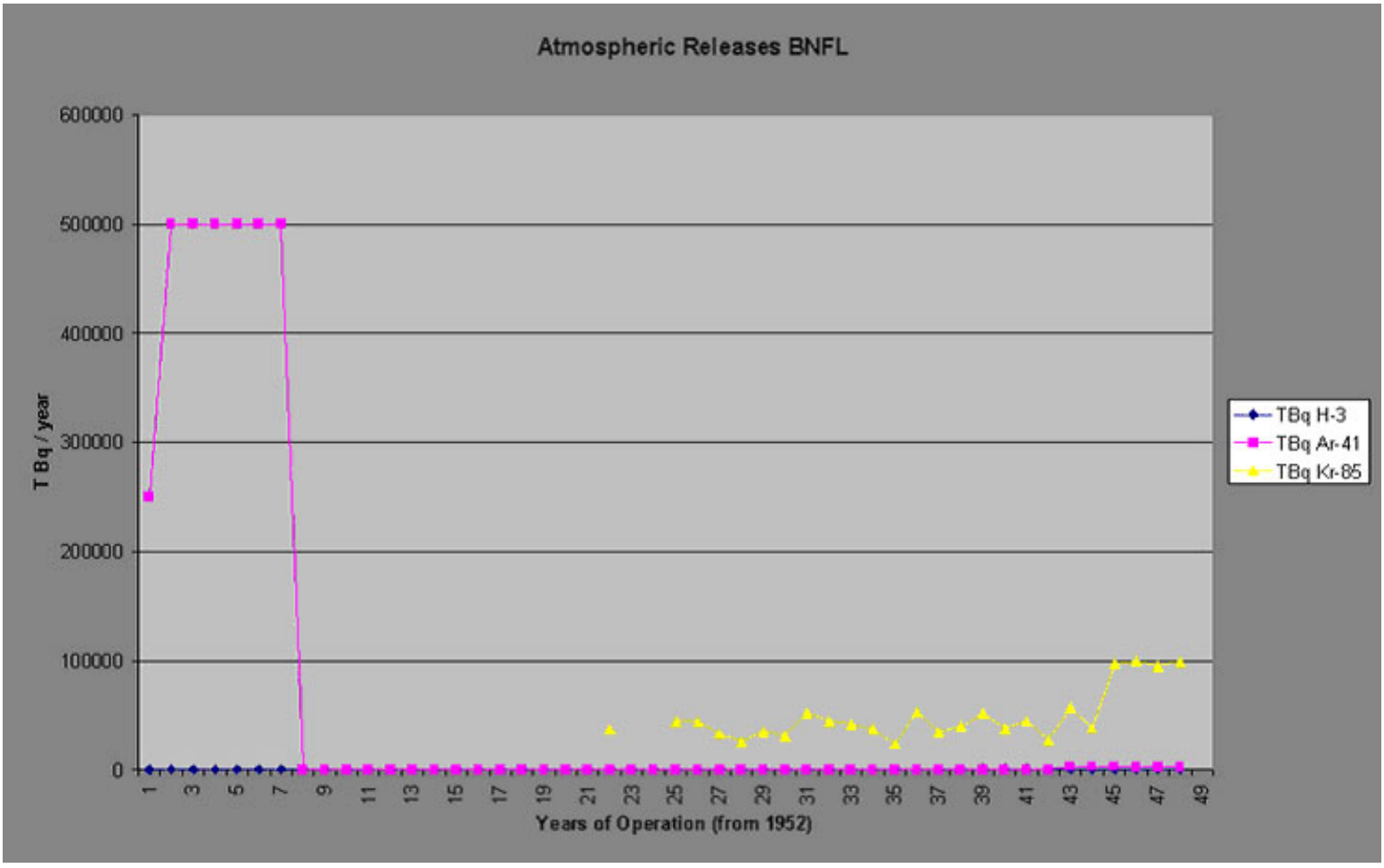
As for liquid discharges, it is possible to confirm the major features of the atmospheric discharge chronology from environmental measurements by use of an environmental model.

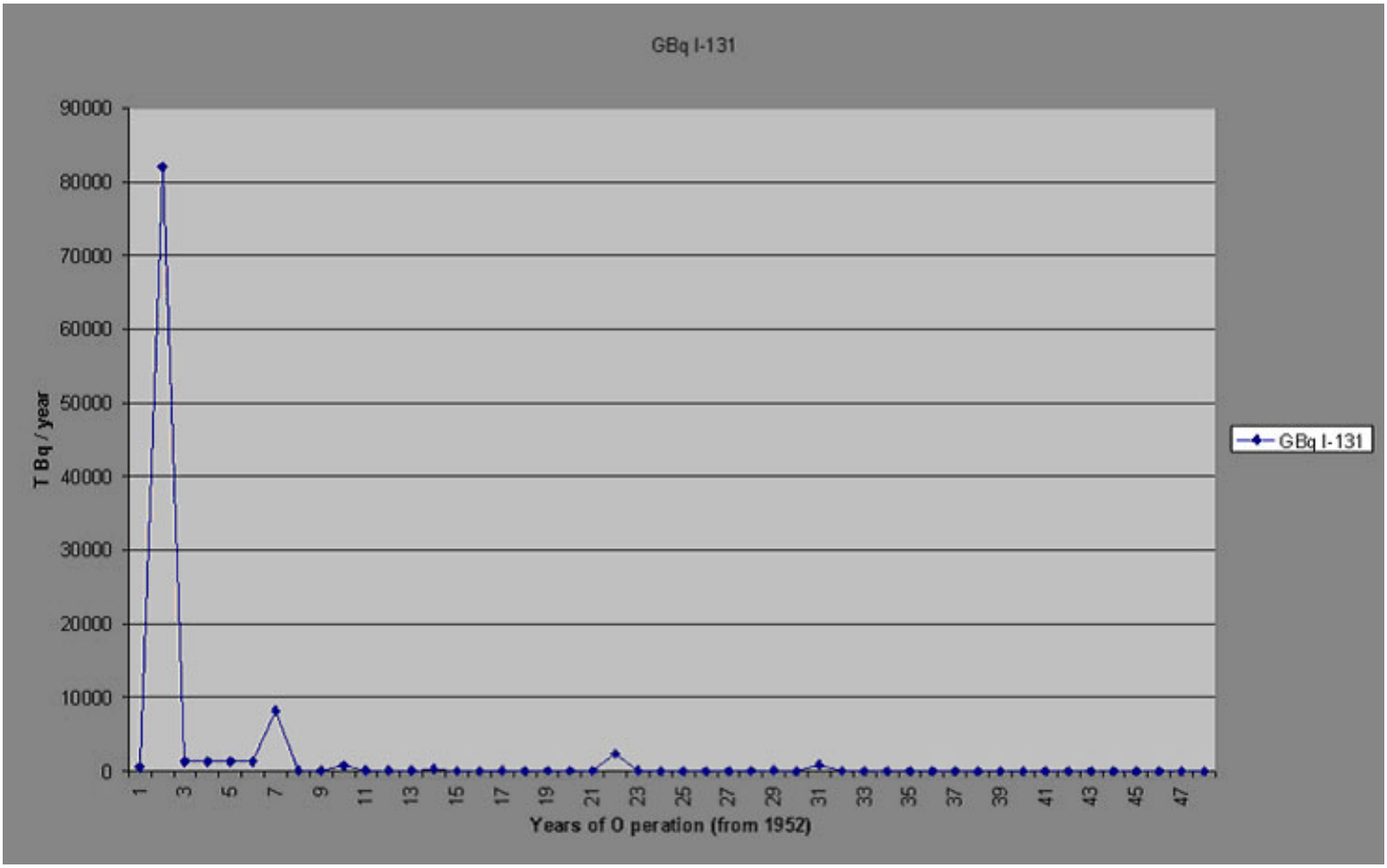
· The air concentrations were calculated using the ATMOS module of SEAM.

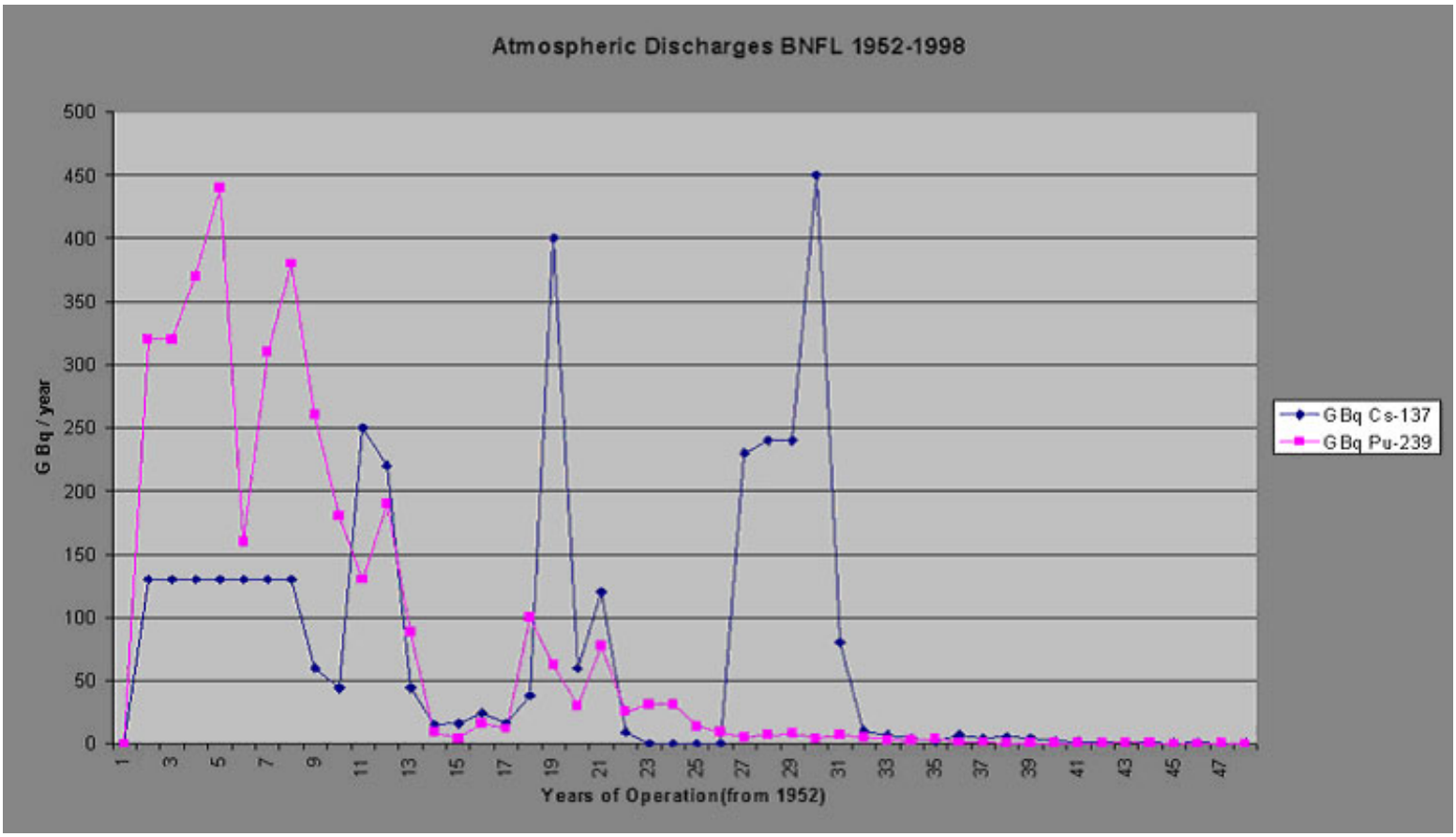
· Pu deposition and lake sediment cores : two sediment cores taken from Ponsonby Tarn a small lake located 1.8 km from Sellafield have been shown to contain deposition chronologies. I t is reassuring that the calculated deposition rates account well for the profile. Thus, the discharge chronology accounts both for the total deposition of Pu alpha near the site and its temporal distribution.

· Milk is a good indicator of a number of fission products in the environment, including Sr-90, 131 I and 137Cs. Generally the results for 131 I are below the limit of detection, except for times of known abnormal releases (Pile I Fire, Chernobyl accident). Results for Sr-90 and 137Cs are consistly positive, but of course sources such as weapons testing fallout need to be considered in interpreting the time series monitoring data.

· Further verification of the atmospheric discharge chronology for plutonium may be obtained by reference to analysis of autopsy tissues of eight non-occupationally exposed cases, resident in Seascale or the surrounding area from the early days of site operation until the time of their death between 1980 to 1984 (Stather et al 1988). The intake of plutonium by inhalation has been calculated for an adult continuously resident in Seascale from 1950 to 1984 using the SEAM model, using conventional assumptions for inhalation dose assessments. From these intakes the Pu content of bone and liver has been calculated using the metabolic models recommended in ICRP publication 30 (ICRP 1978) as modified by ICRP publication 48 (ICRP 1986). The predicted content of both organs is overestimated by comparison to the measured content : -for liver by a factor of 4; and-for bone by a factor of 10. The inhalation intakes reflect discharges from the high stacks at Sellafield in the pre-1964 period. This timing is consistent with the Pu isotopic ratios reported for the autopsy tissues (Popplewell et al 1989).







10.3 Pathways (L.Vintro et al **.)**

Exposure pathways (Ann.Rpt.BNFL)

Atmospheric discharges

Inhalation	Radionuclides in the plume
	Resuspended radionuclides
Ingestion	Cow meat and liver
	Cow milk
	Cow milk products
	Sheep meat and liver
	Grain
	Green vegetables
	Root vegetables
	Fruit
External gamma	Radionuclides in the plume
	Deposited radionuclides
External beta	Radionuclides in the plume
	Deposited radionuclides

Marine discharges

Inhalation	Radionuclides in seaspray
Ingestion	Marine fish
	Crustaceans
	Molluscs
External gamma	Radionuclides in sediment
	Radionuclides in fishing gear
External beta	Radionuclides in sediment
	Radionuclides in fishing gear

River/lake discharges

Inhalation	Resuspended radionuclides
	Seaspray
Ingestion	Drinking water
	Cow meat and liver
	Cow milk
	Sheep meat and liver
	Grain
	Green vegetables
	Root vegetables
	Freshwater fish
	Marine fish
	Crustaceans
	Molluscs
External gamma	Deposited radionuclides

10.3.1 Aquatic exposure pathways

Radioactive materials released to the marine environment become involved in a complex series of physical, chemical and biological processes. Some of these processes lead to progressive dilution, others to physical or biological reconcentration, followed by transfer through various and sometimes independent pathways to man (ICRP, 1979). The generic manner in which human exposure can occur following the release of radioactive materials to surface waters is illustrated in Figure 1. In practise, the pathways will be more complex than those depicted in the figure, and will greatly depend on the details of the local marine environment and on the extent to which marine resources are exploited for man's use. Nevertheless, the figure highlights the importance of the feedback loops that control and regulate the transfer of radionuclides within a particular ecosystem.

When the design of Windscale Works (Sellafield) was first being considered, a number of preliminary studies were carried out to investigate possible problems arising from the projected discharges to the Irish Sea (Seligman and Scott, 1948; Seligman, 1956; Dunster, 1956; 1958). Hydrographic dispersion experiments using dye tracers, in conjunction with studies of tidal-streams using current meters and drift markers, supported by data of salinity distribution in the north-eastern Irish Sea, showed that the effluent would leave the pipeline and rapidly mix with large volumes of water, moving up and down the coast by the oscillating tidal stream and slowly diffusing into the northern Irish Sea, eventually exiting into the Atlantic Ocean through the North Channel (Dunster, 1958).

Potential pathways to humans were also examined and assessed in detail, including consumption of fish and seaweed, external irradiation from the shore, ingestion of sand or seawater and the use of seaweed as a fertiliser (Dunster, 1952). Programmes of work were undertaken to establish the distribution and commercial capture of edible fish from the vicinity of the pipeline, and to identify the harvesting locations of *Porphyra* seaweed (manufactured into the foodstuff laverbread) along the neighbouring coast. These studies demonstrated that although fish in the pipeline region made small seasonal movements (probably driven by temperature changes), very few travelled beyond the limits of the north Irish Sea (Dunster, 1956). The proportion of marked fish in commercial landings also indicated a significant dilution by fish from other areas remote from Windscale. The studies of seaweed showed that *Porphyra* was actively harvested within about 20 km of the effluent outlet and that the bulk of the harvest was sent to one area in South Wales, were it represented a considerable fraction of the total supply for the manufacturing of laverbread (Dunster, 1958).

These studies were completed by a series of laboratory experiments in which fish and seaweed were exposed to labelled seawater with a view to determining appropriate concentration factors between seawater and the edible materials.

The above preliminary hydrographic and biological studies concluded that the pathways likely to give rise to the greatest exposures were associated with the consumption of fish and seaweed, and with direct irradiation from the shore (Dunster, 1952). By combining these forecasts with radiological guidance from the *International Commission on Radiological Protection* , and following the application of appropriate safety factors to account for uncertainties in the assessments, maximum permissible discharge rates were derived, and authorised discharges commenced in 1952.

10.3.1.1. Porphyra/laverbread pathway

The extensive monitoring programme that ensued after the first discharges from Windscale (Sellafield) showed that uptake of 106 Ru by *Porphyra* and its consumption as laverbread constituted the most important pathway to public radiation exposure in the U.K. arising from this source (Wix *et al.* , 1960; Longley and Templeton, 1963). Detailed habit surveys of this route of exposure (Hampson, 1957; Preston and Jefferies, 1967; 1969) identified the critical group as being high-rate laverbread consumers in South Wales. The laverbread pathway remained dominant up to 1971 (AEMR, 1967–1972), when an abrupt cessation in the collection of *Porphyra* as a consequence of rail network changes in 1972 resulted in the sudden disappearance of this route as a source of public radiation exposure. Nevertheless, monitoring of *Porphyra* continued (and is still part of the monitoring programmes) in view of its potential importance. A reconstruction of radiation doses using present-day, ICRP-60 (ICRP, 1991), methodology estimated that for the South Wales critical group the peak dose would have been 1.2 mSv y –1 in 1956, fluctuating about the 1 mSv y –1 level until 1971 and then sharply declining (Figure 2) (Hunt, 1997). In this reconstruction, contributions from 90 Sr, 95 Zr/ 95 Nb, 106 Ru, 134 Cs, 137 Cs, 144 Ce, 238 Pu, 239+240 Pu, 241 Pu and 241 Am were included, and the dilution with seaweed from locations further afield, as well as the absorption of water during cooking, were both taken into account. Doses were mainly due to 106 Ru, but from the mid-1960s the actinides began to contribute, with 35% of the dose in 1970 due to plutonium and americium isotopes (Hunt, 1997).

10.3.1.2. External exposure pathway

Although, at first, much effort was put in the monitoring of the laverbread pathway, the importance of other routes was always kept under review. Indeed, external exposure due to irradiation from contaminated local estuarine environments had been recognised as a secondary pathway of importance from early studies (Dunster, 1952).

Marine sediments concentrate many of the radionuclides released from Sellafield, with fine-grained muds and silts accumulating these radionuclides to a much larger extent than the courser-grained sands. As a consequence, dose rates tend to be higher in locations where mud tends to accumulate, such as estuaries and harbours, and lower along open beaches. External radiation exposure can result from a wide range of recreational and occupational activities. Recreational activities include bait digging for angling, wildfowling, living on houseboats, small boat maintenance and beach walking. Occupational activities include fishing, farming, commercial bait digging, turf cutting, boat and river maintenance work and policing of nature reserves and fisheries

(Kershaw *et al.* , 1992).

Over the years, the sites giving rise to the highest external exposure have been kept under review by means of habits surveys and environmental monitoring (Hunt, 1997). Until 1980, salmon garth fishermen working in muddy areas of the Ravenglass Estuary were identified, on the basis of measured concentrations and surveys on occupancy times, as the critical group for this pathway. With the disappearance of the laverbread pathway in 1972, external exposure to these individuals was reported as the critical pathway in 1972/73 (AEMR, 1975). In 1980, the garth fell into disuse, and a new cohort, represented by fishermen living on board their boats in Whitehaven harbour, was identified as the critical group. In 1989 and 1994, bait diggers were reported to be the most exposed individuals in the Cumbrian region (AEMR, 1990; 1995). Since 1986, and as a result of the decrease in radiocaesium discharges being more noticeable near to the Sellafield vicinity than further afield, exposure of houseboat dwellers in the Ribble Estuary were identified as the group receiving the highest external exposures from the effects of discharges from Sellafield (AEMR, 1987-95; RIFE, 1996–99; Hunt, 1997).

A reconstruction of external doses in Whitehaven harbour, chosen to be a representative for the Cumbrian coast, as well as measured exposures to houseboat dwellers in the Ribble Estuary from 1981, are given in Figures 3 and 4, respectively. The model calculations, carried out by Hunt (1997), concluded that from 1952 to the mid-1960s, 106 Ru was the dominant contributor to the external dose. From 1964, with the introduction of new reprocessing facilities and the change in operations, 95 Zr/ 95 Nb and 144 Ce contributions became more important. By the mid-1970s, however, radiocaesium became the dominant nuclide. The peak dose rate was about 0.9 mSv y^{-1} in 1975. The decline in doses afterwards is a general reflection of the reduction of discharges. Nevertheless, the observed rate of decline has been lower than in the actual discharges, a sign of the contribution of historic discharges retained in the sediments, which are only slowly remobilized (Hunt, 1997; Mitchell *et al.* 1999).

10.3.1.3. Consumption of fish and shellfish pathway

By 1970, following the increased radiocaesium discharges from Sellafield, a third pathway of exposure, due to the consumption of fish and shellfish, had become apparent. This route was reported to be the critical pathway from 1974 until the late 1980s and, accordingly, much of the emphasis in U.K. monitoring programmes over this period was put on its evaluation, with particular attention being given to critical groups such as consumers in the local fishing community near Sellafield and consumers associated with commercial fisheries based primarily at Whitehaven, Fleetwood and the Morecambe Bay area.

The fish and shellfish fauna in the Irish Sea is similar to neighbouring seas, although the relative abundance of several species are somewhat different (Grainger, 1989). The main demersal species are cod (*Cadus morhua*), whiting (*Merlangius merlangus*), plaice (*Pleutoronectes platessa*) and sole (*Solea solea*), which together account for about 60% of the demersal catch. The only important pelagic species is herring (*Clupea harengus*). Of the commercial shellfish species, by far the most important ones are the Dublin prawn (*Nephrops norvegicus*), scallops (*Pecten maximus*) and queen scallops (*Chlamys opercularis*). In comparison with the fisheries, mariculture is not of major importance in the Irish Sea and is almost exclusively confined mussels (*Mytilus edulis*) and oysters (*Ostrea edulis)* . All of these species of fish and shellfish have been (and continue to be) regularly monitored, together with other species of less commercial value. Analyses have concentrated on 90 Sr, 106 Ru, 134 Cs, 137 Cs, 238 Pu, 239 +140 Pu, 241 Pu and 241 Am, although other nuclides such as 14 C and 99 Tc have regained attention in recent years due to changes in the discharge composition.

To illustrate the temporal evolution of this pathway, time trends of activity concentrations of 106 Ru, 137 Cs, Pu- **a** and 241 Am in fish and shellfish from Sellafield are given in Figures 5 and 6, respectively. It is clear from these figures that, in general, radionuclide concentrations in fish and shellfish sampled in the NE Irish Sea peaked in the early- to mid-1970s and declined thereafter, in broad agreement with the discharge pattern (see §10.22). The reductions in the concentrations of fission and activation products have been greater than those of the transuranium nuclides, due to a longer lag period between the decrease in transuranic discharges and its reflection in environmental materials (Hunt, 1985).

Although estimated dose rates for critical groups of fish and shellfish consumers have been reported annually (AEMR, 1967-94; RIFE, 1996–2000), changes in radiological protection guidance and assessment methodologies over the years have resulted in a set of doses calculated on different bases (Hunt and Smith, 1999). To bring these estimates to a common basis, a reconstruction of annual effective doses for the critical group comprised of consumers in the Sellafield local fishing community in the period 1952-93 using present-day, ICRP-60 (ICRP, 1991) methodology, was carried out by G.J. Hunt in 1997. The estimated dose rates, shown in Figure 7, are based on consumption rate surveys, monitoring and modelling data, and include the contributions from 90 Sr, 95 Zr/ 95 Nb, 106 Ru, 134 Cs, 137 Cs, 144 Ce, 238 Pu, 239+240 Pu, 241 Pu and 241 Am. According to this reconstruction, doses up to the late 1960s were mainly due to 106 Ru in shellfish, with radiocaesium and actinides becoming progressively significant from the early 1970s. Doses peaked at about 2 mSv y^{-1} in the mid-1970's, with the main contribution being due to radiocaesium. From the mid-1980s, following the reduction in radiocaesium discharges, actinides in shellfish provided the most important contribution

to dose (Hunt, 1997). Although doses to this critical group are estimated to have exceeded the current ICRP-recommended principal dose limit for members of the public of 1 mSv y^{-1} in the period 1970-81, since 1982 doses have been well within this limit and are now about 0.2 mSv y –1 . A perturbation in the dominance of actinides to present dose rates occurred following the increased discharges of 99 Tc in 1995–97, with contributions from this radionuclide being reported to dominate dose rates in 1996 and 1997 (RIFE, 1997–98).

Farther afield, in the Republic of Ireland, public radiation exposure from radioactive waste discharges to the Irish Sea are also mainly due to the consumption of fish and shellfish taken in the Irish Sea and landed at east coast ports. Since the late 1970's radioactivity levels in fish and shellfish from these waters have been the subject of extensive monitoring by Irish laboratories. 137Cs and, to a lesser extent, 134 Cs have been identified as the principal radioactive contaminants where consumption by the general public is concerned (McAulay and Doyle, 1985; Cunningham and O'Grady, 1986; Cunningham *et al.* , 1988; O'Grady and Currivan, 1989; McGarry *et al.* , 1994). However, this is no longer the case for that hypothetical group consuming large quantities of shellfish taken from the loughs and estuaries along the north-east coast of Ireland, where the contribution from plutonium and americium to the, admittedly, small individual committed effective dose now exceeds that from radiocaesium (Crowley *et al.* , 1990; Mitchell *et al.* , 1991).

The annual dose to a member of a hypothetical group of heavy consumers of fish and shellfish (harvested in the north-western Irish Sea) has declined from an estimated maximum of 160 m Sv in 1976 to about 2 m Sv at the present time (Pollard *et al.* , 1996), while the annual dose to an average Irish seafood consumer has fallen from a peak of almost 30 m Sv to about 0.3 m Sv over the same period (Pollard *et al.* , 1996; Ryan *et al.* , 2000). These doses are but minute fractions of the ICRP-recommended principal dose limit for members of the public, namely 1 mSv. By comparison, the annual dose to a heavy consumer arising from the presence of naturally-occurring 210 Po in fish and shellfish is estimated to be about 150 m Sv, while a figure for the typical consumer is about 30 m Sv (Pollard *et al.* , 1996).

10.3.1.4. Other aquatic pathways

Although the consumption of fish, shellfish and seaweed, together with external exposure to contaminated sediments represent the main pathways of exposure from discharges of radioactive waste to the Irish Sea, other routes of exposure, such as the inhalation of resuspended beach sediments, the inadvertent ingestion of contaminated seawater and sediment, or the handling of fishing gear are constantly kept under review.

Doses to man from the inhalation of marine aerosols and resuspended particles in coastal areas have been shown to be small, and mainly due to actinides (Pattenden *et al.* , 1980; Knight *et al.* , 1980). Nevertheless, the existence of a sea to land transfer of radionuclides (particularly actinides) has been clearly demonstrated (Cambray and Eakins, 1980; Eakins *et al.* , 1982). Although not large, this transfer provides a potential source for uptake into terrestrial food, as well as airborne resuspension followed by inhalation (Hunt and Smith, 1999). The peak dose from plutonium and americium for a hypothetical critical group in west Cumbria arising from the transfer of marine discharges to land has been estimated to be 35 m Sv y^{-1} in 1973 (Howorth and Eggleton, 1988). Maximum effective doses due to the ingestion of seawater and sediment whilst swimming in beaches close to Sellafield have been estimated to be similarly small, with peak doses of 1.5 m Sv y^{-1} and 3 m Sv y^{-1} for water and sediment ingestion, respectively (Hunt and Smith, 1999).

External radiation of fishermen due to the handling of fishing gear, which may entrap contaminated sediment during immersion, has been regularly monitored since 1983. Doses to the skin arising from this pathway have been estimated to be less than 0.3 mSv, which is less than 1% of the dose limit appropriate for exposures to skin of members of the public.

10.3.2 Terrestrial exposure pathways

Artificial radionuclides enter terrestrial ecosystems either directly from the atmosphere or via surface or ground waters. In the case of Sellafield, inputs to the terrestrial environment take place either by direct deposition to the ground of gaseous emissions from the site, or by indirect pathways that involve transfer by wind of radioactive contaminants (Cawse, 1983). The latter mechanisms include resuspension by wind of contaminated surface soil dust and, in certain localities, the deposition of sea-spray to coastal soils as a result of bubble bursting and wind shear (Pattenden *et al.* , 1981, McKay and Pattenden, 1990).

Radioactive effluents are discharged to the atmosphere from the Sellafield site via a number of individual discharge points with different release heights. The main components of these releases are noble gases (41 Ar and 85 Kr) and 3 H, although gases and vapours containing 14 C, 129 I, 131 I, 241 Am and plutonium isotopes are also discharged. The chronology of aerial discharges has already been reviewed in detail in §1.2.3. As discussed in that section, a number of uncertainties were associated with early estimates, mainly related to the lack of radiochemical measurements prior to 1964 and the presence of a number of unmonitored

sources of atmospheric discharge in the early years (primarily from the Piles pond and the plutonium preparation plants). Taking account of inefficiencies in the sampling of stacks and examining previously unreported data, estimates of aerial emissions were substantially amended by Gray *et al.* (1995). These estimates, validated with environmental monitoring data, represent the most reliable chronology of atmospheric discharges to date.

In addition to routine authorised discharges, a number of other releases, mostly accidental and short-term in nature, have also been documented, which may have contribute to the exposure of populations living in the vicinity of the Sellafield site and farther afield. In the early years, accidental releases associated with plutonium finishing operations, fuel storage tanks in the Windscale Piles and a specific incident in one of the Calder reactor tower basins, resulted in the emission of an estimated 80 GBq of actinide nuclides (Stather *et al* ., 1986). During operation of the Windscale Piles in the 1950s, uranium oxide particles were also emitted from the pile stacks (Stather *et al.* , 1986; Chamberlain, 1987; 1996). These emissions dominated the deposition of 90 Sr and 137 Cs around the site prior to the pile fire in 1957, the most serious accident in the history of operations at the site.

The accident in the Windscale No. 1 reactor (an air-blast cooled, graphite moderated reactor designed for the production of military plutonium) in October 1957 was caused by overheating during a procedure to release Wigner energy. This led to the melting of fuel in 150 channels, containing 8 tonnes of uranium, and affected channels containing bismuth oxide, for production of plutonium, and lithium/magnesium alloy, for the production of tritium (Chamberlain, 1996). The activities released from the pile stack over a period of approximately 24 hours were principally those of the volatile fission products, namely isotopes of the noble gases, tellurium, iodine and caesium, and also polonium and tritium (Command 302, 1958; Chamberlain, 1996).

In more recent years, two incidents involving the release of plutonium and americium to the atmosphere have been reported. In 1979, approximately 11 GBq of plutonium were released from the effluent treatment plant (BNFL, 1980; Stather *et al.* , 1986; Gray *et al.* , 1995). In 1984, about 0.4 GBq of 241 Am were released from a sludge storage tank (BNFL, 1985; Gray *et al.* , 1995).

The fate of radionuclides released from Sellafield to the atmosphere depend on a number of complex processes including release characteristics (source, emission height), dilution and transport, chemical reactions, washout by cloud droplets and precipitation, resuspension, etc. The manner in which human exposure can occur as a result of these processes is illustrated in Figure 8. Regular terrestrial monitoring programmes around Sellafield are carried out independently by the site operator (British Nuclear Fuels plc), MAFF and the Environment Agency. Monitoring activities focus on those pathways considered to be the main route of radiation exposure, including external exposure from contaminated air and ground, and internal exposure from the inhalation of contaminated air and the consumption of local agricultural produce. Analysis of a wide range of foodstuffs, including milk, fruit, eggs, meat and offal, mushrooms, game, honey, cereals, as well as air and indicator materials such as grass and soil, are carried out in order to determine radionuclide activity concentrations and radiation doses relevant to these pathways. The habits and consumption rates relating to each pathway, essential for the estimation of realistic doses, are kept under constant review.

10.3.2.1. Exposure to contaminated air: inhalation and external exposure

Although air sampling in the vicinity of Sellafield has been conducted since the beginning of operations, data of sufficient quality are only available from the late-1970s. Samplers located close to the site perimeter and in nearby centres of population to sample airborne particulate radioactivity have been used to monitor radionuclide concentrations in air. Filters are replaced regularly and analysed for particulate activities of 90 Sr, 95 Zr/ 95 Nb, 103 Ru, 106 Ru, 125 Sb, 134 Cs, 137 Cs, 144 Ce, Pu-alpha, 241 Pu and 241 Am. Estimated doses incurred from the inhalation of particulate material at three locations in the vicinity of Sellafield are given in Figure 9. From 1993, activities in most filters have been below the detection limits for each nuclide, so no dose has been reported for these locations.

Inhalation is believed to be one of the main pathways of plutonium into the body. Measurements of 239,240 Pu carried out by Popplewell *et al.* (1989) in autopsy livers from four subjects who had resided within 5 km of Sellafield (but were not employed there) showed average concentrations of 93 mBq kg^{-1} . This compares with a median activity of 26 mBq kg^{-1} in 13 subjects from Oxfordshire, ascribed to the uptake of plutonium from weapons fallout (Chamberlain, 1996).

In addition to the inhalation of particulate activity, the effects of activity present in a gaseous form must also be taken into account. Radionuclides in a gaseous form are not efficiently trapped by air filters, and their dose contribution must be estimated from discharge levels using dispersion models. Estimates carried out on this basis since 1983 suggest that the dose to people at the nearest habitation has been below 0.1 mSv y^{-1} , with the main contribution from 41 Ar. The dose from 41 Ar is mainly due to skin dose from immersion in the plume, so the estimated dose represents less than 1% of the dose limit appropriate for exposures to skin of members of the public.

10.3.2.2. Internal exposure from the ingestion of terrestrial foodstuffs

The transfer of radioactivity from the atmosphere to vegetation involves deposition, interception and retention. All three parameters are sensitive to the particle size and chemical characteristics of the depositing material, the vegetation or ground surface characteristics, prevailing weather conditions and state of growth of the ground cover (SCOPE, 1993).

10.3.2.3. Deposition of artificial radionuclides from Sellafield

A number of studies have been carried out to estimate the deposition of artificial radionuclides from Sellafield. By comparing the cumulative deposition of 137 Cs and 239+240 Pu in soils from the vicinity of the site with expected depositions from weapons fallout (taking into account rainfall and using average depositions throughout Britain), Cawse (1983) quantified the impact of Sellafield discharges on the terrestrial environment up to 1977. Enhanced 137 Cs inventories were found not only at locations near the site (to distances of up to 10 km), but also some 20 km to the SSE. The latter accumulations, up to three times higher than those expected from fallout, were attributed to the dispersion of 137 Cs from the accidental release which followed the fire in Windscale Pile No. 1 in 1957. In addition, enhanced depositions were observed at most coastal grasslands sites, which decreased with distance inland. These accumulations were attributed to the transport of radioactive material from sea to land in marine spray and/ or resuspended marine sediment (Cawse, 1983). A similar pattern was found for plutonium, with enhanced accumulations taking place in the vicinity of the plant and in coastal grassland areas. The effect of the Windscale accident in this case, however, was not apparent.

A more detailed study on the distribution of plutonium, based on three separate surveys carried out in 1975–77, 1987–88 and 1992, was carried out by Jones *et al.* (1996). It appears that the variation of plutonium deposition with distance from the northern part of the chemical reprocessing area at Sellafield, containing the pile ponds and a number or earlier processing plants that handled separated plutonium in liquid and solid form. High levels of deposition are observed in the immediate vicinity of this point, with measured inventories of Pu– a reaching up to 22000 Bq m^{-2} . These high levels, however, decline very rapidly with distance. The low 238 Pu/ 239+240 Pu activity ratios measured at the sites of highest deposition are strongly suggestive of an origin associated with site operations in the 1950's or early 1960's, when production was almost entirely associated with low burn-up material for military purposes (Jones *et al.* , 1996).

10.3.2.4. Food ingestion

Ingestion doses have been reported annually for a critical group in west Cumbria using food monitoring data and estimated consumption of foodstuffs based on observed or possible habits (BNFL, 1976–99; TRAMP, 1989-–95; RIFE, 1996–2000). The most exposed group consists of local people living near the site perimeter and who obtain all their food from products produced on land adjacent to the site (Jones *et al.* , 1991). The primary goal of these calculations has been to demonstrate that the exposure of this critical group has not exceeded the recommended annual dose limit (Sanchez *et al.* , 1999). Milk has been identified as the most important foodstuff contributing to dose, with infants and children (for which milk is an important part of their diet) receiving the highest dose. Dose estimates arising from the consumption of milk by infants, based on consumption rates recommended by MAFF and NRPB, are shown in Table 10.4.13.

Ingestion exposure estimates are likely to be an overestimate of the actual dose, given the conservative nature of the assumptions made. In an attempt to determine the degree of overestimation of these model calculations and obtain a more realistic assessment of radionuclide intake, Sanchez *et al.* (1999) carried out the analysis of duplicate diets in recruited volunteers during 1986, 1995 and 1996. The surveys involved the collection of a complete duplicate of all foods, as prepared for consumption at home, during a 7-day period. The study groups participating in each survey were all recruited from the general area of west Cumbria, but the control groups were recruited from two different locations in Lancashire and Devon. Two different groups, children aged 3–5 years and adults over 18 years were selected for each survey. The results shown that radiocesium was Table 1. Radiocaesium was the dominant contributor to the west Cumbrian dose in the 1986 surveys immediately after Chernobyl. A maximum dose of 87 m Sv due to 137 Cs was estimated for an adult in west Cumbria in August 1986. By 1995, annual doses from 137 Cs had decreased considerably and showed values comparable to pre-Chernobyl (March 1986) doses.

The dose from 90 Sr and 239,240 Pu ingestion were much lower than those for 137 Cs, and no significant difference was observed between control and study groups. The results from 1995 and 1996 showed that, of the radionuclides analysed, 14 C was the most important contributor to the dose of both study and control groups, accounting for at least 75% of the total. Comparison of dose rates for the study and control groups, however, points naturally-occurring 14 C of cosmogenic origin as the main source for this nuclide.

The estimated annual doses from the published monitoring data are significantly higher than those derived from the diets study, probably because of contributions from radionuclides other than those analysed, as well as differences in the assumed consumption of local foods (Sanchez *et al.* , 1999).

Present estimates of individual radiation exposures due to the consumption of terrestrial foodstuffs near Sellafield are given in Table 10.4.13 (RIFE, 2000). The critical group remains that of infants consuming milk and vegetables produced in the vicinity of the site. The annual dose for this group, at 44 m Sv, is approximately three times lower than that estimated for the critical group of houseboat dwellers in the Ribble estuary (due to external exposure), and is similar to that for the critical group of seafood consumers.

10.3.2.5. Deposition of activity from the Windscale accident

The Windscale accident resulted in the release of a large quantity of radioactivity into the atmosphere over a period of approximately 24 hours. From the radiological perspective, the most important release was that of 131 I, which led to restrictions on the consumption of milk in areas where the activity of this nuclide exceeded 3.7 kBq l^{-1} . The highest recorded 131 I level was 50 kBq l^{-1} in a sample collected from a farm lying in the direct path of the plume.

During the emission, rainfall in England and Wales was light and patchy, and fallout was mainly by dry deposition (Chamberlain, 1996). Following the accident, relatively simple models were used to define the source on the basis of air concentrations measured throughout the United Kingdom (Cabtree, 1959). The release appears to have taken place mainly in two peak periods. A weak frontal system passing at the time of the first peak made it difficult to establish the initial dispersal pattern, although it is clear that it was mainly eastwards. However, during the second peak, the meteorological conditions resulted in a well-defined plume dispersing SSE.

In the area of maximum deposition, 3–8 km SSE from Windscale, the 137 Cs deposit was about 20 kBq m^{-2} (Chamberlain, 1959). By extrapolation back from the activity measured at various dates after the accident (Dunster *et al.* , 1958), it has been estimated that the peak level of 137 Cs in milk may have been 1400 Bq l^{-1} (Chamberlain, 1996). This compares with 350 Bq l^{-1} in the same area following the 1986 Chernobyl accident (Jackson *et al.* , 1987). By the time the 131 I levels in milk had decayed enough to lift sale restrictions, the cows were on winter feed. The uptake of 137 Cs from agricultural soil is very poor, so it is likely that by early 1958, the 137 Cs activities in west Cumbrian milk were little more than those observed in the coming years all over Britain as a result of nuclear weapons fallout (Chamberlain, 1996).

Surveys carried out following the Chernobyl accident showed that sheep from certain areas had levels of 137 Cs in tissue exceeding 1000 Bq kg^{-1} . These areas included locations located some 20 km SE of Sellafield. The possibility that some of this 137 Cs was attributable to the Windscale accident was investigated by Beresford *et al.* (1992). They concluded that by 1989/1990, about a quarter of the 137 Cs in sheep might have been derived from Windscale.

Nevertheless, comparison of 137 Cs body burdens between subjects from west Cumbria and farther afield suggests that the contribution of the Windscale accident to 137 Cs activities in local residents was very small (Hesp, 1965; Newton *et al.* , 1977, Chamberlain, 1996).

10.4 Dose assessment

10.4.1. Dose exposure from Sellafield discharges (M.Savkin **)**

The term ‘dose' refers to the effective dose and is the sum of the annual external effective dose and the committed effective dose to adults for intakes over one year. Doses were determined in accordance with the most recent recommendations of ICRP using dose coefficients given in ICRP Publication 72.

Radiological impact assessments for a practice usually involve two aspects. The first is the calculation of individual doses. Annual doses to representative typical individuals residing near nuclear sites have been calculated as a way of providing a general perspective on the comparative radiological impact of different sites. An additional method is the calculation of annual effective dose to individuals representative of the most exposed group, otherwise referred to as the critical group.

The second aspect is the calculation of radiation dose received by an exposed population, otherwise referred to as the collective dose. The collective dose is the sum of doses received by members of the exposed population from all significant pathways. Long-lived radionuclides can give rise to doses over extended times, long after a release has stopped. To account for this, the annual individual doses in the exposed population are summed over various times following the year of release. If doses are summed over all time then the resulting quantity is known as the collective dose or collective dose to infinity. If doses are summed up to a specified time – for example, 500 years – then the quantity is referred to as collective dose truncated at 500 years.

Tables 10.4.1 to 10.4.5. show the collective doses to the UK and Europe and the annual doses to typical individuals from Sellafield nuclear site discharges. Discharges for 1975, 1985 and 1993–1995 have been selected to represent three decades of operation. Average annual discharges over the period 1993–1995 are taken to be typical of the situation in the mid-1990s. The collective and individual doses are used to give a holistic view of the radiological impact of the routine discharges from the UK nuclear industry.

TABLE 10.4.1 . Collective effective doses to the European population truncated at 500 years from Sellafield civil nuclear discharges

	Collective dose (man Sv)		
Discharge	1975	1985	1993–1995*
Atmospheric	5.56 10 1	2.25 10 1	1.59 10 1
Liquid	2.79 10 2	1.92 10 1	1.24 10 1
Total	3.35 10 2	4.17 10 1	2.83 10 1

TABLE 10.4.2. Collective effective doses to the European population to infinity from Sellafield civil nuclear discharges

	Collective dose (man Sv)		
	Discharge year		
Discharge	1975	1985	1993–1995*
Atmospheric	1.93 10 2	7.26 10 1	3.75 10 1
Liquid	2.97 10 2	3.52 10 1	8.50 10 1
Total	4.90 10 2	1.08 10 2	1.22 10 2

TABLE 10.4.3.. Collective effective doses to UK population truncated at 500 years from Sellafield civil nuclear discharges

	Collective dose (man Sv)		
	Discharge year		
Discharge	1975	1985	1993–1995*
Atmospheric	1.04 10 1	4.09 10 0	3.12 10 0
Liquid	1.08 10 2	7.14 10 0	2.59 10 0
Total	1.19 10 2	1.12 10 1	5.71 10 0

TABLE 10.4 4 . Collective effective doses to UK population to infinity from Sellafield civil nuclear discharges

	Collective dose (man Sv)		
	Discharge year		
Discharge	1975	1985	1993-1995*
Atmospheric	2.12 10 1	8.02 10 0	4.81 10 0
Liquid	1.10 10 2	8.54 10 0	9.10 10 0
Total	1.31 10 2	1.66 10 1	1.39 10 1

The main contributor remains carbon-14, but its contribution (49%) to the UK collective dose is lower than its contribution to the European collective dose, showing the importance of global circulation in the collective dose to the European population. The truncated UK collective dose from liquid discharges shows a similar trend to the corresponding collective dose to the European population. The contribution from caesium-137 (7%) is much smaller for discharges in the mid-1990s than for those in 1985 (59%). The contribution from reprocessing (60%) is 20% less than the percentage contribution in 1985, while the contribution to doses from the group of miscellaneous sites has increased, up 15% from 1985 to 38% in the mid-1990s.

TABLE 10.4.5.. Typical annual individual doses from Sellafield civil nuclear discharges

	Individual dose (m Sv)		
	Discharge year		
Discharge	1975	1985	1993-1995*

Atmospheric	2.03 10 1	5.77 10 0	3.48 10 0
Liquid	3.69 10 2	2.71 10 1	6.83 10 0
Total	3.89 10 2	3.28 10 1	1.03 10 1

10.4.2. Dose uptake to members of the public from marine pathways (Ann. Rpt. BNFL, 1998 **)**

Using habits surveys, MAFF has identified the marine critical group for seafood consumption, as consisting of people in the Cumbrian coastal community who consume fish and/or shellfish, at high rates, from the Sellafield area between St Bees and Selker. Consumption and occupancy rates are kept under regular review and are published annually by MAFF. In this report, the consumption and occupancy rates assumed by BNFL for dose assessment purposes are an average of the data published by MAFF for the five years 1993-97. This approach is considered to provide the most appropriate data for assessing changes in doses resulting from changes in discharges since it smoothes out fluctuations caused by short term changes in habits and also allows doses for each year to be compared directly.

The different species are consumed by several sub-groups which have been identified by MAFF for assessment purposes, however, it is assumed that a single group of people consumes fish, molluscs and crustaceans at these rates and that above average consumers of one sub-group are not high rate consumers of another sub-group.

Studies by MAFF using adult human volunteers have suggested that a gut uptake factor of 0.0002* is appropriate for consumption of plutonium and americium in winkles from near Sellafield. This value has been endorsed by the NRPB (Harrison et al.,1990) and is used in this report. It is supported by recent studies which suggest that radionuclides associated with sediments (the form in which most of the activity is present in harvested winkles), as opposed to those associated with flesh, may be less readily absorbed through the human gut, leading to lower dose uptakes. For all seafood, other than winkles local to Sellafield, the NRPB considers the assessment of doses to the critical group

Table 10.4.6. Dose (µSv) to critical group consumers of seafood (St Bees - Selker)

Radionuclide	Cod	Plaice	Lobster	Crab	Nephiops	Winkles	. Linipets	Mussels	Cackles	Total dose from radionuclide (a)
Carbon-14	0.74	0.87	0.46	0.84	0.1	0.46	0.07	0.13	0.11	3.8
Cobalt-60	<0.014	0.01	0.07	0.088	<0.004	0.49	0.04	0.06	0.10	0.88
Strontium-90	0.15	0.11	<0.05	028	0.01 9	0.89	0.35	0.11	0.08	2.0
Zirconium-95	<0.005	<0,004	<0.003	<0.004	<0.002	<0.008	<0.001	<0.002	<0.0006	<0.04
Niobium-95	<0.0009	<0.0008	-	<0.001	<0.0004	<0.005	0.0009	0.003	<0.0001	0.003
Technetium-99	0.06	0.09	21	1.3	1.6	5.0	2.8	0.98	0.08	33
Ruthenium-106	<0.18	<0.12	0.08	-	<0.062	2.6	0.46	0.41	0.20	4.1
Silver-110m	-	-	0.09	0.082	-	0.19	0.03	<0.002	<0.002	0.39
Caesium-i 34	<0.06	<0.04	-	-	-	-	-	-	.	<0.09
Caesium-137	1.9	0.99	0.20	0.30	0.18	1.0	0.22	0.06	0.10	5.5
Cerium-i 44	-	-	<0.02	<0.04	<0.02	<0.08	<0.001	<0.01	<0.007	<0.19
Neptunium-237		.	0.01 5	0.008	0.001	0.03	0.005	0.011	0.04	0.11
Plutonium alpha	0.074	0.075	0.57	1.1	0.20	7.7	4.5	2.9	3.6	21
Plutonium-241	-	-	0.11	0.27	0.044	1.4	0.84	0.6	0.7	4.0
Americium-241	0.074	0.087	7.7	2.2	0.93	11 .	5.8	3.9	6.6	38
	3.2	2.4	31	6.5	3.1	31	15	9.7	12	
Total dose (µSv) to critical group (a)	113									

Table 10.4.7. Local consumers of seafood

Radionuclide	Whitehaven fisheries consumer	Whitehaven boat dweller	Angler	Typical fish eater
	Seafood	Seafood	Seafood	Seafood
Carbon-14	4.1	1.8	1.2	1.0
Cobalt-60	0.04	<0.03	<0.02	<0.018
Strontium-SO	1.6	0.17	0.12	0.05
Zirconium-95	<0.041	<0.01	<0.007	<0.006
Niobium-95	<0.015	<0.002	<0.002	<0.0016
Technetium-99	18	0.1	0.07	<0.12
Ruthenium-106	<1.5	<0.41	<0.29	<0.24
Silver-110m	0.04	-	-	
Caesium-134	<0.20	<0.15	<0.10	<0.08
Caesium-137	7.8	4.1	2.8	2.4
Ceriurn-144	<0.26	-		-
Neptunium-237	0.013	-		
Plutonium alpha	6.3	0.25	0.17	0.14
Plutonium-241	1.2	-		-
Americium-241	17	0.38	0.26	0.21
External dose(µSv)	-	46	51	-
Total dose°(µSv)	59	54	56	4.4

o. These totals do not necessarily reflect *the* the *summation of individual doses shown in the table which have been rounded to two significant figures,*

*using a gut uptake factor of 0.0005 for both plutonium and americium will not lead to underestimates(14,15).

Tables 10.4.6. and 10.4.7. detail the doses to the critical group of consumers of seafood (caught locally between St Bees and Selker), and to other local groups of people: consumers associated with the Whitehaven fishery, typical members of the fish- eating public, local anglers and occupants of vessels in Whitehaven Harbour, The external doses in table 10.4.7. are discussed further in the next paragraph . The estimated critical group dose, based on sampling, did not exceed about 110 µSv. This represents a decrease from 1997 (130 µSv) due mainly to a decrease in the dose from technetium-99. This group may also receive doses from other pathways, such as inhalation and consumption of agricultural produce. However, advice from MAFF suggests that this would increase its dose by only about 10%. it should also be noted that doses from the consumption of molluscs are likely to be overestimated because no account has been taken of the effects of food preparation procedures, such as the soaking of winkles. Estimated doses to typical, fish-eating members of the public remained low at around 4 µSv.

MAFF(1998,Doddington et al.,1990) and the Environment Agency (1991) continue to keep under review the amount of time spent by members of the public on inter-tidal areas of the coastline bordering the north-east Irish Sea and more inland locations. in West Cumbria, MAFF has identified a group of local anglers who fish in Whitehaven Harbour and on local beaches. BNFL estimates that the maximum external exposure of these individuals in 1998 was about 51 µSv in addition to any dose received from natural background radiation. Additional exposure due to the consumption of locally caught seafood would result in a total estimated dose in 1998 for this group of about 56 µSv. Doses to boat dwellers in Whitehaven Harbour were slightly lower and were estimated not to have exceeded 46 µSv from external radiation, or 54 µSv including the contribution from seafood consumption. In future years, doses to Whitehaven Harbour users will be significantly reduced following the installation of lock-gates and flooding of the inner harbour as part of the marina development.

. The influence of discharges from Sellafield can also be measured in more distant areas. For example, doses to houseboat dwellers on the River Ribble in Lancashire were estimated by BNFL to have been about 130 µSv in 1998, only about 10% of which is due to discharges from Springfields (see Springfields report). In south west Scotland, stakenet fishermen are estimated to have received doses of up to 26 µSv again due mainly to discharges from Sellafield (see Chapelcross report).

10.4.3. Dose uptake to members of the public from terrestrial pathways (Ann. Rpt. BNFL, 1998 **)**

For some years BNFL has been developing realistic methodologies for estimating doses from terrestrial pathways arising from aerial discharges. Several surveys of local habits have been carried out and the results used to determine mean consumption rates and occupancy factors for the 'critical group'.

Table 10.4.8 . ***Consumption rates of critical group consumers associated with aerial discharges***

Foodstuff	Consumption rate (kg/ a)		
	Adults	Children	Infant
Milk	240(a)	240(a)	320°
Beef	29.3	14.7	7.0
Mutton	9.2	2.7	3.0
Sheep liver	1 .6	0.9	2.0
Green vegetables	22.2	14,4	30
Root vegetables(b)	48.5	30,2	50
Fruits(c)	11.0	5.6	1.2
Poultry	5.9	3.0	3.7
Eggs(d)	28.9	1 5.2	
Fish (caught locally)	7.6	4.4	14.5
			1 3.0

a.based on NRPB/MAFF recommendations18
b. local potatoes only
c. soft fruit only
d. hens'eggs only

In addition to exposure from the consumption of local produce, the critical group will also receive an immersion dose from argon discharged from the reactors at Calder Hall and, to a lesser extent, from krypton-85 discharged from the reprocessing plants (table 10.4.9.). Sampling for radioactivity in these gaseous forms is less straightforward than for particulate material. However, the resulting doses can be estimated from discharge levels using dispersion models (Jones et al.,1991) which take into account such factors as the shielding of buildings. On this basis, in 1998, the doses to adults, children and infants living near to Sellafield would have been respectively no more than 42, 28 and 26 µSv, mainly from argon-41, using modelling and dosimetry recommended by the ICRP(1991). The contribution from krypton-85 would have been no more than 1.4 µSv. The group will also receive a small external dose, estimated to be 4.4 µSv, from radioactivity deposited on local beaches, where their occupancy time is estimated to be no more than 100 hours per year. If all the above pathways are considered to be additive, the maximum dose (to infants) in 1998 did not exceed 75 µSv, a reduction from the dose reported for 1997 of 81 µSv.

Table 10.4.9.. Summary of doses to the terrestrial critical group in 1998 (µSv)

Pathway	Adult	Child	Infant
Foodconsurnption	12.9-15.9	13.4-17.7	23.9-42.9
Inhalation	1.5-1.7	1.2-1.4	0.7-0.8
Immersion			
Argon-41	41.1	26.7	25.3
Krypton-85	1.35	1.19	1.18
External	4	4	4
Total	61-64	47-51	55-75

Collective dose estimates

Table 10.4.10.. Collective doses from Sellafield discharges

Radionuclide	Collective dose (manSv)	
	Aerial discharges	Marine discharges

	UK	Europe	World	UK	Europe	World
Tritium	0.17	0.40	0.48	0.0012	0.0051	0.10
Carbon-i 4	0.64		55	0,89	3.3	44.4
Krypton-85	0.49	5.8	28	-	-	-
Technetium-99	-	2.7	-	0.10	0.27	0.28
lodine-129	1.2	-	8.1	0.012	0.039	0.16
Caesium-137	0.0018	5.7	0.0043	0.11	0.28	0.32
Plutonium alpha	0.0045	0.0043	0.0072	0.012	0.020	0.021
Americium-241	0.0060	0.0072	0.010	0.0011	0.0013	0.0013
Other nuclides	0.24	0.010	0.33	0.1 6	0.29	0.30
		0.33				
Total	2.8	15	92	1.3	4.2	46

Collective doses resulting from the effects of discharges from Sellafield in 1998, summed over 500 years, have been calculated . The results, shown in table 10.4.10, give total collective doses, as committed effective doses (CED) of about 4.1 man-Sv to the UK population, 19 man-Sv to the European population (including the UK) and 140 man-Sv to the world population

Table 10.4.11. Annual collective dose commitment from natural radiation

Source of collective dose	Collective dose commitment (man-Sv per year)		
	UK population	European population	World population
Natural carbon-14	660	8400	70,000
All sources of natural radiation	130,000	1,500,000	13,000,000

a. In this context, Europe includes Greenland, Iceland, Scandinavia, and western Russia up to 50 °E. This represents a total European population of 700 million, including 55 million in the UK

Table 10.4.12. Comparison of average annual doses (m Sv) in diet surveys carried out in west Cumbria (study) and Lancashire/ Devon (control). The maximum individual doses are in parentheses (from: Sanchez *et al.* , 1999)

Survey	**Participants**		**134 Cs**	**137 Cs**	**90 Sr**	**14 C**	**239+240 Pu**
Sellafield (March 1986)	Children	Control (10)		<0.3 (0.4)	1.3 (1.6)		<0.02 (0.02)
		Study (19)		<0.5 (0.9)	1.8 (3.5)		<0.04 (0.04)
	Adults	Control (16)		<2.6 (13)	1.3 (2.6)		<0.03 (0.03)
		Study (31)	<1.7 (3.2)	<12.7 (90)	1.6 (5.2)		<0.05 (0.29)
West Cumbria (June 1986)	Children	Control (8)	<2.2 (4.3)	<2.9 (5.4)			<0.008
		Study (9)	<14 (38)	<18 (49)			<0.01 (0.03)
	Adults	Control (8)	<3.1 (3.5)	<2.8 (4)			<0.16 (1.0)
		Study (9)	18.7 (44)	27 (64)			<0.009 (0.02)
Sellafield (August 1986)	Children	Control (9)	2.6 (4.1)	4.1 (7.6)	1.4 (2.0)		<0.03 (0.06)
		Study (15)	<5.8 (25)	10 (40)	1.8 (3.8)		<0.05 (0.12)
	Adults	Control (9)	6.9 (12)	11 (20)	1.1 (2.4)		<0.03 (0.05)
		Study (22)	16 (52)	36 (87)	1.9 (4.4)		<0.16 (1.2)
Sellafield (1995)	Children	Control (5)		0.29 (0.57)	<3 (8.7)	9.0 (10.3)	<0.08 (0.17)
		Study (18)		0.26 (0.41)	<9.8 (34)	9.8 (14.5)	<0.09 (0.6)
	Adults	Control (5)		1.09 (2.9)	<4 (16)	8.5 (13.8)	<0.06 (0.22)
		Study (22)		0.84 (2.9)	<4 (25)	8.6 (14.6)	<0.23 (1.9)
West Cumbria (1996)	Children	Control (5)		<0.2 (0.2)	<0.6 (1.1)	7.4 (8.5)	<0.06 (0.10)
		Study (19)		<0.3 (0.6)	<1 (5.7)	6.0 (9.3)	<0.05 (0.15)

	Adults	Control (6)	<0.5	<1 (2.8)	4.6 (6.1)	<0.02 (0.03)
		Study (19)	<0.5 (0.9)	<0.8 (2.8)	4.9 (8.0)	<0.05 (0.16)

Table 10.4.13. Present estimates of individual radiation exposure due to the consumption of terrestrial foodstuffs near Sellafield (from: RIFE, 2000)

Exposed population	**Key**	**Exposure (m Sv)**												
	foodstuffs	**Total**	**14 C**	**35 S**	**60 Co**	**90 Sr**	**95 Zr**	**106 Ru**	**125 Sb**	**129 I**	**131 I**	**137 Cs**	**144 Ce**	**Others**
Consumers near Sellafield aged 1 y	Milk	44	6	4	5	11		10	2	2	2	2		<1
	Potatoes													
Consumers near Ravenglass aged 1 y	Milk	26		1	4	3	2	7		1		1	3	<2
	Fruit													
Typical adult member of the public	Milk	13	1			2		3		1		2		<3
eating food grown near Sellafield	Potatoes													

10.5 Impact on population health (Chapter 9 of COMARE IVth Report **)**

SUMMARY AND CONCLUSIONS

9.1 We have reviewed the epidemiological, dosimetric and other scientific data relating to Seascale and the Sellafield Nuclear Site which have become available since the publication of the report of the Black Advisory Group and our first report. A major aim of this report was to draw conclusions about the main advances in scientific knowledge since the time of the Black report and to clarify where progress has been made and where uncertainties remain. Our conclusions are reported below and the remaining uncertainties identified will form the basis of our advice and recommendations to Government.

9.2 We have examined the incidence of cancer, according to five diagnostic groups defined in para 2.8, among young people age 0-24living in the vicinity of Sellafield for the time period 1963 to 1992, the latter being the last year for which we have national data for comparison.

9.3 The whole period 1963-1992 was subdivided into the period examined by the Black Advisory Group (1963 to 1983) and the period following publication of the Black report (1984 to 1992) in order to see whether the raised incidence of malignant disease in young people identified by Black had persisted.

9.4 For the period 1963-1983, the conclusions of the Black report regarding an increased incidence of leukaemia in 0- 24 year olds, are confirmed. Our results show a significant increase in "all malignancies" (Observed (O) = 6, Expected (E) = 2.18, Observed / Expected (O/E) = 2.75, one sided probability (p) = 0.024) in 0-24 year olds in Seascale Ward, which is primarily due to a significant excess of cases of lymphoid leukaemia and NHL (O= 5, E = 0.49, O/E = 10.16, P = 0.00016). There was one case of cancer other than leukaemia or NHL.

9.5 The analysis for the "Post-Black" period 1984-1992 was designed to test the null hypothesis that no excess of leukaemia or other cancers in 0-24 year olds has occurred in the vicinity of Sellafield during that time period. We agreed the diagnostic groups, areas and calendar periods to be analysed in advance and these were based on the original Black findings.

9.6 Our main finding rejects the null hypothesis described in the paragraph above and strengthens the original Black observations because for the post Black period 1984-1992, for the age group 0-24 there is a significant excess of "all malignancies" in Seascale Ward (O = 5, E = 0.78, O/E = 6.4, p = 0.0012). This excess is composed of a significant excess number of cases of lymphoid leukaemia and NHL (O = 3, E = 0.16, O/E = 19.1, P = 0.0006). In addition there were two cases of other cancers which showed a non-significant excess (O = 2, E = 0.62, O/E= 3.2, p = 0.129).

9.7 Our overall conclusion is that there is good evidence for a continuing, significantly elevated level of all malignancies in young

people (0-24) throughout the period considered in the Black report (1963-83) and our subsequent analysis(1984-92), covering a total period of three decades. This is primarily due to a significant excess of lymphoid leukaemia and NHL throughout the period (1963--92). Although the relative increase in 1984-1992 was greater than that in 1963--1983, this was based on only three cases and the difference between the relative risks is not statistically significant. If we consider also the cases diagnosed outside the analysis period (1963-1992), there is the suggestion that "other cancers" might also be elevated.

9.8 The excess found among young people did not extend to the older age group 25-74, nor did it extend to the two county districts nearest to Sellafield or to Cumbria generally, although there was a less marked excess of leukaemia in Egremont.

9.9 When Seascale is examined in the context of the national distribution of childhood leukaemia plus NHL it is highly unusual and the most extreme relative increase in time and scale that has been observed. However, it should also be remarked that since leukaemia in children and young people is, in fact, a very rare disease, even the increase in risk reflected here, which appears to be confined to a small area, represents a small absolute risk and a small number of cases.

9.10 We have addressed possible reasons for these epidemiological findings and have considered a number of possible hypotheses which might explain the Seascale findings. We also note that any hypothesis has to explain why the excess is confined to Seascale.

9.11 First we considered the initial hypothesis, previously investigated by the Black Advisory group and in our first report, namely that an association existed between the doses received by the local population from environmental radiation and the incidence of childhood leukaemia and other cancers.

9.12 Since the time of the Black Report, we have obtained further data on routine and accidental discharges of radioactivity which are as comprehensive,complete and reliable as reasonably achievable. These data include a detailed reassessment of the aerial discharges during the early years of plant operation. This reassessment of aerial discharges, carried out by BNFL principally for litigation purposes, was made available to NRPB and ourselves.

9.13 At our request, and with our collaboration, NRPB carried out a complete reassessment of the doses and risks to the Seascale population in the light of this further information from BNFL and advances in scientific knowledge. The assessment is based on the recognised principles and methods of the International Commission on Radiological Protection, which have been recently revised. To cushion the assessment against some potential uncertainties in the dose estimates, NRPB also carried out a sensitivity analysis on selected major components or unusual pathways.

9.14 Changes from the previous assessment for the Black investigation and our first report include:-

I. inclusion of the doses from the radioactive fallout from the Chernobyl accident and the radioactive discharges from the Albright and Wilson chemical plant,

II. a comprehensive review of BNFL discharges which has revealed to some important increases in atmospheric discharges in the early yearsof the operation of the Sellafield site,

III. the use of the most recent biokinetic and dosimetric models, which include a new respiratory tract model, changes in gastro-intestinaJ uptake factors, use of physiological models with recycling for some elements and the use of comprehensive age-dependent models,

IV . the use of new models to calculate the risk of radiation-induced cancer as as described in a recent report on estimates of late radiation risks to the UK population and computing a best estimate rather than making 'worst case' assumptions.

9.15 Our principal conclusions regarding the original hypothesis (para 9.11) are listed below.

I. For the study population in Seascale, natural radiation contributes the largest equivalent dose to the red bone marrow (80%) whereas the discharges from Sellafield, both routine and accidental contribute less than 9%. Medical exposures are estimated to contribute an equivalent dose of about 5% and weapons fallout about 6%.

II. In their report R276 the NRPB have concluded that in the study population in Seascale, that is 1348 children born between 1945 and 1992 and followed to their 25th birthday or 1992 whichever is sooner , the number of radiation-induced cases of leukaemia and NHL would be expected to be less than 1 (0.46). The number of other cancers expected from radiation exposure from all sources is also less than 1 (0.22). These estimates have to be compared with the 12 cases of leukaemia and NHL and 4 cases of other cancers observed in the Seascale population between 1955 and 1992.

III. The expected number of cases of leukaemia and NHL between 1945 and 1992 calculated to be attributable to radioactive discharges from Sellafield is less than 0.05. Considering Sellafield discharges alone, both routine and accidental, the associated doses would have had to be about 200 times greater to account for the excess number of leukaemia and NHL cases on the basis of current scientific knowledge. We consider the probability of such a discrepancy to be highly unlikely.

IV. Having reviewed discharges and environmental monitoring data, and having noted previous underestimations of some airborne discharges, we consider that it is very improbable that the epidemiological findings could be attributed to undetected discharges, particularly of long-lived radionuclides, because the dose assessment relies primarily on the environmental monitoring data and only to a much lesser extent on the discharge data.

V. Our review of habit data suggests that intakes of radionuclides have been not been substantially underestimated nor have environmental pathways delivered substantially greater doses than previously estimated. The sensitivity analysis provides supporting evidence.

VI. We have considered the possibility that the biological effectiveness of particular types of radioactive material principally alpha emitters) in particular tissues may be greater than presently attributed by the International Commission on Radiological Protection, the conventional radiation weighting factor of 20 being used in this report(ICRP 60). However, as discussed in Chapter 3, and the sensitivity analysis, unreasonably large weighting factors for alpha radiation would be required for them alone to account for the epidemiological findings. Alpha radiation from all discharges is estimated to contribute only about 3% to the total equivalent dose from all sources to red bone marrow, whereas that from natural background alpha radiation is more than 10 times greater. We also draw some confidence from the NRPB's review conclusion that for leukaemogenesis "it would appear that there is no scientific basis for choice of an RBE value for alpha- radiation in excess of 20. Indeed, the evidence would support a somewhat lower value" (NRPB R276).

VII. We recognise that uncertainties inevitably remain. For example, fetal haemopoietic tissue and lymphatic tissue in the bronchial and intestinal regions of young people could have particular leukaemogenic sensitivity. It is also possible that uncertainties in biokinetic modelling of individual radionuclides in the body could lead to higher doses to relevant tissues than currently estimated, or that microdosimetric features of localisation within a tissue could lead to higher doses to some critically important cell type. However, it seems highly improbable that such factors would apply uniquely to the Seascale population, or that their dosimetric consequences would be sufficiently large for particular discharge radionuclides but not for any natural background radionuclides. We have found only one situation in the past where the high LET dose attributable to Sellafield discharges might have exceeded the high LET dose due to natural background, namely the high LET dose to the tracheobronchial lymph nodes. However, we know of no human data that suggests that human leukaemia can originate in the tracheobronchial lymph nodes, although it is recognised that many human lymphomas arise from lymph node tissue and these could include thoracic nodes.

VIII. The possible microdosimetric effect of tritium was specifically considered. However, both the sensitivity analysis and the absence of effects in the Canadian group of workers having particular exposure to tritium, demonstrate no significant contribution from this source. These considerations are kept under review by the International Commission on Radiological Protection, whose latest recommendations have been used.

9.16 To sum up, despite these remaining uncertainties, we consider the current estimate of the radiation doses to the Seascale population, due to both routine and accidental discharges, to be far too small to account for the observed excess of cases of leukaemia and NHL on the basis of present knowledge. Consequently, it seems highly unlikely that radioactive discharges from Sellafield have been the sole cause of the excess Seascale cases. Clearly, it is not possible to state categorically that environmental radiation, including natural background, could not have been a contributory factor for some Seascale cases, particularly if a combination of factors were involved. However, such a combination of factors would have to be unique to this particular locality and play a role in leukaemogenesis.

9.17 We have found no evidence that other radiation exposures to Seascale residents differed from those to residents elsewhere by virtue of unusual levels of environmental radiation (including radon), unusual medical procedures or experimental investigations

9.18 There are two possible mechanisms by which parental occupation could increase the risk of cancer in their offspring;
i. preconception effect through irradiation of the gonads ii. unrecognised pathways of exposure via workers

9.19 Gardner et al (1990a) suggested that paternal germ cell mutations from exposure of the gonads to ionising radiation could increase the cancer rate in subsequent offspring sufficiently to explain the excess in Seascale. Although there is a plausible genetic and mechanistic basis for a PPI effect, we conclude that the level of risk implied by this explanation is inconsistent with the radiation doses actually received via occupational exposure and current estimates of. genetic risk. Alternative explanations for this inconsistency have been suggested,in particular that the measured dose of external radiation may be a surrogate measure for internal exposure to radio-nuclides or to chemicals. Such data as exist do not support this suggestion.

9.20 While the principle that preconception paternal irradiation could cause cancer in offspring is currently sustained by a small body of experimental data in animals and by current knowledge of data on human genetic determinants of cancer, quantitative considerations of mutation rates according to accepted models have led us to believe that the size of any such effect so far demonstrated is too small, by at least an order of magnitude, to explain the Seascale phenomenon. We conclude that there remain some important questions about the microdosimetric and biological aspects of germ cell response to radiation, particularly in relation to internal radionuclides and the mechanisms by which effects may be transmitted through the germ cells at high frequencies (seeChapter 4). However, these are in our view most unlikely to explain the Seascale phenomenon alone since they would have to be unique to those workers (a minority of the work force) who lived in Seascale.

9.21 In addition to the data on radioactive discharges from Sellafield, we have considered whether there were unrecognised pathways of exposure via workers whereby radioactive material was inadvertently removed from the site or other activities had led to an increased risk of exposure to on site radioactive materials. We have reviewed the evidence from three studies performed on housedust in houses in Seascale. Although the data we have seen indicate that such pathways via workers may have existed, they also indicate that radionuclides in housedust in Seascale are not likely to be a significant source of dose.

9.22 Whilst there is evidence that some *adult* leukaemias may be associated with *occupational* exposure to certain chemicals such as benzene, of which there were very large quantities discharged in the early years of plant operation, there are currently no data showing a link with *environmental* exposure and subsequent cases of *childhood* leukaemia. Any hypothesis which purports to explain the Seascale cluster as being due to exposure to chemical discharges from the Sellafield site would need to take into account that adult (25 to 74 years old) leukaemia rates in Seascale are not elevated and that the leukaemia rate is not similarly raised in other nearby villages. We found no evidence of exceptional chemical exposures to Seascale residents. We have concluded, therefore, that exposure to chemicals is unlikely to explain the observed excess of childhood leukaemia in Seascale.

9.23 On the evidence that we have reviewed, we have concluded that it is probable that population mixing is a factor in the increase in childhood leukaemias described in some population groups. Therefore, it follows that the excess childhood leukaemia incidence in Seascale is likely to be causally associated, at least in part, with related demographic factors such as geographic isolation and mixing between residents who have migrated from different areas,or additional exposure to infections such as from a sewage outflow. Such factors may reflect the involvement of transmissible infectious agents in the aetiology of childhood leukaemia. However, it is not possible to quantify this effect in a satisfactory way in order to relate it to the effect of population mixing on leukaemia incidence in Seascale since no areas in the published studies are directly comparable with Seascale. The evidence, available at present, does not convince us that such a large relative risk persisting over more than three decades could be wholly attributed to population mixing.

9.24 We investigated other factors unique to Seascale and its neighbourhood which might be associated with the epidemiological findings. In particular we investigated the activities in the Sellafield area before the establishment of the nuclear site and whether there was any sign of an elevated childhood cancer or leukaemia rate in Seascale before the site was developed.

9.25 In the period 1941-45, Seascale had a large chemical factory either in construction or productive operation within a few miles both to the north and south of the village. This has led to the presence of large mobile work forces housed in the vicinity since that time.

9.26 We analysed the death certificates for the period 1900-1945. Our analysis has shown that there was no evidence of an excess of childhood cancer or leukaemia in this part of Cumbria during that period

9.27 We conclude that it is unlikely that there was any unusual genetic predisposition to childhood cancer in the population of Seascale around 1950. It is possible to speculate that some carcinogenic factor entered the environment of Seascale about that time. It is also possible to conjecture that it is associated with the existence of the Sellafield site, perhaps with its construction, its operation, or its effect on the make-up of the local population, or on their lifestyle, or with some combination of these factors. However, it is not possible to demonstrate such associations or why they should be confined to the village of Seascale.

9.28 None of the factors that we have discussed appears, on its own, to be able to account for the increased incidence of cancer in

young people in Seascale. We considered the possibility that these factors might interact. However, we have been unable to identify any such interaction that could explain the excess of lymphoid malignancies at Seascale. If there were an interaction between some factor and radiation it has to be acknowledged that the greater part of the radiation exposure of Seascale inhabitants comes from sources other than Sellafield and is similar to that experienced by the inhabitants of other parts of West Cumbria, indeed of the UK, which would make the elevated incidence of childhood cancer in Seascale alone difficult to explain.

9.29 We conclude that there has been a continuing excess of leukaemia and other cancers in 0-24 year olds in Seascale Ward in the post - Black period 1984- 1992, primarily due to an excess of acute lymphoblastic leukaemia and non Hodgkin's Lymphoma (NHL). Taken together with the results for the earlier period 1955-62 (for which comparable statistical analysis is not possible) and 1963-1983, the data show that there has been a continued excess of leukaemia and NHL in Seascale for four decades. Such evidence as we have does not indicate any excess between 1900 and 1945. We have investigated possible causes of the excess in later decades and conclude that:-

I. On current knowledge, environmental radiation exposure from authorised or unplanned releases could not account for the excess. Much work has been done to reduce the uncertainties present in the previous assessment although some uncertainties do still remain.

II. On current knowledge occupational exposure to radiation is very unlikely to account for the excess. Although there are uncertainties regarding internal radiation exposures it is not clear how these could affect the population of Seascale and not the other residents of small towns and villages nearby where workers from the Sellafield site also live.

III. Other possible hypotheses regarding chemicals and infectious aetiology have been considered. We conclude that environmental exposure to chemicals is unlikely to offer an explanation although admittedly the data are sparse. We do, however, believe that a mechanism involving infection may probably be a factor affecting the risk of leukaemia and NHL in young people in Seascale.

9.30 We conclude that the excess of leukaemia and NHL in young people in Seascale for the period 1963 to 1992 is highly unlikely to be due to chance alone. Various factors considered above could affect the incidence of leukaemia and NHL but no one factor alone could account for the increase. We cannot rule out interactions between different possible factors but, as yet, have no way of quantifying their effects nor of saying why the interaction would be unique to Seascale.

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Chap.11 IMPACT MITIGATION /REMEDIATION

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11.1 *METHODOLOGY*

STRATEGIES & TECHNIQUES FOR CLEANING RADIOACTIVELY

CONTAMINATED SITES (Ref: W.Eberhard Falck in IAEA Bulletin and TECDOC 1279)

Actions for a cleaner and safer environment have risen on social and political agendas in recent years. They include efforts to remediate contaminated sites posing a radiological risk to humans and the surrounding environment.

Responding to the needs of Member States, the IAEA has launched an Environmental Remediation Project dealing with the problems of radioactive contamination world-wide and aimed at collection and dissemination of information by publishing documents on key problems of environmental remediation of contaminated sites.

The term ‘remediation' is used here to encompass all activities leading to reduced exposure to radiation and to improved environmental and/or economic value of a site. It does not, however, necessarily imply recreation of pristine environmental conditions.

The terms‘rehabilitation' and ‘restoration' are often used interchangeably in a similar context, depending on the language and other national peculiarities. In the present context the term ‘remediation' refers to the management of contamination, that is, removal, fixation,monitoring, and so on.

Factors Influencing the Decision Making Processes and the Objectives of Site Remediation (W. Eberhard Falck)

Introduction

An overarching objective of any environmental remediation project for former uranium mining sites is that remediation should not just simply improve the radiological situation, but that it also should result in some added value to the region. Thus, a range of non-technological factors will influence the strategy to be followed and the choice of techniques to be employed. These factors and suitable mechanisms for accounting for them in a quantitative and traceable way in decision making, with the aim to reduce programmatic risks and increase public acceptance of the project, will be briefly discussed in this paper.

The Context of Restoration Projects

Environmental restoration projects, in particular those in former mining regions, inevitably take place

against a backdrop of overall social goals and values. These goals can include, for example, full employment, preservation of the cultural, economic and archaeological resources, traditional patterns of land use, spiritual values, quality of life factors, biological diversity, sustainability (in the environmental and economic sense) , protection of public health, and desirable level of public participation. There is a strong link between the overall set of societal goals and the availability of resources, including funding, man-power and skills. These issues are embedded within both a national and local socio-cultural context, and will shape the way in which the remediation process is played out. The context will shape both the overall objectives of a restoration activity within the framework of competing societal goals, as well as generate constraints on the decision making process. Most decision are not made in isolation, but are built on decisions that have already been taken and affect the choices that will be available in the future. It must be understood that resources spent on remediation activities are typically not available for use in achieving other goals of the society. Their availability, therefore, may be controlled by priority setting within the society. The balancing of the various goals of social policy are often handled in a political context which specifies the level of resources available for restoration.

Socio-Economic Benefits

The choice of a restoration strategy may be tailored to the socio-economic needs of a region or the respective resources available. Thus the overall socio-economic benefit in a region might be improved by choosing an appropriate technique involving the local man-power and other resources. Drawing out a project over a longer time scale, thus keeping local staff employed for a longer period of time, might be more economic at the bottom line than earlier completion followed by paying unemployment benefits; and it may add a social dividend.Economic impacts of contamination situations may manifest themselves in a variety of direct and indirect forms, including loss of property value, loss of markets for agricultural produce, job losses, relocation costs, costs of extended commuting to farther workplaces, or higher cost of food-stuffs. Hence, remediation activities offer local communities a considerable potential for economic benefits.It is probably fair to expect that public benefit from public money be maximised. Therefore, the economic benefits, or detriments for that matter, should be evaluated *a priori* as far as feasible.

Perception and Acceptance Issues

Various groups of the public will be affected by both the mining legacy and the restoration process in different ways. There will be also a considerable difference between actual effects, risks, benefits and detriments ensuing and those perceived. Individual or group decision makers dealing with radioactive contamination issues, naturally base their decisions on the problem as they perceive it. Hence, it is important to recognise that perceived risks are as ‘tangible' as real risks, as far as the decision making process is concerned.
A sustainable solution - in a societal context - can only be found with the support of the problem stakeholders. Therefore building trust and effective communication between the interested parties are key issues which will be highlighted in the paper.

Environmental Impact from Restoration Projects

Restoration objectives and the technologies used to achieve these objectives have to be evaluated in terms of their potential impact on human life and the environment. The implementation of a restoration project may result in a variety of environmental impacts in addition to those resulting from the contamination itself. Such adverse impacts to ecological receptors on-site or off-site may be due to the deployment of a remediation technology, causing significant disturbance to the site ecosystem and its surroundings. For instance, certain measures, such as removal of topsoil or soil washing, indeed effects the removal of surface contamination, albeit at the cost of destroying the soil ecosystem.
A remediation project may result in possibly significant off-site environmental impacts and risks, through e.g. removal, transport and disposal of residual wastes, such as tailings or waste rocks, to locations other than that of their original deposition. Also, the deployment of technology may require an area larger than the actual contamination and space for intermediate storage of wastes and other materials.

Future Site Use

The envisaged site use and improved image of a mining region may be the main driver for remediation as such and may determine the projected end-point apart from radiological considerations. The most beneficial use will depend upon the site's particular traits, strengths, and weaknesses, as well as the goals that the affected governments and communities, and other interested parties would like to fulfil through re-use. Therefore, the most beneficial use of one property at a site may be industrial re-use, while that of a different parcel at the same site may be as a recreational space or habitat preserve. Establishing the most beneficial use of a site requires a sound understanding of the site's specific features, its legal and environmental status, and the re-use constraints they may be impose. Information gathered through site assessments, environmental audits, cultural resource plans, and other research must be considered when evaluating alternative future uses.

11.2 REMEDIATION OF WASTE MANAGEMENT FACILITIES

11.2.1.Objectives and strategies

Waste rock and tailings impoundments and sites of former mines and mills not in compliance with applicable criteria and standards may need remediation. The objective of remediation is to remove any potentially harmful effects on the environment and human health and to render impoundments stable over prolonged periods of time. The methods and objectives for remediation are similar to those followed in ordinary closeout of such facilities. In addition to the mineralogical, geochemical and geotechnical characterisation as discussed earlier, additional information must be gathered in order to development the final plan for remediation and close-out:

• Agreed final land use.

• Physical characteristics: tonnage and area of the rock piles and maximum area which can be

used for final disposal site, maximum height for contouring, maximum permitted slope angles,

erosion characteristics for proposed combinations of waste rock and slope, and possible limitations on use of erosion control structures of final cappings.

• Availability, quantity and quality of soil for use in revegetation, availability of suitable seeds and/or plant stocks for use in revegetation.

• Experience with revegetation of similar rock types in the region.

Methods for remediating selected problems are discussed in more detail below.

11.2.2.THE LONG-TERM STABILISATION OF URANIUM MILL TAILINGS

Draft Summary of TECDOC describing the results of an IAEA CRPHistorical practices

Tailings produced from the milling of uranium ore in the 1950s and 1960s were regarded as little or no different to other non-radioactive mill tailings in terms of their potential hazard. The general poor level of knowledge as to the potential radiological effects is clearly demonstrated by use of uranium tailings as a building material in many places close to uranium mines and mills. The tailings were placed as a matter of convenience and cost in the nearest receptacle, which would commonly be a natural depression or lake if available. If no suitable natural depression was available, one would be constructed by building an embankment or low dam across a valley or across the lower slopes of gently falling ground. Where no depressions or slopes were available the tailings were sometimes placed on flat ground in dry climates, or a ring dyke would be built in wetter areas. However, there was generally little or no attempt to prevent flow of water which had contacted the tailings into streams and rivers. Scant regard was paid to dispersal as dust, and generally no action was taken to remediate areas affected by a containment failure or to collect and return the spilled tailings back to the containment.

Containment practices began to improve in the mid-1960s, and more substantial impoundments were commonly constructed, especially at new mine and mill sites where improved tailings dam designs were incorporated into tailings management plans – such as the upstream method of construction where cycloned tailings would be used to build raises on the dam embankment. However, unsuitable practices for tailings disposal continued at some sites until the 1970s and later, especially where uranium production was subject to tight government control and secrecy.

Some of the options for placement of tailings that we would consider suitable today were used historically, but more by coincidence than design. An example is the backfilling of old open pits; however, no amendments were made to limit the potential for contamination of surface or ground waters. In general, no consideration was given to the different climatic situations in which the tailings were stored and the different levels of risk of containment failure or the consequences to human health or to the environment. This lack of concern was based on ignorance of the risks and hazards. Development of an understanding of these risks and hazards grew out of the growing body of knowledge about the effects of radiation on the human body. Legislation aimed primarily and protecting the health of workers was developed from the 1940s, but it was not until the mid 1960s that concern for impacts on the wider community and on the environment led to a major change in

the way that the risks and hazards of uranium mill tailings were perceived, including the long-term nature of those risks and hazards. From this time a major change took place in the approach to design of tailings containments. A new approach gradually developed which considered issues such as climate, possible agents for containment failure, long-term containment, and the values and sensitivity of the surrounding environment in order to reduce the risk of containment failure and potential hazards to the environment.

Environmental impacts

Poor practices in the placement and management of mill tailings in the past have contributed significantly to the negative legacy of uranium mining. The dangers specific to uranium mill tailings relative to tailings from other types of mines were unknown and they were treated in the same manner. That manner was to dispose of the tailings cheaply and conveniently – in topographic depressions to contain tailings and liquor in wet environments (the depressions may have been valleys, lakes etc), or to pile them on flat areas in drier climates. The main vector for contamination in wetter regions is water erosion, leading to contamination of water courses and lakes, while in dry regions the main vector is dust. The contaminants comprised radioactive material as well as toxic metals and other chemical compounds, in many instances accompanied by acidity and salinity.

As was the general case in the mining industry in the first 60 years of last century, there was little or no maintenance of tailings piles; for example, if fences had been provided they were not mended or replaced if breached or stolen, and there was no rigorous restriction on access to and re-use of the tailings material.

Health and environmental impacts of a wide variety occurred, relating variously to:

- Catastrophic failure/collapse of containments, in some cases causing deaths;

- Uncontrolled public access to and inappropriate re-use, leading to increased radiation doses and cancer risks;

- Overflow and/or seepage of tailings liquor into surface water systems, causing contamination and ecosystem impacts along rivers and in lakes;

- Seepage into surface and groundwater systems, leading to contamination of water resources important for drinking, irrigation, public amenity and tourism.

The recognition of radiation exposure due to the re-use of tailings as a building material in the USA, mainly as aggregate for concrete production and for fill material, led to an understanding of the level of risk that tailings posed to human health. Subsequently, the first regulations applying specifically to uranium mill tailings were developed. An understanding of the risks posed to the environment has been slower to develop, starting from a concern that uptake and bio-accumulation in the food chain could increase the total dose to humans.

Assumptions using man as the indicator species to determine a safe radiological dose rate for all

species appear to have been useful approximations upon which to base standards for protecting the natural environment from the risk of damage from ionising radiation. However, the long-term risks of chronic exposure are not understood, particularly in terms of potential long term (ie genetic) effects on species populations, density, ecosystem dynamics, and biodiversity. A new body of research is building in this area which is focussing on risks and effects in the fabrication, power generation and disposal parts of the nuclear fuel cycle; it has yet to adequately address risks arising from lower activity levels from tailings impoundments.

Uranium mill tailings are made up of a cocktail of potentially toxic components, some of which are known to be significantly more toxic that the radioactive minerals. Studies of impacts in the past, as well as planning better tailings management in the future, needs to take into consideration the full suite of toxicants present in uranium mill tailings.

Remediation programmes

Remediation of uranium mill tailings piles has been undertaken and/or is in progress in virtually every country, where uranium has been or is being produced. Early attempts at remediation have been variable in their success. Assessments of effectiveness are few in number and generally limited in quantitative and comparable information. Even with the most careful planning, there is room for certain critical concerns to be overlooked. As knowledge on environmental sensitivity grows and regulations and standards evolve to reflect this knowledge in response to public concern, the design standards for remediation will become more demanding.

Much is being learned from the remediation programmes as they are undertaken and as monitoring data are collected after completion. A distinctive message that comes out of the work done to date is that there is no single best approach. Each site must be studied closely to determine the optimal approach. The amount and type of work, and the associated costs, will differ markedly from site to site. Short-cuts will probably lead to parts of the work having to be re-done. Methods of construction and design that are harmonious with and emulate nature are preferable to engineered designs that are built to resist, rather than to harness natural processes for long-term stability.

The challenge of remediating areas of environmental impact from old mines has proven difficult on technological and economic grounds. Even the well-funded Uranium Mill Tailings Remediation Action Programme (UMTRA) in the USA took almost twenty years to undertake. Remediation works and costs are most demanding when planning and incremental preparation for closure and remediation are not integral to the operational life of the mine and tailings facilities. Where uranium mining is undertaken by the private sector, regulations may be developed and imposed to ensure adequate and timely planning and funding for remediation to reduce or remove the probability of liabilities being transferred to government. Where uranium mining is undertaken by government institutions, similar arrangements may be put in place to ensure that remediation planning and implementation are identified as the responsibility of the operators. Funding normally takes place on the basis of approved programmes and is subjected to comprehensive control.

Present day practices

In general terms the technologies used in the uranium mining industry are no different from those used for other mill tailings. Most of the environmental problems experienced with uranium tailings are similar to those found at other mines and mills. In fact, a significant source of environmental hazard related to uranium mill tailings may come from the non-radioactive component of the contaminant inventory. Hence, the principles developed for other types of mining can generally be applied to uranium mill tailings. Examples of most of the different types of containment and method of their construction can be found in the uranium mining industry. For tailings facilities developed during the last 25 years, detailed information is readily available and in the public domain.

The containment of mill tailings is closely related to the site-specific setting of the mine and mill. The main considerations for defining the most appropriate practice are technical, environmental, economic and societal. While engineering design provides a wide range of options for the containment of mill tailings, the nature of the site where they are located generally determines the containment method employed. What can be considered the best or the most cost-effective containment will differ from site to site, depending on climate, ore/tailings type, impounded volume, seismicity, remoteness, available transportation and logistics, and availability of natural or constructed openings. Clearly, a careful analysis needs to be undertaken for each individual site to ensure that the most appropriate option is chosen.

Tailings dam failures have occurred in the past, but their occurrence and frequency are not readily related to certain types of dam or construction methods. There is statistical evidence to support the view that most failures relate to the saturation, liquefaction and rheological characteristics of wet tailings held in dams, and that the risk is much higher during the operational phase. Clearly, water management is a critical issue for risk reduction. Dams can fail after closure, mainly as a result of earthquakes, geotechnical factors, and overland flooding. Often, poor or non-existent care and maintenance are at the root of these failures. Accordingly, close-out designs should pay particular attention to mitigating these hazards. A large body of information exists with respect to tailings dam failures outside the uranium industry, which is directly relevant to uranium tailings management.

Containments other than dams that utilise natural depressions, such as lakes, or constructed voids, such as mine pits and underground openings, offer certain advantages because of their inherent physical stability after closure. Risk from earthquakes and overtopping is mostly removed. The main mechanism for environmental pollution from below-ground containment is the contamination of groundwater.

Methods available to reduce the risk of pollution from containments involve reduction of possible contaminant source terms by tailings preparation and treatment, isolation from the environment by covers and seals, as well as active and passive effluent treatment. In some cases relocation may be the most appropriate remedial solution, particularly, if the tailings are in the immediate proximity of populated areas.

A large body of work is available on capping design. Cover designs and construction needs to be site-specific, taking into account the local climate, availability of construction materials, nature of the tailings impoundments, regulatory constraints, as well as local community demands and acceptability. Although site-specific information is needed for each site, it is probable that research

work into designs is being repeated unnecessarily in several countries. It seems to be time for this large body of work to be assimilated so that it is readily available and comprehensible to all. Nevertheless, the local availability or non-availability of generally preferred construction materials, such as clay for cappings, and the limited financial resources to obtain these materials on the world market, may make it necessary to develop local designs in some Member States.

Research specific to uranium mill tailings containment goes beyond research into containment of non-uranium mill tailings, because of the focus on longevity and the problems specific to radioactivity (particularly radon emanation). Specific areas of research into longevity include, climate change and variability, erosion, long-term geotechnical stability, monitoring, and long-term model development and calibration.

However, non-uranium tailings also pose long-term hazards, particularly due to acid mine drainage generation. There is potential for the benefits of research into uranium tailings management to feed into other, non-uranium tailings research areas and *vice versa* , and for co-operative research on shared issues of concern, such as the longevity of physical and chemical performance of containments.

In summary, considerable progress has been made in the safe containment of uranium tailings during the last 20-30 years.

Outstanding issues

The outstanding issues relating to stabilisation and isolation of uranium mill tailings concern the confidence in long-term secure containment, prevention of seepage from the containments, and chemical mobility of contaminants in the short and long term. A new concept is developing that seeks to embrace natural processes as much as possible in improving physical and chemical stability by understanding and taking advantage of natural assimilation and attenuation (ecological design). This could lead to a fundamental change in the way that impoundments are designed, away from structures engineered to keep their contents out of contact with the environment, to structures that somehow utilise natural processes to assimilate the entire structure and its contents with the surrounding environment over the long term.

New approaches

A hiatus in the level of research occurred in the 1990s following the conclusion of much of the research undertaken in north America under the US Uranium Mill Tailings Remediation Action Programme and the Canadian National Uranium Tailings Programme. The results and lessons learned from those programmes are still relevant today, and form the basis of basic research into design and planning of remedial works in other countries today. However, the results of the earlier work are not always readily accessible and a comprehensive critical evaluation is not available, so that valuable funds and research resources are not spent on un-necessary repetition and duplication of research.

The main foci of current research are methods to stabilise tailings. Whilst the above discussion attempts to divide the description of this work into physical stabilisation and chemical stabilisation of

tailings piles, and stabilisation of covers, much of the work being done cuts across all three areas. This is because the majority of the work is on methods to ‘cement' together the tailings with agents that are able to absorb or co-precipitate the contaminants (with emphasis on the metals) as a result of redox reactions and modifications to pH. Therefore both chemical and physical stability result from the one process. The agents vary from tried and tested Portland cements, to other inorganic and organic reagents, and high-tech polymers. Some harness and enhance natural diagenetic processes, and others take no account of them.

The result is a large body of work offering tantalising potential opportunities for application in the isolation and stabilisation if uranium mill tailings, at the placement stage, during non-operational pre-closure stages, during remediation preparation, remediation works, and *ex post facto* . However, much of the work is not sufficiently developed and demonstrated to allow the potential benefits and costs and operational requirements to be evaluated. Also, techniques that have been developed and implemented successfully for non-uranium tailings have not been adequately tested on uranium tailings for their suitability to be fully apparent (e.g. acid drainage mitigation techniques which would also probably reduce uranium mobility in the case of acidic/sulfidic tailings, paste and dry cake technology for dewatering and pacing tailings).

The requirement for high security tailings isolation for periods of time in the order of thousands of years is peculiar to the uranium mining industry, even though sulfidic tailings dumps are now known to pose environmental risks for up to a thousand years. There is a growing level of interest in a new approach to designing mine closure in a way which is cognisant of the effectively infinite time frame, rather than approaches based on finite design lives and, therefore, probable future failure. Similarly, nature provides various mechanisms that assist in stabilisation of contaminants, and there is now high interest and research activity into understanding these processes so that their potential can be maximised in order to develop better ‘passive' systems and reduce the probability of failure inherent in interventionist systems.

A new generation of stabilisation techniques based on high-tech polymers and sophisticated organic chemistry is developing, and promises to provide more effective and durable techniques for operational and *ex post* stabilisation than those based on Portland cement paste technology. This field of research is developing rapidly. Much of the information is based on laboratory scale testing with only limited field trails, and information on its feasibility for application in the field is generally lacking.

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11.3 CASE STUDY: WISMUT *Peter Schmidt*

A) OPTIMISING THE REMEDIATION OF SITES CONTAMINATED BY THE WISMUT URANIUM MINING OPERATIONS IN GERMANY

Initial Situation and Criteria for Evaluation

The large industrial scale uranium mining operations in densely populated regions resulted in severe impacts on the environment. Radioactive and other contaminants were dispersed in the soils, the groundwater and the atmosphere.

Radiation protection is one of the main motives behind remediation in uranium mining, but by no means the only one. The licensing of measures to ensure mining safety, groundwater protection and further land-use has to consider radiological implications.

The current environmental regulations in Germany have the aim to prevent undue impacts on the basis of precaution. This applies also to measures in planning. In dealing with intervention situations, the planning has to consider not just the current impacts, but also those that might arise due to the

remediation measures. It applies both to radiological and to non-radiological impacts. International recommendation, hence, stipulate that any exposure, including those resulting from remediation activities, have to be justified, optimised and limited.

These three principles are applied to practices as well as to intervention situations.

Any individual remediation measure is justified, if the associated benefits exceed any

detriment that might be related either to the contamination itself or the remediation measure.

Optimising consists in identifying options that maximise benefits while minimising detriments. Hereby the ‘do nothing'-option serves as the benchmark to evaluate benefits. The evaluation has to encompass radiological, environmental, nature conservation and cost aspects and also to consider the acceptability of any proposed solution within the stakeholder community.

Wismut is working towards an efficient progress in remediation.

Individual remediation measures have to be integrated in a meaningful way into the overall remediation strategy.

Based on a careful site investigation and evaluation of the degree of contamination resulting from uranium mining and milling, the site specific needs for remediation are defined and an optimised remediation strategy is developed, considering achievable remediation goals. The selected remediation option is to be approved by the licensing authorities.

Environmental Impact Assessment

Optimising stands for reducing health risks while minimising the socio-economic cost at the same time. Planning of remedial measures and site investigations are an integral part of a remediation project and expenditure on those has to be carefully balanced against requirements to fulfil the criteria of justification, optimisation and risk reduction.

In many instances of remediation projects those environmental impacts that will be controlled

by legislation can be assessed sufficiently on a deterministic basis. In this case, the current state of the site and the effect of the remediation, including any protective and precautionary measures, and the state following remediation are assessed and evaluated. Based on a site specific assessment of exposure pathways the exposure of the public in general and of the workers on the remediation project is estimated. The need for remediation is justified on the basis of action levels for individual doses to reference persons of the general public.

Additional exposure of the general public and the workers due to the remedial action is to be limited. In cases where no alternative remediation strategies are feasible or no alternative remediation technology exists, the proof of optimisation is effected by comparing the different protective and precautionary measures.

Evaluation of Remedial Actions

Extensive projects and projects of potentially significant environmental impact are evaluated on the basis of a more detailed catalogue of criteria with respect to the various alternative remediation strategies. This includes a comprehensive assessment of socio-economic implications. In addition to cost and environmental and health risks, remediation options are evaluated with respect to their public acceptance, the use of resources such as soil and water, as well as their impact on the regional development, e.g. stimulation of investment as desirable side-effect of the remediation effort, preservation and creation of job etc.

During the process of optimisation a preferred solution is derived from several technically feasible and regulatory acceptable strategies that have been developed on the basis of predetermined criteria. Transparency and traceability of the decision making path by which the preferred solution has been developed is one important prerequisite for regulatory acceptance. The method used for this purpose are probabilistic cost and risk assessments, and multi-attribute decision making methods.

Probabilistic Cost and Risk Assessment

The cost and risk assessment is performed using an iterative probabilistic ‘top-down' model of the remediation project as an integrated system. Initially all relevant processes are captured in a rather abstract and simplistic way. To this end, functional relationship are established between uncertain variables, the value of which are represented by probability distributions. In the course of the model development those variables and processes, to which results have been shown to be sensitive, are described in more detail. In this way resources available for modelling are efficiently deployed without loosing focus and meaningful conclusions can be drawn early in the process, even though some parts of the system may not be known yet in detail. This approach is also useful for identifying any gaps in the knowledge base that have to

be filled in the course of the decision making.

In the course of development from the qualitative, conceptual model to the quantitative model, the time-dependent costs and risk are modelled for each envisaged course of remedial action:

1. Collection and evaluation of data on the site and pertinent remediation strategies;

2. Identification of processes and events relevant for the site in question;

3. Identification of the various cost and risk elements (e.g. cost of implementation, major exposure pathways, risk of failure of engineered structures, such as dams or surface covers);

4. Conceptualisation of the relevant processes and events of the various remediation strategies and their effect on costs and risks;

5. Development of the mathematical model to describe the system behaviour (balancing equations, cost functions, concentration-dose and concentration-risk relationships, risks and costs as a result of losing institutional control);

6. Deterministic and probabilistic parameterisation in order to quantify certain and uncertain parameter values;

7. Programming of model using software tools suitable to describe parameter uncertainty;

8. Calculation of time-dependent probability distributions for costs and risks for each

remediation option.

9. Identification of the most sensitive variables and assessment of their uncertainty in order to be able to further detail the model in the next step of iteration.

Multi-Attribute Decision Aiding Tools

Multi-attribute decision aiding tools are used to identify a preferred remediation solution taking into account the deterministically and probabilistically derived data on expected costs and health risks. Depending on the complexity of the problem in hand, various methods,

ranging from simple pareto- or dominance analysis to probabilistic models are employed.

The requirement for optimisation, also with respect to socio-economic impacts, is met by including other variables in addition to costs and health risks.

Costs Health Risks Acceptance

implementation of remedial action radiation, chemical toxicity, accidents socio-economic aspects (employment) water treatment during and after remediation quality of life factors maintenance, monitoring workers and general public institutional factors additional land required ecological aspects, management of scarce resources

The various criteria influencing the assessment and the optimising are partly in competition with each other. For instance, a certain option that might be preferred on the grounds that it minimises health risks could turn out to be the most expensive and would be rejected in favour of a less expensive solution that might entail higher health risks, if cost were an overriding criterion. Similar mutual relations can be observed for other sets of criteria.

For this reason, trade-offs have to be found by weighing the criteria in a way that is acceptable to society.

The relative weight of the criteria can only be determined satisfactorily on the basis of a uniform

measure (e.g. a rating). Monetarisation of criteria has been used in the past, but did not find universal acceptance in society. For instance, the assumed numerical value for the monetary value of loss of one year of collective life expectancy varies in the published literature between US$ 17000 and US$ 450000.

However, a solution based on a cost–benefit assessment and trade-offs can only be considered robust, if it remains stable upon changes in the relative weights of criteria and parameter values. For this reason a test of robustness has to follow the identification of parameters that are relevant to the final decision.

Multi-attribute analysis tools have the advantage over other, more subjective decision making methods that they

__ allow decisions on a rational basis;

__ allow to trace decisions made and criteria employed;

__ allow to document the weight given of single criteria.

These properties facilitate the communication between problem holders, licensing authorities, consultants and the public and thus facilitate consensus formation on complex decision making problems.

B) REMEDIATION WORKS at WISMUT (Germany)

Objective, Strategy and Tasks

Termination of the mining and milling of uranium ores in the German states of Saxony and Thuringia in the East of the country and initiation of remediation work at the beginning of the nineties laid the foundation for the gradual reduction of environmental impacts caused by uranium production and its legacy.

Rehabilitation of the Wismut legacy in Saxony and Thuringia is one of the largest ecological and economic challenges facing the reunited Germany. The corporate purpose of the federally-owned company WISMUT GmbH is to decommission its former uranium mining and milling facilities and to rehabilitate the devastated land for future reuse. This involves a surface area of about 3,700 hectares; of this more than 2,300 hectares are occupied by waste dumps and tailings facilities. The large-scale operation is funded by the federal government which earmarked a total 13 billion marks for the completion of the project.

In terms of complexity and size, the Wismut project is unique, even by international standards. Although activities within this complex environmental remediation task are related, each site has a unique set of clean-up problems, which represent a total of more than one thousand challenging individual projects. The overall project includes

· abandonment and flooding of underground mines,

· relocation and covering of waste rock piles,

· dewatering and geomechanical stabilisation of tailings ponds,

· dismantling and demolition of structures and buildings, and

· site clearance and rehabilitation.

The primary objective to be achieved by the remediation is to reduce radiological, chemical and other exposures related to the uranium mining legacy. From a radiological point of view, the German Commission on Radiological Protection proposed a primary recommended limiting level for the effective dose of 1 mSv/a as a criterion for decision-making on remediation of areas, buildings and waste dumps contaminated by uranium mining [SSK-92]. This level conforms with the variation width of the natural radiation exposure and applies to contamination-related exposures, i.e. in addition to background exposure levels.

The establishment of remediation need is done on a object-specific base (justification of a remedial measure). Based on an exposure pathway analysis, the environmental impact posed by the individual objects is then quantified and evaluated. When remediation is required, different options are compared and exposures via all realistic pathways will be established for situations before, during and after the implementation of remedial measures. With due regard to ecological, economic and other criteria (social factors, stakeholder involvement, etc.) a preferred option is selected as the result of a complex optimisation procedure and then submitted to a licensing process (optimisation of the remediation project). For the optimisation of complex projects, WISMUT uses a multi-attributive approach.

The remediation of the objects is geared to comply with re-use requirements of municipalities or future owners of the rehabilitated sites. WISMUT GmbH applies an integrated system of quality assurance to all levels of remediation work.

The principal tasks in remediating the legacy of former uranium mining and milling sites were:

- Closure of underground mines

When SDAG Wismut terminated the mining and processing of uranium ores at the end of 1990, nine mining shafts were still active. A total of 56 major shafts and 1,400 kilometres of mining adits, drifts and galleries were still in operation. Early decommissioning of this large network of underground workings, and preparing the mines for flooding and eventual closeout had been a priority ever since. Prior to initiating the flooding process, a number of preparatory measures had to be taken:

- removal of grease/oils and of hazardous chemicals from underground mines,

- damming and sealing of individual mine fields to ensure control of water and air circulation,
- backfilling of mines that have the capacity to cause subsidence at the surface,
- permanent filling and plugging of pit shafts, adits, and large diameter bore holes.
- Remediation of waste rock piles and open pit backfilling

During active uranium mining, stockpiling of sub-grade ore, waste rock and overburden created 48 waste piles at the different sites of Wismut GmbH. At the end of uranium ore mining, these piles contained more than 310 million cubic metres of waste rock and covered a surface area of approximately 1,520 hectares.

Sitting there bare and unprotected these waste rock piles could not have been left in their original state. Depending on their location, shape and contaminant inventory, they presented various hazards to humans and the environment. Among the major hazards were:

- exhalation of radioactive radon gas,
- dust emissions and the release of dust-borne long-lived alpha emitters,
- release of radioactive and chemotoxic contaminants by seepage from the dumps,
- lack of stability.

In the remediation of waste rock piles, WISMUT GmbH follows different approaches. Technically most challenging is the option of

- excavating and moving entire waste rock piles

either to the worked-out Lichtenberg open pit uranium mine (Ronneburg site, Eastern Thuringia) or to engineered sites. In cases where relocation is not feasible on technical or financial grounds, WISMUT GmbH opts for in situ which implies.:

- Grading and covering of the recontoured waste rock pile

Both the excavation and the subsequent grading and covering of relocated waste rock piles involve moving of immense quantities of waste rock and barren material (cover materials).

· Stabilisation of Tailings Ponds

Tailings ponds cover a total of more than 570 hectares and contain about 150 Mill. m 3 of fine-grained residues or tailings from the processing of uranium ore. The tailings were discharged into the tailings impoundments as slurry. In order to achieve long-term stabilisation of the tailings ponds, dry

in-situ stabilisation with partial dewatering of tailings was selected as the most appropriate option . Tailings dams will be contoured, covered and designed to achieve protection against erosion.

Tailings pond stabilisation will involve the following individual steps:

- removal, treatment and discharge of supernatant pond water,
- interim covering of exposed tailings areas,
- regrading of dam and tailings surfaces,
- final covering of contoured surfaces,
- landscaping and revegetation,
- collection, treatment and discharge of seepage, and
- long-term monitoring.
- Dismantling, demolition and site reclamation

Following the termination of uranium ore mining and processing, the majority of installations and buildings owned by Wismut GmbH are destined for dismantling and demolition. Dekontamination and subsequent rehabilitation of the objects is neither technically possible nor can it be justified for economic reasons. After identification and evaluation of contaminated plant areas, clean up goals are specified that will allow future industrial use of the rehabilitated sites.

- Water Treatment

Contaminated water from Wismut remediation operations has to be collected and treated in purpose-built water treatment plants to protect ground and surface waters against pollution. Such waters are primarily:

Flood water: Ground water that is pumped from a mine for flood control purposes or that overflows at the surface when mine flooding is completed.

Pond and pore waters: Mill process waters and precipitation contained in tailings ponds, and

Seepage: Surface water infiltrated into waste rock piles or seeping from the toe of the dump or seeping from tailings that is collected at the toe of dams.

In treating the water, contaminants are separated, immobilised and safely disposed of.

· Environmental Monitoring

The mission of the environmental monitoring is to measure the impact the various liabilities have on the environment as well as to examine the impact remedial action itself has on soil, air and water. Monitoring is not only performed before and after the completion of remediation works, but also during their implementation. Since 1991, public information includes Environmental Reports, which document the results of environmental monitoring.

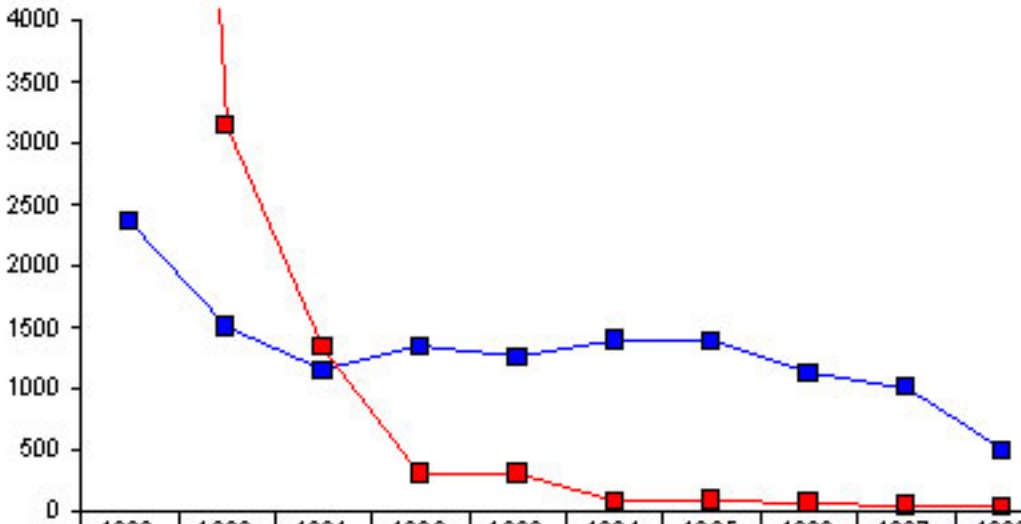
State of remediation of former WISMUT sites:

Since the beginning of remediation work in 1991 the following tasks were completed by May 2001 (Percentages indicate the ratio of completion):

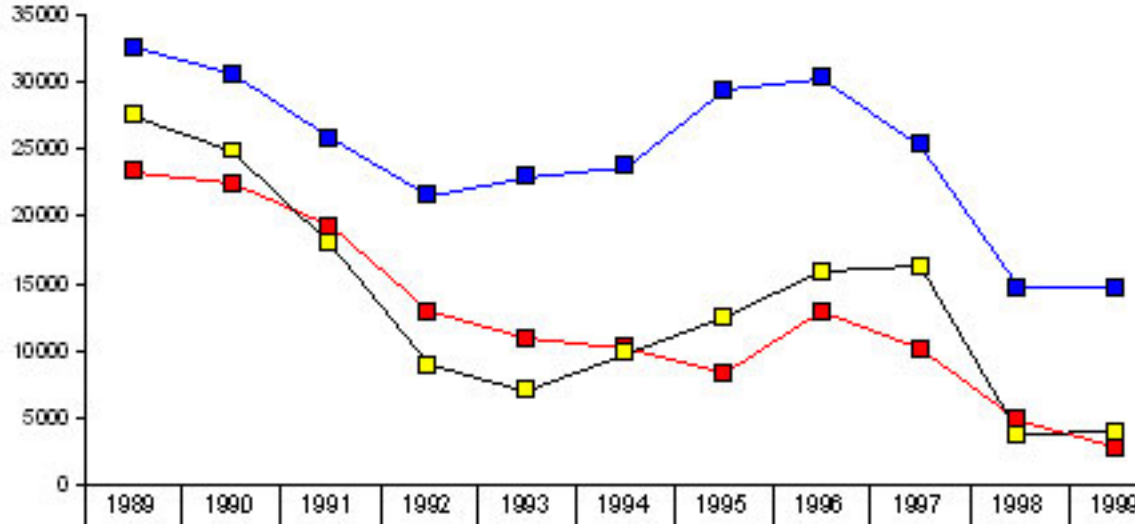
Underground remediation		**Total work**	**Completed**
Mine works cleaned and filled	97 %	1440 km	2005*
Shafts and tunnels filled	96 %	1.4 Mill. m^3	2005*
Mines flooded	76 %	72.1 Mill.m^3	2005*
		* Königstein 2015	
Surface Remediation			
Demolition of structures and plants	78 %		2015
Mine dumps, relocation	54 %	146 Mill. m^3	2007
Mine dumps contoured and covered	32 %	4.8 Mill. m^3	2009
Filling of the Lichtenberg open pit	55 %	127 Mill. m^3	2010
Tailings covering	58 %	7.8 Mill. m^3	2015
Site reclamation	30 %	1,530 ha	2015

As a result of the advance achieved in remediation, there are only few locations left where the recommended limiting values of radiation exposure of 1 mSv/a for individuals are exceeded. In practice, readings are well below the limiting values laid down by the GDR Nuclear Safety and Radiological Protection Ordinance and which continue to be applicable to WISMUT sites.

The progress in remediation is also demonstrated by two other features, namely by the gradual reduction in environmental impact (cf. figure 11.2.1 below) on the one hand and by the visible rehabilitation of formerly devastated landscapes on the other (cf. figure 11.2.2). Chapters 1 of this report referring to Wismut contains other impressive examples.



	1989	1990	1991	1992	1993	1994	1995	1996	1997	1999
Radon emission in TBq/a	2364	1505	1141	1344	1253	1392	1384	1123	1004	491
Emission of long-lived Alpha emitters in MBq/a	15492	3140	1332	303	308	81	85	61	43	30



	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Ra-226 emission in MBq/a	23421	22360	19242	12879	10868	10178	8301	12889	10136	4886	2699
Uranium emission in kg/a	27490	24868	17942	8916	7103	9781	12388	15849	16335	3776	3820
Water discharge in 10*m*	32595	30613	25845	21618	22929	23832	29452	30318	25258	14671	14726

Fig.11.2.1: Evolution of radioactive discharges from objects of WISMUT
(via the atmospheric pathway [upcast air] - upper graph; via the water pathway - below)

Fig. 11.2.2: Waste rock pile “Hammerberghalde” at Schlema (Aue site), after remediation.

References

[SSK-92] Radiological protection principles concerning the safeguard, use or release of contaminated materials, buildings, areas or dumps from uranium mining. Recommendation of the German Commission on Radiological Protection (Strahlenschutzkommission - SSK); Publication 23 of the SSK; Gustav Fischer Verlag, Stuttgart 1992.

11.4 CONCLUSIONS AND RECOMMENDATIONS OF THE SCOPE-RADSITE WORKSHOP ON remediation achievements after uranium mining and Milling

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11.4.1 INTRODUCTION

The SCOPE-RADSITE Project provides a unique international scientific forum where the radioactive wastes generated in the development of nuclear weapons, including their potential impact on the environment and human populations, are studied and reviewed. Slated to be completed in three years (1999-2002), the project will ultimately produce an integrated world-wide assessment of sources of radioactivity, subsequent and potential radionuclide releases into the environment, and associated potential risks to the population health and environment.

The IAEA estimates that about 360,000 metric tons of natural uranium, or about 20 percent of the world's production, has been used for military purposes. Given the longevity of the radioactive isotopes in these wastes and the huge amounts of wastes produced by uranium mining and milling, it

may in some countries be an important legacy which has to be dealt with for full elimination of the hazards.

The goals of the workshop on “Remediation Achievements after Uranium Mining and Milling” held in Munich on 8-9 September 2000 were 1) to review the present status of the legacy from uranium mining and milling activities, the impacts on health and the environment and the regulatory framework for remediation for some major regions of the world such as North-America, Europe and the former Soviet Union; 2) to consider a few case-studies of remediation and to assess the effectiveness of the countermeasures applied after the closing of the extraction activities; (3) to formulate recommendations for remediation of past uranium mining and milling liabilities.

11.4.2. SYNOPSIS OF THE WORKSHOP PRESENTATIONS

A team of experts was invited to the workshop and presented the current status of uranium mining and milling operations in the United States, in the former Soviet Union (FSU) and in Central and Eastern Europe. The effect of radiocontaminants resulting from the uranium mining and milling operations to species other than humans and the combined effects of environmental radiation and other agents were discussed. Finally, three cases of remediation projects were presented: remediation at COGEMA sites in France, the WISMUT rehabilitation project in Germany and uranium mine reclamation in Texas.

11.4.2.1. Uranium mining and milling legacy and regulations in some major regions in the world

11.4.2.1.1. Current status of uranium mines and mills in the United States of America [Chung, T.,1994;DOEa,1999;DOEb,2000;WISE).]

Uranium was first mined in the USA in 1871 in Colorado. Significant deposits were later discovered in Southwest Colorado, East Utah, Arizona, New Mexico, South Dakota, Texas, Washington, and Wyoming. Commercial uranium (U 3 O 8) production reached a peak of approximately 20,000 metric tons in 1980 but has declined steadily since that time. The 1999 production was approximately 2,000 metric tons. Most of the uranium from the USA currently comes from in situ leach (ISL) facilities. Reclamation and restoration of the uranium mining and milling facilities has now become the main activity of the industry, with few operating conventional mines and mills remaining.

At this time, the USA government does not specifically regulate technologically enhanced naturally occurring radioactive materials (TENORM) which includes uranium mining wastes, (typically waste rock or overburden). Uranium mine wastes are, in some cases, regulated by the states. There are about 3600 uranium-mining sites in the USA of which 1300 surface mines and 2300 underground mines, the majority operated by private citizens. (More recent information indicates that this number might exceed 4,000.) The status of those small mines is difficult to assess. In 1990, only 29 mines were listed as operating facilities: 2 surface mines and 27 underground mines. None of the surface mines has produced ore since 1993 and only three underground mines were listed as operating in 1999 producing 330 metric tons U 3 O 8 . Two uranium mine sites have been declared “Superfund” sites by the Environmental Protection Agency and are, or will be, reclaimed under the guidelines for such sites.

With a few exceptions the conventional uranium mills in the USA are closed and either reclaimed or in process. The Uranium Mill Tailings Radiation Control Act (UMTRCA), enacted in 1978, established two programs to protect public health and the environment in this context. The “Title I” program dealt with cleanup of mills that provided uranium beginning in the 1950s for the U.S. weapons program and provided for joint federal and state funding for reclamation. The “Title II” program deals with licensed commercial sites. The NRC has the authority to control the radiological and non-radiological hazards and to ensure that the sites meet the applicable standards. Some of the in total 22 “Title I” sites were stabilised in place while at other sites, the tailings were moved to disposal cells specifically constructed to contain the tailings. The surface remediation at the “Title I” sites was complete by 1999. The groundwater remedial action program is not yet completed at all sites.

There are approximately 27 “Title II” conventional uranium mills, 11 ISL facilities, an ion-exchange facility, and a commercial disposal facility. Surface reclamation is complete at only two of the conventional mill tailings sites. Once a site is reclaimed to meet the criteria and the license is terminated, the U.S. Department of Energy (DOE) accepts the responsibility for long term control unless the state chooses to do so. Two of the conventional mills are currently operating, processing stockpiled ore or alternate feed materials, with two other mills on standby. Groundwater remediation remains an issue for many of these sites. Four of the ISL facilities are operating; the others are inactive with restoration in progress.

Technical criteria for the remediation of uranium mills follow groundwater protection criteria and regarding the waste itself, the cover should sustain at least 200 years, average 222 Rn emission should not exceed 0.74 Bq/m²/s and 226 Ra concentrations should not exceed 190 Bq/kg at the surface (0.15 meters) and 560 Bq/kg below the first 0.15 meters.

Some examples were given of successful reclamation of uranium mine and mill sites in the United States.

Some issues raised

• The lack of consistent regulation for uranium mining wastes sometimes results in contradictory situations, e.g. when uranium mine wastes (non-regulated) and wastes from milling activities (e.g., tailings; regulated)) are disposed off adjacent to each other.

• Contrary to the approach generally applied in W. Europe where the remedial target is the dose to the most exposed individual, in the USA the remedial target is acceptable residual radio-contaminant levels in the environment.

• In the USA there is a clear statement of the period over which the remedial action has to be effective, preferably 1000 years but at least 200 years.

• Very often the uranium mining and milling sites are located in remote, isolated areas. Therefore the risk of intrusion is minimal. There were examples of residual environmental contamination exceeding

the 226 Ra clean-up criteria of 190 Bq/kg, but the destruction of a valuable habitat was considered more harmful than leaving the contamination in place

11.4.2.1.2. Uranium Mine and Mill Site Remediation in the Former Soviet Union [TACIS,1998)]

More than one hundred uranium mine or mill sites in more than 20 mine districts are distributed over six countries of the FSU: Russia, Ukraine, Kazakhstan, Kyrgyzstan , Uzbekistan and Tadjikistan. Nowadays, many installations have been abandoned or closed for economic reasons, others continue to operate mostly at reduced capacity or are subjected to industrial conversion. Environmental and radiological impacts are mostly associated with ponds or impoundments with ore processing residues, dumps of low grade ore, heaps of leached ore, in-situ leaching mining sites, abandoned mines, and contaminated buildings and equipment. Impacts resulted mainly through contaminated surface and groundwaters and through radon exhalation from mine ventilation shafts, uncovered tailings and radioactive mine waste dumps, through un-authorised use of processing residues or mine waste for construction, and through impoundment failures and erosion of dams or waste piles, dusting of tailings and radioactive mine dumps in the arid regions.

For the majority of the major uranium mining and milling districts in the FSU the full remediation option should be considered due to the proximity of population (in many cases) and severe impacts on public health and on the environment . Institutional controls are in general in place but need to be improved. Relocation is only considered for inhabitants of houses with high radon levels due to the use of tailings for construction materials. Minimal remediation actions as limited treatment of mine waters and, even more exceptionally, revegetation of mine dumps and tailings were performed yet without the establishment of a long term remediation concept. Complete remediation including the establishment of a cover design for the mill tailings ponds with treatment of seepage water, stabilisation of dams and impoundments and groundwater treatment are now envisaged but can hardly be realised due to lack of funding.

Even though regulatory frameworks for the definition of remediation objectives are now in the process of completion or at least reviewed, practical guidelines for remedial action and for the monitoring of remediation progress are still lacking in the FSU.

Some issues raised

• In many FSU countries there is public pressure for restoring the situation. The public wants and needs to be informed and involved.

• Given the lack of funding in most of the FSU countries, prioritisation of the sites to be remediated and of the actions to be taken is essential.

• Where money is not sufficient for complete remediation, the remediation plan could propose steps with intermediate objectives (e.g., limitation of further contaminant dispersion, collection and treatment of waste waters, institutional control, monitoring, intrusion prevention, access and use restrictions etc.…).

• The next step in remediation would be to create a set of relevant pilot projects which could be subject to international funding at specific locations and with specific and clear objectives. A set of such potential projects has been elaborated by the regional TACIS Project “Assessment of Urgent Measures to be taken for Remediation at Uranium Mining and Milling Tailings in the CIS” which at present are partly put into realisation by the EC (e.g. the Mailuu Suu Project in Kyrgyzstan). The practical experience gained and the results obtained should be made available and applicable at other sites and situations in the FSU. All similarly impacted countries of the FSU should actively participate. Synergy could be provided with the recently completed PHARE Pilot Project Programme of the EC which has achieved valuable results relevant to the legacy of uranium mining and milling in Central and Eastern Europe.

11.4.2.1.3. Uranium mine and mill rehabilitation in Central and Eastern European countries [Uranerzbergbau-GmbH,1998]

In several countries of Central and Eastern Europe there are major residues of past or ongoing uranium exploration and mining and milling activities. Often, uranium production operations were carried out without appropriate care for environmental consequences. In Albania and Estonia, only exploratory uranium mining was done (in Estonia there was on the other hand milling of uranium ore). In Bulgaria, Czech Republic, Hungary, Poland, Romania, Slovakia and Slovenia ore was mainly extracted from underground mines. In Bulgaria, Czech Republic and Slovakia open pit mines were operated as well. Today uranium exploration, mining and milling operations ceased in most countries. Only in the Czech Republic and in Romania some uranium is still produced.

In the framework of a consulting project, UEB - Uranerzbergbau-GmbH in co-operation with nine participating countries established a database on uranium liabilities. The data of 831 objects for which reliable information was found were assembled in a database. As part of the the assessment of the database on the uranium liabilities a risk ranking was performed. The major conclusions are the following:

(1) The results show clearly that tailing ponds and processing plants are of major concern.

(2) The majority of dumps is found in the lower risk group. The high-risk dumps require attention. These are located mostly in the Czech Republic and Bulgaria.

(3) Out of four heap leach operations three are in the intermediate risk group. These are located in Bulgaria and Hungary.

(4) The majority of ISL operations are in the lower risk group. Two intermediate risk group operations are located in the Czech Republic.

(5) Open pits belong to a large extent into the intermediate risk group. Objects in Romania, Slovakia and Bulgaria require attention.

(6) Most underground objects and other objects belong in the lower risk group.

Rehabilitation activities should concentrate on the objects in the highest risk group. Prior to the implementation of large scale rehabilitation measures, information on the pathways and to be protected goods need to be collected in greater detail.

The most advanced remediation activities can be reported from Hungary. In the Czech Republic, and to a lesser extent in Bulgaria and in Slovakia remediation has begun and continues, depending on the funding available. In Estonia and in Slovenia the sites are quite well investigated, remediation plans have been developed and field work is in preparation. In Albania, in Romania and in Poland remediation is prevented mainly by lack of funding.

11.4.2.2. Potential effects on biota from contaminations linked with the uranium industry

11.4.2.2.1. Ecological effects of emissions from uranium facilities [PSL2,2000;Bird,2000]

In most approaches to remediation the target is man. However, the Canadian new environmental regulatory process also requires the assessment of the impact of the release of contaminants, including radionuclides, on non-human biota. Ecological risk assessment was performed by exposure, effect and risk characterisation following laboratory tests and modelling. Field validation is however limited.

The result of the study showed that releases of radionuclides from uranium mines and mills and waste management areas are entering the environment in quantities or concentrations or under conditions that have or may have an immediate or long-term harmful effect on the environment or its biological diversity. Therefore, it is proposed that releases of radionuclides from uranium mines and mills and waste management areas be considered “toxic” as defined in Section 64 of the Canadian Environmental Protection Act, 1999. Further research into the estimated no effects thresholds for exposure of non-human biota to radiation should be a priority.

Some issues raised

- In case reduction of the dose to man is the target of the remedial action, individuals are protected. When other biota represent the target, the survival of the individual is not as important as the survival of the population. Yet most tests to assess the effect of contaminants on non-human biota survival screen at the individual level.

- Based on laboratory experiments, toxicity coefficients for a number of agents and species are put forward. Further testing under field conditions is however required.

11.4.2.2.2. Combined effects of environmental radiation and other agents [Burkart et al.,1997; id,1998]

At uranium mining and milling sites, people may be exposed to contaminants other than radionuclides. In general, assessment of toxicity, carcinogenicity, and mutagenicity is directed towards a single agent despite our daily exposure to a multitude of physical, chemical, and biological agents. This approach assumes that toxicants act independently from each other. However, combined

exposures may lead to health effects that differ from those expected from simple additive effects.

The low probability for significant combined effects for those common low exposure situations where toxic agents with non-linear dose effect relationships and apparent thresholds are involved, is evident. Yet, epidemiological data based on lung cancer rates of miners show strong evidence of a strong combined effect of a simultaneous exposure to radon and arsenic. A valid quantitative assessment based on experimental data of the contribution of synergistic interactions to the total detriment is far from being attained and we are unable to generalise and predict the outcome of combined exposures. Only an understanding of the mechanisms involved in the agents under consideration on the physico-chemical, molecular and cellular level will allow to predict the effects of combined actions, and the rejection of overly conservative assessments.

Some issues raised

- Since exposure to toxicants is often linked with low concentrations of the contaminants, and since most dose-effect relationships in the low dose range are assessed according to the linear no threshold - approach (LNT-approach), which is substantially conservative, addition of expected effects of several contaminants will be in general sufficiently conservative to protect the human individual.

11.4.2.3. Factors important in decision making process

11.4.2.3.1. Integrated risk assessment of radioactive and chemical wastes [Goldammer, 1999]

Clean-up of sites contaminated by radioactive and chemical wastes must take into consideration a variety of different contaminants and risks to humans and the environment arising *via* various pathways. Traditionally, the assessment of hazards and risks is made under various jurisdictions depending on the context considered, e.g. radiation protection, water protection, mining legislation etc., with different philosophies, methods and standards. These separate assessments, however, do not give due consideration to the overall risk originating from a site and can therefore lead to inappropriate decisions with respect to remediation.

In the present approach, the determination of cost-efficient clean-up measures involves cost/benefit considerations, taking into account all improvements achievable in the different sectors on a common (monetary) basis and relating them to the required financial expenditure. This makes it necessary to develop an assessment approach within which all relevant risk and damage components can be quantified consistently in an integrated method.

Human health risks are expressed as a loss of life expectancy, a concept directly applicable to lethal effects. For non-lethal effects the deterioration of the quality of life is assessed and combined with the lethal effects to give the “mean effective loss of life expectancy”, which is then converted in an equivalent monetary value. Damage to ecosystems is expressed in monetary terms based on willingness to pay and ability to pay for the prevention or mitigation of an ecological damage. On this basis, clean-up options can be assessed in terms of their benefits in relation to the financial expenditures required. Uncertainty and sensitivity analyses can be performed. The approach establishes a basis for rational and transparent decision making in site remediation.

Some issues raised

- Positive about this type of quantitative decision aiding systems is that they may render the decision aiding process more transparent. The problem is however that these tools might be erroneously regarded as ready-to-use decision making tool.

• There was concern that the validity of these tools depends largely on the underlying models and data input. Thus, limitations and the range of application should be clearly identified to avoid the use of this tool for inappropriate situations.

• Monetarisation of all possible kinds of damage and benefit components was considered difficult if not prohibitive.

- The approach was viewed as useful in decision aiding, however to be used with minimum caution.

11.4.2.3.2. Factors influencing the decision making process and the objectives of site remediation [IAEA TECDOC]

Any environmental remediation project for former uranium mining should not just simply improve the radiological situation, but should also bring some added value to the region. Thus, a range of non-technological factors will influence the strategy to be followed and the choice of techniques to be employed. Expert groups at the IAEA have developed a tool to increase the awareness of the decision makers concerning factors influencing the decision making process. Acknowledgement of these factors and suitable mechanisms for accounting for them in a quantitative and traceable way in decision making, will reduce programmatic risks (see below) and increase public acceptance of the project. The overall objective is to enable regions in the world with restricted resources and technologically less advanced to focus their efforts and choose appropriate strategies for risk abatement.

Programmatic impacts and risks consist of

- Economic factors (employment, infrastructure, cost, funding, availability of sources)

- Regulatory aspects (clean-up standards, competing legislation)

- Public perception and acceptance and public participation

- Feasibility of deployment of a remediation technique (uncertainty in technical performance, unforeseen side effects,…)

- Occupational hazards

- Environmental impacts

- Socio-economic impacts

- Restoration objectives (target, future land use,…)

Quantitative decision aiding methods (e.g. CBA, MAUA,…) render the decision making process more transparent and will serve as instruments for QA/QC.

11.4.2.4. Case studies of remediation of uranium mining and milling sites

11.4.2.4.1. COGEMA sites [Daroussin,2000;Bof,1998]

COGEMA has been operating uranium mines and mills throughout the world for several decades. Site remediation at uranium mining and milling sites, alreadyforeseen and prepared during the operations, is usually started immediately after the end of operations and is funded by cash flow of the project (provisions).

The remediation objectives are (1) public security and health through control and limitation of the long-term radiological impact to the surrounding population; (2) long-term stability of the reclaimed area and prevention of intrusion; (3) limitation of future technical supervision requirements; (4) reduction of total land consumption to reduce need for institutional control; (5) site integration into the surrounding landscape.

The objectives should comply with all regulatory constraints especially rules concerning radiological impact, should match with the wishes of the local or regional groups and should be technically and economically workable.

The Ecarpière mining and milling site in France was given as an example. Main actions were dismantling and cleaning up, backfilling of mining works, resloping and capping of waste management facilities, water management and treatment. Detailed studies (petrography, geochemistry, leaching and selective leaching tests) on the tailings conclude that only limited releases of radium are expected and that most of the radium is fixed on newly formed large “specific surfaces” minerals. Highest residual doses to members of the critical groups was within the 1 mSv limit.

Besides from the remediation of mining and milling sites, another objective of COGEMA is to support the future development of the mining areas, e.g. through re-industrialisation operations.

Some issues raised

- An early and adequate public information and involvement is very important.

- Trust-building is essential: “ tell what you do, do what you tell” .

- In a naturally radioactive environment, compliance with the 1 mSv/a target is impossible to prove statistically given measurements and assessment uncertainties.

11.4.2.4.2. WISMUT sites [Barz, 1998;Jakubick et al., 1999]

More than forty years of uranium mining and processing operations in the states of Saxony and Thuringia in East Germany have left a legacy of considerable environ-mental contamination. The 220,000 t of uranium produced was accompanied by a total amount of 800 10 6 t of waste, and resulted in seriously affected areas at differ-ent sites in a densely populated region of about 10,000 km 2 . In 1990, uranium production was ceased and in 1991 the WISMUT company received the task to decommission the mines, mills and other facilities still in operation by 1991. The German Federal Government provides the financial resources for the total resto-ration of the WISMUT sites (DEM 13 billions). There is 37 km 2 of operating areas in need of remediation of which 48 waste rock piles (15.4 km 2), 14 tailing ponds (7.3 km 2) and 1 open pit mine (1.6 km 2).

Radiological assessment is carried out for each liability to justify the restoration (comparison with the 1 mSv/a-criterion). Decision aiding techniques as for instance multi-attribute analysis are applied in selection of the most suitable remedial options.

Small heaps or waste rock piles are relocated to other piles or to an open pit or are contoured and covered. Tailing ponds are consolidated, contoured and covered.

The status of the underground remediation works is as follows: about 95 % of the mine workings are cleaned and closed and shaft and tunnels filled and 75 % of the shallow mine workings are remedied. The surface remediation is in a less advanced state: 76 % of plants and structures are demolished, 47 % of dumps are relocated and contoured and 24 % of the dumps are covered, filling of open pits is accomplished for 44 % and 53 % of the tailings are covered and site reclamation is achieved for 19 %.

After the rehabilitation work has been finished as planned some long-term activities will be left such as water treatment, care and maintenance of restored land and of ancillary mine workings, mine damage control and compensation and environmental monitoring.

Some issues raised

- A reliable public information and involvement is very important at all stages of the remedial process. This proved to be very effective for obtaining acceptance for the remedial options proposed.

- In some instances, e.g. the backfilling of the uranium mining pits, this action could not be justified on radiological grounds (dose already below 1 mSv/a before remediation) but it was important in terms of employment and landscape value.

11.4.2.4.3. Uranium mine reclamation in South Texas [RRC,1994;RRC,2000]

In 1954, discovery of uranium deposits in Karnes County Texas was followed by extensive prospecting, exploratory drilling and open pit mining. In 1975 the Texas Surface Mining Act was passed, requiring the reclamation of uranium mines. By that time over 40 uranium mines were

inactive or abandoned. Since these mines were "pre-law", reclamation of the mines fell to the responsibility of the State and is administered by the Abandon Mine Lands section (AML) who began to prioritise the sites for reclamation based on health, safety and environmental criteria.

The sites were prioritised for risk to the public from a health and safety standpoint and risk to environmental quality. The major criteria for health and safety risks are (1) physical hazards including area disturbed, slope steepness and highwall height; (2) existence of a water body; (3) general site condition including debris or waste dumps; (4) public accessibility and activities; (5) residential proximity. Environmental risks were based on (1) surface water runoff and sediment transport; (2) vegetation stress; (3) erosion; (4) water use; (5) radiological and chemical quality of soils/spoils, water, vegetation and sediments.

The data collected indicated that the water from the Uranium mine pits were not suitable for drinking, recreation or irrigation purposes, but were suitable for livestock and wildlife. Consequently, the ideal design elements for a Texas AML reclamation project are complete backfill of mine pits with gentle slopes (less than 25% grade), drainage designed to minimise off-site sediment transport and complete revegetation of the site with low selenium uptake species. If complete backfill were not possible due to funding or site configuration/land ownership constraints, ponding of water would be held to a minimum.

Review of the current Butler-Weddington Area 6 AML reclamation plan and design showed that acidic soil areas (associated with radiation) will be moved to the lower portions of the pit after dewatering. Backfill of the pit will continue with clean soils for a minimum thickness of 10 feet above the acidic soils. The remaining depression at the pit location will provide a stock/wildlife pond from primarily surface runoff water. The AML will maintain and control the site for a minimum of two years after reclamation, to establish vegetation before the site is released to the landowner.

Pre-reclamation and post-reclamation photographs of eight completed AML reclamation projects visually indicate successful reclamation of the sites. Ponded waters were eliminated or greatly reduced. Slopes are gentle and erosion/sediment transport is minimal. Complete revegetation was accomplished and the vegetation is healthy and dense.

South Texas is currently in a drought cycle. Current photographs of reclaimed sites indicate that vegetation is under stress from the drought and over grazing. Photographs from reclaimed sites that are currently under the custodial care of the AML and other Uranium operators show healthy vegetation stands despite the drought conditions. Consequently, long-term land management practices will most likely be an issue in the future. Land use practices that maintain a sustainable vegetative cover through proper grazing practices or the addition of soil amendments will need to be investigated. Cost support to limit brush and tree development and provide incentives for limited grazing will also need to be addressed.

Some issues raised

- The re-utilisation of contaminated areas, e.g. for leisure (fly-fishing in the remedied tailing ponds or open pit mines) was considered dangerous in the sense that the contamination could be forgotten.

11.4.3 ISSUES RAISED AND RECOMMENDATIONS

When planning remedial activities a number of factors influencing the decision making process and the objectives of the site remediation should be carefully considered.

11.4.3.1. Regulatory basis

In many countries there is a lack of regulations regarding the remediation of uranium mining and milling sites. It should be recommended that these countries set up or adopt regulations since past uranium mining and milling activities may result in an important health and environmental risk. In general, there is a good correlation between the funds made available and the extent and stringency of the regulatory framework.

Often, remediation should abide at a number of concurrent regulations: radiation protection, mining legislation, water protection, soil and nature protection,... Sometimes these other regulations are much more stringent than the radiation protection ones and should be considered when evaluating remedial options.

In Europe there are in general no stringent radiation protection regulations for intervention situations or for past practices dealing with TENORMs. Therefore, in most countries the added 1 mSv/a to an average member of the critical group is used as minimum radiological requirement.

11.4.3.2. Identification of impacts and risks

In the planning of the remediation, relevant risk components should be identified. These risks, impacts and financial expenditures should then be integrated and assessed.
Risk related characteristics that need screening and evaluation are: radiological and chemical risk components (potential for affecting ground and surface water, extent of the radiological risk), stability of the structures, ecological risks (detrimental impact on ecosystems and resources).

11.4.3.3. Identification of restoration objectives

The optimal remediation option proposed will depend on the remediation objectives. General objectives are:

· The long-term stability of the remedied area

Regarding the long term stability of the remediation of uranium mining areas and more specifically uranium mill tailings, the stability of the cover, the limitation of the Rn emissions and the long-term compliance with groundwater limits are primordial. The first issue is a more physical one and can be rather efficiently solved following detailed characterisation of the site geomorphology and an attempt to mimic it. Regarding the radon emissions, adequate capping should be sufficient to protect the members of the critical group up to some predefined time in the future. Additionally, covers should be as natural as possible. The last issue, long-term protection of the groundwater, is a more difficult

one. Evaluations are extremely site-specific and uncertainties must be carefully dealt with in hydrogeological modelling.

One of the factors potentially affecting long-term stability is intrusion. Only with a strict and reinforced record keeping and some kind of continued institutional control, prohibition of intrusion may be possible.

· The reduction of health risks and impacts

It is important to clearly identify the target of the remediation activity, to define what we want to protect: people, biota or the environment.

The impact on the biota and the environment is even more difficult to assess than the impact on man. The approach is also different. For man, welfare and survival of the individual is the issue; for biota, the survival of the species is the goal. Nevertheless most experiments aiming to assess the impact of contaminants on biota still are performed on observations of individuals.

Attention should also be paid to potential secondary effects of a remediation option. Some remediation options which may reduce the availability of one toxic component, might enhance the long term dispersion of others.

· The prevention of intrusion and institutional control

When trying to select the most appropriate remedial option, the optimal option considering all criteria might be one requiring institutional control (including reinforced record keeping) with all the questions regarding extension to the long term.

The likelihood of intrusion may also be incorporated in the decision process. If it is unlikely that people will go and live at a given site (e.g. in the middle of a dessert), the dose following intrusion may be an irrelevant factor in decision making.

In most developed countries, a soil analysis is performed before any construction starts at a suspected site. This is expected to reduce the likelihood of intrusion on a previously ”remediated” contaminated site.

Intrusion, if it would occur, would not immediately result in serious health effects. People will have the opportunity to realise the hazard that they are facing at the intruded site, and to react accordingly.

Foreseeing a specific end-use to the site (e.g. industrial allocation) during in the remedial process may prevent unwanted intrusion for some time.

· The reduction of total land occupied by remedial actions and of sites requiring institutional control

In case of complex sites it is best to concentrate the residues at one place. If possible residues should be relocated to a site with appropriate characteristics (presence of natural permeable layers, site not located in flood plain of rivers, deep water table and no seepage to groundwater, remote from human presence, ...).
Apart from ensuring prohibition of intrusion, the institutional control may also involve continued monitoring and maintenance and repair operations. Although it is considered that options requiring the least institutional control are preferable, it is considered unlikely that we can achieve this.

· A chievement of landscape integration and future use of the land.

As mentioned earlier, remedial actions should as much as possible mimic the site geomorphology and natural aspect, not only to improve long-term stability but it will also contribute to a higher landscape value and increased public acceptance.The allocation of future land use should, if applicable, already be incorporated within the remediation planning. Public involvement and acceptance is very important in this regard (see stakeholder involvement). If future land use can be envisaged, part of the remediation may be paid by the value of the land. Therefore a responsible party/counterpart who is interested in reuse is needed. In some cases this may be the local population.

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CHAPTER 12
ENVIRONMENTAL IMPACTS: A CASE STUDY OF THE SAVANNAH RIVER SITE

T. G. Hinton

12.1. Introduction

The Savannah River Site (SRS), a U.S. Department of Energy facility described in Chapter 5, was chosen for a more in-depth analysis of the environmental impacts from operating a nuclear production facility for over 50 years. All of the large industrial facilities described in the previous chapters were associated with nuclear weapons programs during a time when urgency was paramount for competing in the nuclear arms race. Vast quantities of contaminants, many of which were radioactive, were produced along with the nuclear products of interest. Much of the contamination was released into the environment. During the early years of operating these facilities there were few environmental regulations and the technologies for removing contaminants from waste streams were poorly developed.

The SRS was chosen for an analysis of the environmental impacts because the quantities of contaminants released from the SRS were recently estimated by the U.S. Centers for Disease Control and Prevention (CDC). This was part of a large-scale effort to reconstruct the dose experienced by offsite residents due to contaminants released from the SRS during operations from 1951 through 1992. The prime contractor for the CDC, Risk Assessment Corporation (RAC), estimated the release rates of major contaminants from the SRS as an interim step in the dose reconstruction project (RAC, 2001). Although the emphasis of the CDC was strictly on impacts to humans living downwind or downstream from the SRS, the data compiled by RAC is useful for estimating the onsite environmental impacts from operating the SRS over the last 50 years. The latter is the purpose of this chapter, with an emphasis on the radiological contaminants.

12.2. METHODS

12.2.1. *Source of Radiological Contamination Data*

E. I. du Pont de Nemours, the prime contractor during most of the operating period of the SRS, had great foresight, and to their credit established environmental monitoring programs prior to the start up of, and during the entire operations of the nuclear facilities. Dupont also contracted independent organizations to conduct research related to the impact of site operations on the environment. The Savannah River Ecology Laboratory, operated by the University of Georgia, and The Academy of Natural Sciences of Philadelphia have continuously conducted studies on the SRS since 1951. RAC utilized these environmental monitoring results to reconstruct the contaminant source terms. They systematically reviewed *all* records at the SRS. RAC examined about 50,000 boxes of documents and recorded their findings into a computer database. CDC reviewed the document database and then made it available to the public. The contaminant concentrations I used to estimate environmental impacts are taken largely from RAC (2001).

12.2.2. Method of Estimating Environmental Impacts from Radiological Releases

The International Committee on Radiological Protection (ICRP, 1977) and the International Atomic Energy Agency (IAEA, 1992) recommended dose rate limits for organisms exposed to radiation, below which deleterious effects to populations are not expected. They concluded that a chronic dose rate of no more than 10 mGy d^{-1} to the maximally exposed individuals in a population of aquatic organisms, and 1 mGy d^{-1} to the maximally exposed terrestrial organisms would ensure protection of the population. I used their criteria in this report.

To estimate the dose rates received by SRS biota I used an approach that the Department of Energy recently proposed (DOE, 2000). It is a graded methodology that starts with a generic, conservatively based screening model, and then progresses to more detailed and site-specific analyses. The DOE model estimates dose rates to biota from 23 radioisotopes via three pathways: ingested contamination, external exposure to irradiation, and for terrestrial animals, inhalation. Based on the IAEA guidance mentioned above, and on established radioecological principles that govern the transport of contaminants through food webs, the DOE have derived limiting radiological concentrations in water, soil and sediments, called Bioconcentration Guides (BCG). Contaminant activity concentrations above the BCG values result in biota acquiring a dose greater than the IAEA guidelines. DOE derived the BCGs using conservative assumptions and parameter values to purposely enhance the transfer of contamination simulated by the model. Such conservative assumptions insure that the fundamental requirement for a screening model approach is satisfied (i.e. that the predicted doses are larger than the real doses experienced by the biota). If dose rates estimated from the screening model are lower than the IAEA guidelines of 1 and 10 mGy d^{-1} for aquatic and terrestrial organisms, respectively, then it is probable that the actual doses received by the organisms in the environment were even less; and therefore, contamination levels are thought to be inconsequential to the biota population. If, however, doses exceed the IAEA dose rate criteria, then the screening model estimates are rejected and a reevaluation is necessary using more precise calculations with site specific data, rather than the conservative, generic default parameters in the screening model. For example, **Table 12.1** shows the conservative distribution coefficients (Kd) used in the first step of the screening model and the more realistic ones typical of SRS conditions. (Distribution coefficients relate soil-bound contaminant concentrations to the concentration in the soil pore water; the smaller the Kd value, the more mobile the contaminant in the environment).

TABLE 12-1. A comparison of the conservative distribution coefficients (Kd) used in DOE's biota dose screening model to the larger, more realistic ones that are specific to the Savannah River Site (SRS). The smaller the Kd value the greater the contaminant's mobility within the environment. Purposely using small Kds in model simulations make the dose rate estimates larger, representing worse-case type scenarios.

	DOE's	**SRS**
Isotope	**conservative Kd**	**site-specific Kd**
Cs-137	500	32,000
Co-60	1,000	30,000
I-131	10	200
Sr-90	30	1,200

12.2.3 Activity Concentrations in Contaminated Habitat s

Within the framework of RADSITE it was not possible to do a complete impact analysis of all environmental releases from the SRS. Instead, I opted to examine the impacts to the portion of the SRS that received the greatest amount of contamination, and was of sufficient size to potentially impact a significant percentage of the biota population. The latter criterion excluded small (< 0.5 ha), but highly contaminated seepage basins.

Based on the criteria presented above, the natural aquatic streams on the SRS were chosen as the ‘worse case habitat' because (1) the highest percentage of radioactive contamination from all of the facilities on the SRS came from the nuclear reactors (**Fig. 12-1**), and (2) because most of the contamination from the reactors was released to site streams. The primary source terms were large (~1.5 $x10^6$ L) disassembly basins adjacent to the reactor building in which spent fuel and irradiated target rods were stored prior to their transport to the chemical separations facilities. The water in the basins would become contaminated due to leakage from small cracks in the rods. During the early years of operating the SRS, contaminated basin water was routinely purged to onsite streams. With time, seepage basins, settling ponds and tanks became standard containment for wastes, rather than releasing the contaminated water to site streams. Five streams received secondary cooling water from the reactors, as well as radioactive effluents from the reactor disassembly basins. The onsite streams were small creeks with natural flows in the largest of the five systems of about 7 m^3 s^{-1} . However, flow characteristics changed dramatically when reactor discharge occurred (**Table 12-2**).

Table 12-2. Characteristics of Four Mile Creek taken on the SRS in 1951, prior to start of the operations, and again in 1971 when reactor discharges were occurring.

Year	**Mean Flow (m 3 s^{-1})**	**Stream Width (m)**	**Mean Depth (m)**	**Mean Velocity (m s^{-1})**
1951	0.19	4.8	0.5	0.07
1971	13.22	11.0	0.9	1.25

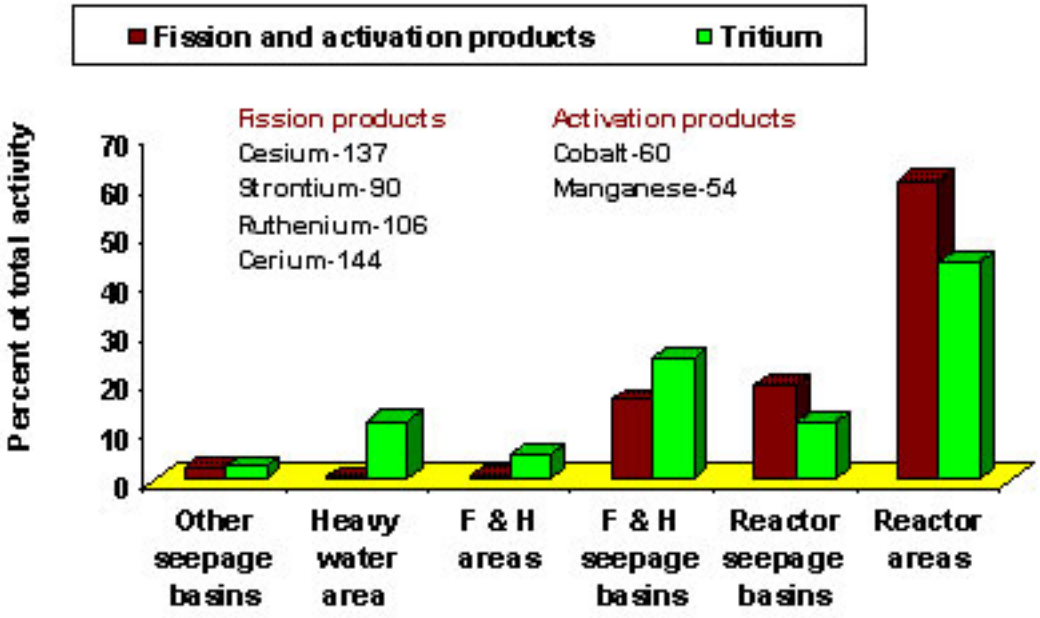

Figure 12-1 *. Percent of total activity released from the various industrial complexes on the SRS. The reactors released the greatest percentage of tritium, fission and activation products (RAC, 2001), and thus their releases were chosen for further examination with the RADSITE project. F & H refer to two chemical separation facilities on the SRS*

Aquatic releases of key radionuclides from the reactors were quantified in **Chapter 5, Fig. 5-12.** Their relative contributions to offsite human doses were estimated (RAC, 2001) using screening calculations of the NCRP (**Chapter 5, Fig. 5-16**). The d ata show that 137 Cs was the radionuclide of main concern for human exposures from past releases to surface streams, and that other radionuclides of importance included: 3 H, 90 Sr, 131 I, 60 Co, 32 P, and 65 Zn. It is reasonable to assume that those same isotopes would be of concern from an environmental perspective. RAC's median estimate of total 137 Cs released into the streams, for all years, was about 9 TBq with the 5th and 95th percentiles of the distribution being 4 and 22 TBq.

Of the five onsite streams, releases were greatest to Steel Creek (**Fig. 12-2**), and peaked in the late 1960's. Steel Creek was thus chosen as a worse case habitat to model the environmental impacts from the SRS.

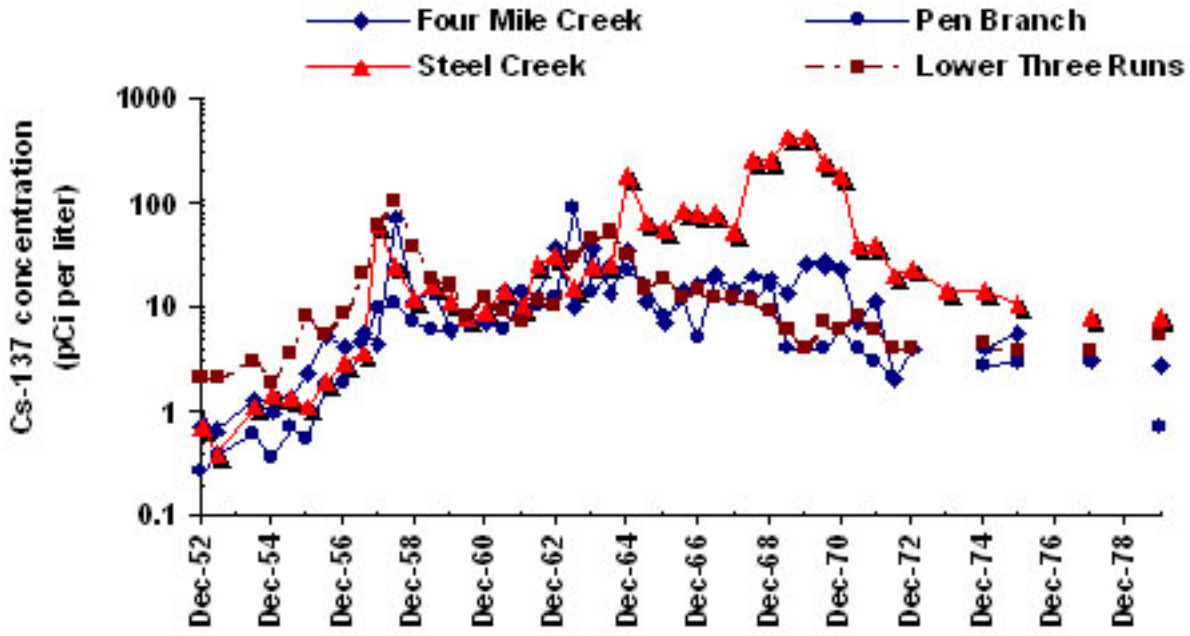

***Figure 12-2** . Surface water releases of radionuclides to the streams on the SRS, exemplified here with 137 Cs, were highest to Steel Creek and peaked in the late 1960s (RAC, 2001). Therefore, Steel Creek was chosen as the habitat for additional radiological impact analysis with the RADSITE project.*

12.3. RESULTS

Concentrations of radioactive contaminants in Steel Creek from 1955 to 1986 are shown in **Fig. 12-3** . The gap in the data presented is because releases to Steel Creek were diverted to seepage basins after 1970, but resumed with the restart of L-reactor in 1981. Tritium was the dominant radionuclide contaminant in Steel Creek, with activity concentrations (Bq L^{-1}) at least four-orders of magnitude greater than other key radioisotopes (**Fig. 12-3**).

To estimate radiological impacts, the isotopic activity concentrations graphed in **Fig. 12-3** were divided by the isotope-specific BCGs determined by DOE (**Table 12-3)** . Recall that a BCG is the isotope-specific activity concentration at which the dose rate to biota is expected to equal the IAEA dose rate criterion (e.g. 1 mGy d^{-1}). Thus a contaminant activity concentration to BCG ratio greater than one indicates that the dose rate estimated from the DOE model is in excess of the IAEA criterion (**Fig. 12-4**). It is interesting that the relative importance of specific isotopes changed drastically when viewed as an activity concentration within the stream (**Fig. 12-3**) compared to a value normalized to the BCG (**Fig. 12-4**). For example, although activity concentrations within the stream were greatest for 3 H, tritium had the lowest ratio relative to the BCG and thus the least impact to biota (**Fig. 12-4**). This is due to the weak energy of 3 H's beta emission. Isotopes that exceeded a ratio of one were 137 Cs, 144 Ce, 131 I, and 90 Sr (**Fig. 12-4**). All other isotopes modeled by the DOE program fell below the BCG ratio of one, indicating that their activity concentrations in the stream were less than what would be required to cause a dose rate that exceeded the IAEA guidelines

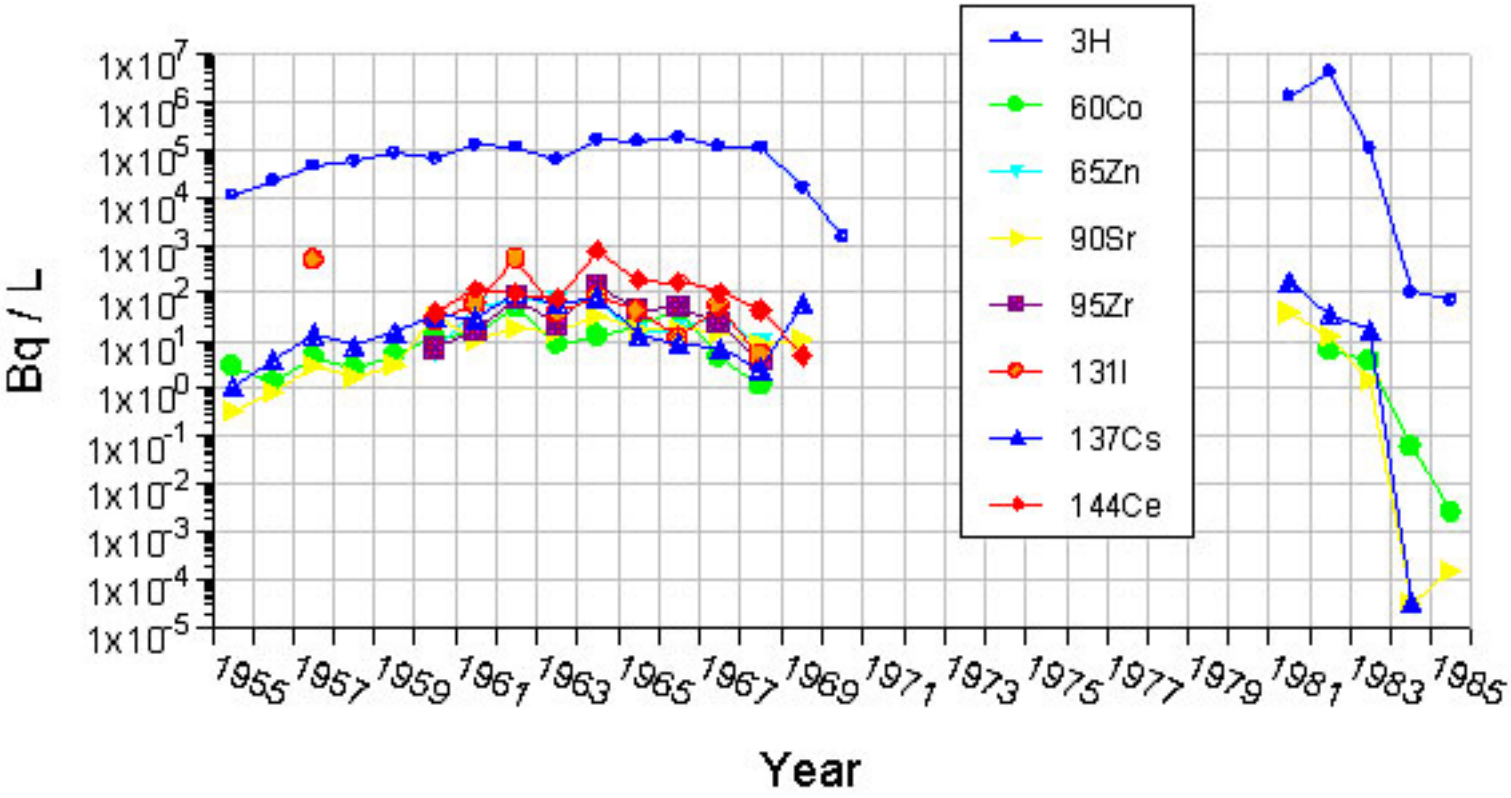

Figure 12-3 *. Concentrations of radionuclides in Steel Creek due to releases from nuclear reactors on the Savannah River Site. Releases stopped in 1970 when reactor effluent was diverted to seepage basins and a cooling reservoir within another stream's drainage basin. Releases began again in 1981 with the restart of a reactor that had been shut down.*

The calculations in this initial screen used DOE's conservative input parameters for distribution coefficients, concentration ratios, etc., and thus intentionally overestimated the actual doses likely to have been received by the biota. The next step in the screening model process is to substitute more realistic, site-specific input parameters for those isotopes whose ratio exceeded 1. When input parameters specific to the SRS where used, only 137 Cs had activity concentration to BCG ratios greater than 1, and this occurred in 8 of the 30 years examined between 1955 and 1985. This suggests that activity concentrations of 137 Cs in Steel Creek during the early years of operating the SRS were sufficient for riparian animals to experience dose rate in excess of 1 mGy d^{-1} . Such dose rates were not large enough to cause mortality, but chronic exposures might have been sufficient to alter reproductive output in the most sensitive organisms and thereby alter population dynamics.

TABLE 12-3 . Bioconcentration Guides (BCG) used by the U.S. Department of Energy for contaminated aquatic systems. The BCG is the radionuclide concentration estimated to cause biota exposures to be greater than the IAEA guidelines (10 mGy d^{-1} for aquatic organisms, 1 mGy d^{-1} for riparian (terrestrial) organisms; DOE, 2002). The bolded number represents the type of organism (aquatic or riparian) that had the most restrictive BCG for that particular radioisotope (i.e. the type of biota most likely to have dose rates that exceeded the IAEA guidelines): aquatic animal for 144 Ce, 60 Co, and 95 Zr; riparian animal for 137 Cs, 3 H, 131 I, 90 Sr, and 65 Zn.

Isotope	BCG for Aquatic Animal (Bq L^{-1})	BCG for Riparian Animal (Bq L^{-1})
144 Ce	**60**	2000

137 Cs	40	2
60 Co	**100**	200
3 H	200.000.000	**10.000.000**
131 I	6000	**500**
90 Sr	2000	**10**
65 Zn	70	**0.5**
95 Zr	**300**	1000

Unfortunately, the DOE model does not currently contain some isotopes with short half-lives. Because numerous short-lived isotopes were in the reactor effluent released to streams, it is probable that the actual dose rates experienced by biota within Steel Creek were even greater than what has been presented herein. For example, approximately 1.3 TBq of 32 P, a short lived isotope (T 1/2 = 14 d) known to bioaccumulate in aquatic organisms, was released to the streams on the SRS between 1964 and 1979 (Carlton and Denham, 1996), and yet was not part of the modeling exercise.

12.4. IMPACTS of THERMAL DISCHARGES

Although radioactive releases were not sufficient to cause mortality to aquatic biota, another pollutant from the nuclear production facilities definitely was. Heat generated from the fission process within the reactors had to be removed to prevent damage to the reactor components. This was done in SRS reactors by circulating heavy water (deuterium oxide) through the reactor system to serve both as a neutron moderator and as the primary coolant. The heavy water flowed in a closed loop through the tubes of heat exchangers that transferred the heat to a secondary coolant (water from the Savannah River). The secondary cooling water was pumped through the heat exchangers on a once-through basis and then discharged into onsite streams.

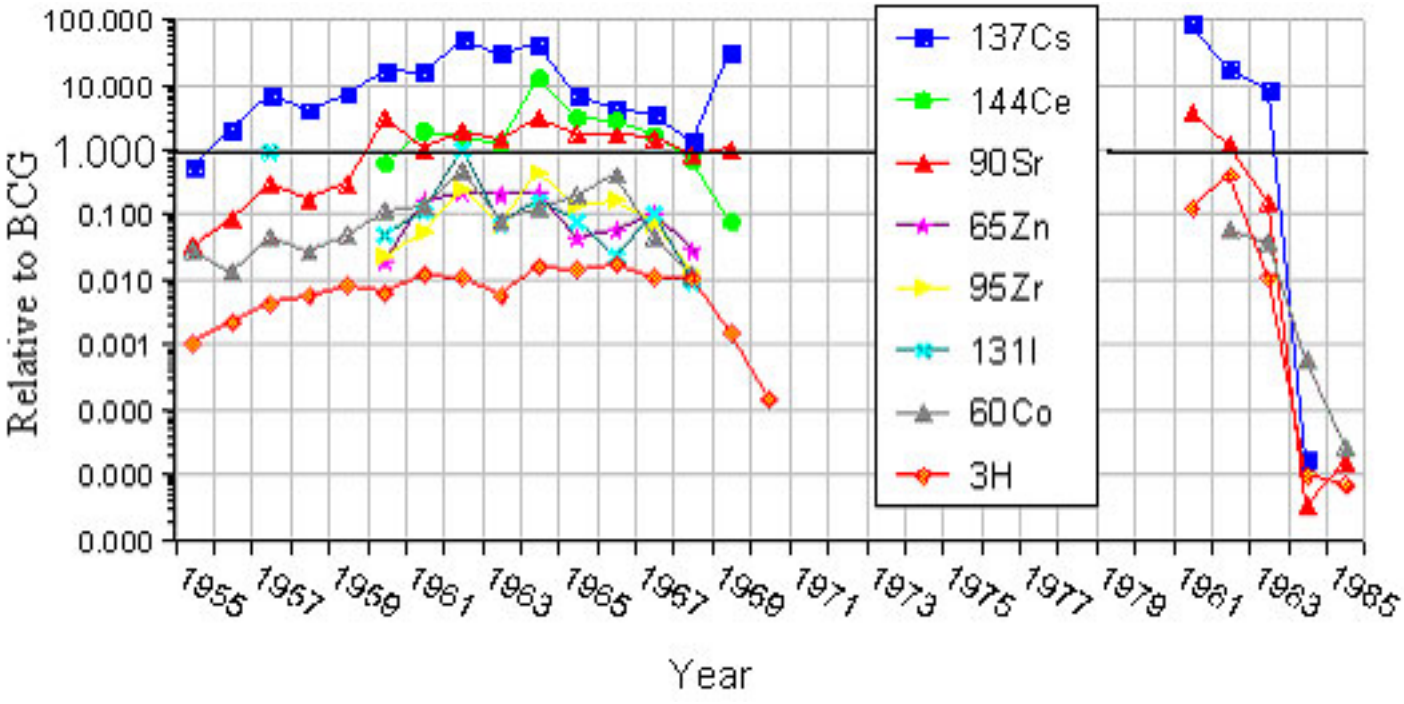

Figure 12-4 *. A plot of the activity concentrations in Steel Creek (see Fig. 12-3) divided by the isotope-specific Biota Concentration Guide (see Table 12-3). A ratio greater than one suggests that the activity concentrations were sufficient for the biota to experience potentially harmful dose rates (i.*

e. greater than those suggested by the IAEA: 10 mGy d^{-1} for aquatic organisms and 1 mGy d^{-1} for terrestrial or riparian organisms). The DOE model revealed that aquatic organisms were at greater risk from exposures to 144 Ce, 60 Co, and 95 Zr, while riparian organisms were at greater risks from 137 Cs, 3 H, 131 I, 90 Sr, and 65 Zn.

Effluent water left the reactors at approximately 70°C (Brown et al. 1972), and along with increased flow rates, dramatically impacted onsite streams (**Fig. 12-5**). Natural flows of Steel Creek increased from about 1 m^3 s^{-1} to over 20 m^3 s^{-1} in the early 1960s. The increased flow flooded the stream banks along much of their length and the elevated temperatures exceeded the tolerance thresholds of numerous aquatic species. Studies on the effects of the flooding showed that numerous species of vegetation were unable to survive (Loblolly pine, flowering dogwood, American holly, Sweet bay, Southern Wax Myrtle, southern red oak and swamp chestnut oak). Shartiz et al. (1974) documented effects in areas receiving elevated water temperatures, but also in areas of ambient water temperature with abnormal flooding and heavy siltation. Within a 3020 ha swamp that received reactor effluents, total tree kill occurred in 227 ha, moderate effects occurred in 263 ha, and 1396 ha were slightly impacted. Additional effects from the thermally elevated effluents included: decreased diversity of woody plant species (Sharitz et al. 1974); decreased abundance and diversity of amphibians (Parker et al. 1971); decreased diversity of waterfowl (Brisbin et al. 1974); decreased fish abundance and diversity (Gibbons et al. 1974); a decrease in aquatic insect species (Howell and Gentry, 1974); and increased parasite loads in fish (Eure and Esch, 1974).

Figure 12-5 *. Perhaps the most visually dramatic effects from reactor operations was the destruction of the hardwood and cypress-gum forest canopy within the Savannah River swamp due to elevated water temperatures and flooding from increase water flows. Although the streams are now recovering, the dead standing timber are still evident.*

12.5. IMPACTS of LAND USE CHANGE

An analysis of the environmental impacts of a large nuclear production facility would be incomplete

without commenting on the impacts due to land use changes. To isolate such a large area (750 km²) from the public for over 50 years is in itself an impact, as indicated from satellite photography (**Fig. 12-6**). Only 15% of the SRS has been used for site operations; the remainder consists of dense forest and wetland habitats that contrasts dramatically with the adjacent land disturbed by a continued and ever-growing human presence. Isolation of the SRS from public use has actually been beneficial to the environment, and from an environmental perspective constitutes a positive impact from operating the nuclear complex (Whicker et al. 2004). The buffer areas established around the large DOE sites, such as the SRS, provide valuable wildlife habitat that is undiminshed by the low level radiation. Ironically, it is largely because of this slight contamination that areas have remained isolated from the public and now support thriving ecosytems, with no evidence of population-level impacts from radionuclide or chemical releases (Whicker et al. 2004). Indeed, the SRS has been designated a National Environmental Research Park and supports several endangered species that do not occur on adjacent public lands.

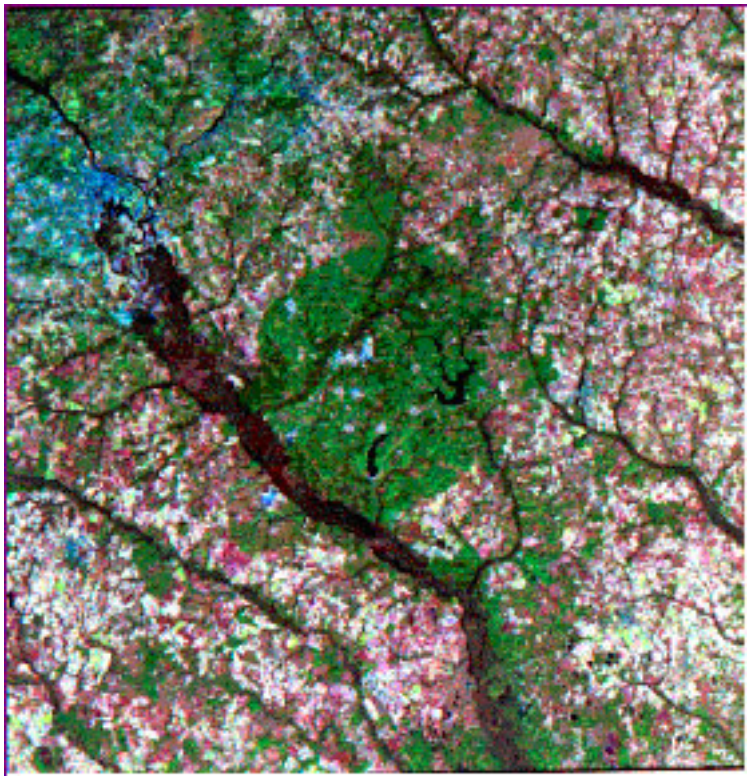

Figure 12-6 *. Satellite photograph of the Savannah River Site showing its dominance by green forest relative to the mosaic disturbance from farming and residential areas surrounding the site. The maroon-colored cord in the center-left of the picture is the Savannah River, flowing from center to lower right.*

12.6 CONCLUSIONS and UNCERTAINTIES

The rather simplistic approach used to examine the radiological impacts of operating a nuclear weapons complex for over 50 years revealed the following:

- During the early years of operating the SRS, releases from nuclear reactor effluents to Steel Creek, the most contaminated stream on the SRS, were probably sufficient to generate dose rates in excess of the IAEA's guidelines for riparian animals (1 mGy d^{-1}).

- There is no evidence that such dose rates were sufficient to cause mortality to biota. Chronic exposures might alter reproductive performance and thereby affect population dynamics. The probability, type and extent of sublethal damage from chronic, low level exposures to radionuclides are currently the subject of International debate.
- Of the 23 radioisotopes within the DOE's model database used in this exercise, 137 Cs was the contaminant that dominated dose rates to biota. The importance of 137 Cs as an environmental pollutant mirrors earlier studies that documented its importance to offsite human doses via aquatic pathways (RAC, 2001).
- The most visually striking, and best-documented environmental impact to onsite streams was not caused from radioactive releases, but by the increase flow and elevated temperatures from the reactor effluents.
- Isolation of the SRS from development and public occupation has had obvious positive environmental impacts that offset the negative ones caused from reactor effluents.

The uncertainties of this analysis include the lack of a complete library of radioactive releases within the current DOE model, and the absence of some short-lived, potentially important radioisotopes (e.g. 32 P and 104&106 Ru) from the analysis. The calculations were also based on average annual activity concentrations of radionuclides within the onsite stream, thus short-term peak releases were not considered and may have caused acute dose rates to exceed those presented here.

The IAEA guidance suggests that population level impacts will not occur if dose rates to the *maximally exposed individuals* are below the criteria (IAEA, 1992). Because annual average releases were used for the DOE model calculations, the results depict dose rates likely experienced by a large percentage of the biota population within Steel Creek, rather than the maximally exposed individuals. The implications of determining dose rates to maximally exposed individuals relative to a group mean have recently been explored (Wilson and Hinton, 2003).

The environmental impacts from releases by the SRS cannot be ascribed to the other nuclear complex facilities described in earlier chapters of this report. Each facility had its own characteristic release of contaminants in regard to quantities, isotopic mixtures, and pathways of exposure. Each environment surrounding the nuclear facilities also had unique characteristics that either dampened or enhanced the impact of radionuclide releases. For example, the sandy soils of the SRS, with a low abundance of illite-type clays and low stable potassium concentrations, enhanced the environmental transport of 137 Cs. These conditions do not exist at most of the other facilities described in the preceding chapters.

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Radiation Units

Radiation Units

Quantity	SI Unit	Symbol	Non-SI Unit	Symbol	Conversion
Activity	becquerel	Bq	curie	Ci	1 Bq = 2.7×10^{-11} Ci
Absorbed dose	gray	Gy	rad	rad	1 Gy = 100 rad
Dose equivalent	sievert	Sv	rem	rem	1 Sv = 100 rem

GLOSSARY

The smallest particle of matter with the same chemical properties

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Source: World Nuclear Association Information Glossary

A-C

Activation product: A radioactive isotope of an element (eg in the steel of a reactor core) which has been created by neutron bombardment.

ALARA: As Low As Reasonably Achievable, economic and social factors being taken into account. This is the optimisation principle of radiation protection.

Alpha particle: A positively-charged particle from the nucleus of an atom, emitted during radioactive decay. Alpha particles are helium nuclei, with 2 protons and 2 neutrons.

Atom: The smallest particle of matter with the same chemical properties. Atoms have a nucleus consisting of positively-charged protons and uncharged neutrons of the same mass. The positive charges on the protons are balanced by a number of negatively-charged electrons in motion around the nucleus.

Background radiation: The naturally-occurring ionising radiation which every person is exposed to, arising from the earth's crust (including radon) and from cosmic radiation.

Becquerel: The SI unit of intrinsic radioactivity in a material. One Bq measures one disintegration per second and is thus the activity of a quantity of radioactive material which averages one decay per second. (In practice, GBq or TBq are the common units.)

Beta particle: A particle emitted from an atom during radioactive decay. Beta particles may be either electrons (with negative charge) or positrons.

Boiling water reactor (BWR): A common type of light water reactor (LWR), where water is allowed to boil in the core thus generating steam directly in the reactor vessel. (cf PWR)

Breed: To form fissile nuclei, usually as a result of neutron capture, possibly followed by radioactive decay.

Breeder reactor: see Fast Breeder Reactor and Fast Neutron Reactor.

CANDU: Canadian deuterium uranium reactor, moderated and cooled by heavy water.

Chain reaction: A reaction that stimulates its own repetition, in particular where the neutrons originating from nuclear fission cause an ongoing series of fission reactions.

Cladding: The metal tubes containing oxide fuel pellets in a reactor core.

Concentrate: See Uranium oxide concentrate (U3O8).

Control rods: Devices to absorb neutrons so that the chain reaction in a reactor core may be slowed or stopped by inserting them further, or accelerated by withdrawing them.

Conversion: Chemical process turning U3O8 into UF6 preparatory to enrichment.

Coolant: The liquid or gas used to transfer heat from the reactor core to the steam generators or directly to the turbines.

Core: The central part of a nuclear reactor containing the fuel elements and any moderator.

Critical mass: The smallest mass of fissile material that will support a self-sustaining chain reaction under specified conditions.

Criticality: Condition of being able to sustain a nuclear chain reaction.

D-F

Decay: Disintegration of atomic nuclei resulting in the emission of alpha or beta particles (usually with gamma radiation). Also the exponential decrease in radioactivity of a material as nuclear disintegrations take place and more stable nuclei are formed.

Decommissioning: Removal of a facility (eg reactor) from service, also the subsequent actions of safe storage, dismantling and making the site available for unrestricted use.

Depleted uranium: Uranium having less than the natural 0.7% U-235. As a by-product of enrichment in the fuel cycle it generally has 0.25-0.30% U-235, the rest being U-238. Can be blended with highly-enriched uranium (eg

from weapons) to make reactor fuel.

Deuterium: "Heavy hydrogen", a stable isotope having one proton and one neutron in the nucleus. It occurs in nature as 1 atom to 6500 atoms of normal hydrogen, (Hydrogen atoms contain one proton and no neutrons).

Element: A chemical substance that cannot be divided into simple substances by chemical means; atomic species with same number of protons.

Dose: The energy absorbed by tissue from ionising radiation. One gray is one joule per kg, but this is adjusted for the effect of different kinds of radiation, and thus the sievert is the unit of dose equivalent used in setting exposure standards.

Enriched uranium: Uranium in which the proportion of U-235 (to U-238) has been increased above the natural 0.7%. Reactor-grade uranium is usually enriched to about 3.5% U-235, weapons-grade uranium is more than 90% U-235.

Enrichment: Physical process of increasing the proportion of U-235 to U-238. See also SWU

Fast breeder reactor (FBR): A fast neutron reactor (qv) configured to produce more fissile material than it consumes, using fertile material such as depleted uranium in a blanket around the core.

Fast neutron reactor: A reactor with little or no moderator and hence utilising fast neutrons. It normally burns plutonium while producing fissile isotopes in fertile material such as depleted uranium (or thorium).

Fertile (of an isotope): Capable of becoming fissile, by capturing neutrons, possibly followed by radioactive decay; eg U-238, Pu-240.

Fissile (of an isotope): Capable of capturing a slow (thermal) neutron and undergoing nuclear fission, e.g. U-235, U-233, Pu-239.

Fissionable (of an isotope): Capable of undergoing fission: If fissile, by slow neutrons; if fertile, by fast neutrons.

Fission: The splitting of a heavy nucleus into two, accompanied by the release of a relatively large amount of energy and usually one or more neutrons. It may be spontaneous but usually is due to a nucleus absorbing a neutron and thus becoming unstable.

Fission products: Nuclei resulting either from the fission of heavy elements such as uranium, or the radioactive decay of those primary

daughters. Usually highly radioactive.

Fossil fuel: A fuel based on carbon presumed to be originally from living matter, eg coal, oil, gas. Burned with oxygen to yield energy.

Fuel assembly: Structured collection of fuel rods or elements, the unit of fuel in a reactor.

Fuel fabrication: Making reactor fuel assemblies, usually from sintered UO2 pellets in zircalloy tubes, comprising the fuel rods or elements.

G-I

Gamma rays: High energy electro-magnetic radiation, virtually identical to X-rays.

Genetic mutation: Sudden change in the chromosomal DNA of an individual gene. It may produce inherited changes in descendants. Mutation in some organisms can be made more frequent by irradiation (though this has never been demonstrated in humans).

Giga: One billion units (eg gigawatt 10E9 watts or million kW).

Graphite: Crystalline carbon used in very pure form as a moderator, principally in gas-cooled reactors, but also in Soviet-designed RBMK reactors.

Gray: The SI unit of absorbed radiation dose, one joule per kilogram of tissue.

Greenhouse gases: Radiative gases in the earth's atmosphere which absorb long-wave heat radiation from the earth's surface and re-radiate it, there-by warming the earth. Carbon dioxide and water vapour are the main ones.

Half-life: The period required for half of the atoms of a particular radioactive isotope to decay and become an isotope of another element.

Heavy water: Water containing an elevated concentration of molecules with deuterium ("heavy hydrogen") atoms.

Heavy water reactor (HWR): A reactor which uses heavy water as its moderator, eg Canadian CANDU (pressurised HWR or PHWR).

High-level wastes: Extremely radioactive fission products and transuranic elements (usually other than plutonium) in spent nuclear fuel. They may be separated by reprocessing the spent fuel, or the spent fuel containing them may be regarded as high-level waste.

Highly (or High)-enriched uranium (HEU): Uranium enriched to at least 20% U-235. (That in weapons is about 90% U-235.)

In situ leaching (ISL): The recovery by chemical leaching of minerals from porous orebodies without physical excavation. Also known as solution mining.

Ion: An atom that is electrically-charged because of loss or gain of electrons.

Ionising radiation: Radiation (including alpha particles) capable of breaking chemical bonds, thus causing ionisation of the matter through which it passes and damage to living tissue.

Internal cost: A cost, eg of waste disposal or environmental impact which is taken into account when calculating the cost, price or economic benefit of a product or service (cf external cost).

Irradiate: Subject material to ionising radiation. Irradiated reactor fuel and components have been subject to neutron irradiation and hence become radioactive themselves.

Isotope: An atomic form of an element having a particular number of neutrons. Different isotopes of an element have the same number of protons but different numbers of neutrons and hence different atomic mass, eg. U-235, U-238. Some isotopes are unstable and decay (qv) to form isotopes of other elements. Light water: Ordinary water (H20) as distinct from heavy water.

J-O

Light water reactor (LWR): A common nuclear reactor cooled and usually moderated by ordinary water.

Low-enriched uranium: Uranium enriched to less than 20% U-235. (That in power reactors is usually 3.5 - 4.5% U-235.)

Megawatt (MW): A unit of power, = 10E6 watts. MWe refers to electric output from a generator, MWt to thermal output from a reactor or heat source (eg the gross heat output of a reactor itself, typically three times the MWe figure).

Metal fuels: Natural uranium metal as used in a gas-cooled reactor.

Micro: one millionth of a unit (eg microsievert is 10E-6 Sv).

Milling: Process by which minerals are extracted from ore, usually at the mine site.

Mixed oxide fuel (MOX): Reactor fuel which consists of both uranium and plutonium oxides, usually about 5% Pu, which is the main fissile component.

Moderator: A material such as light or heavy water or graphite used in a reactor to slow down fast neutrons by collision with lighter nuclei so as to expedite further fission.

Natural uranium: Uranium with an isotopic composition as found in nature, containing 99.3% U-238, 0.7% U-235 and a trace of U-234. Can be used as fuel in heavy water-moderated reactors.

Neutron: An uncharged elementary particle found in the nucleus of every atom except hydrogen. Solitary mobile neutrons travelling at various speeds originate from fission reactions. Slow (thermal) neutrons can in turn readily cause fission in nuclei of "fissile" isotopes, e.g. U-235, Pu-239, U-233; andfast neutrons can cause fission in nuclei of "fertile" isotopes such as U-238, Pu-239. Sometimes atomic nuclei simply capture neutrons.

Nuclear reactor: A device in which a nuclear fission chain reaction occurs under controlled conditions so that the heat yield can be harnessed or the neutron beams utilised. All commercial reactors are thermal reactors, using a moderator to slow down the neutrons.

Oxide fuels: Enriched or natural uranium in the form of the oxide UO2, used in many types of reactor.

P-R

Plutonium: A transuranic element, formed in a nuclear reactor by neutron capture. It has several isotopes, some of which are fissile and some of which undergo spontaneous fission, releasing neutrons. Weapons-grade plutonium is produced in special reactors to give >90% Pu-239, reactor-grade plutonium contains about 30% non-fissile isotopes. About one third of the energy in a light water reactor comes from the fission of Pu-239, and this is the main isotope of value in reprocessing spent fuel.

Pressurised water reactor (PWR): The most common type of light water reactor

(LWR), it uses water at very high pressure in a primary circuit and steam is formed in a secondary circuit.

Radiation: The emission and propagation of energy by means of electromagnetic waves or particles. (cf ionising radiation)

Radioactivity: The spontaneous decay of an unstable atomic nucleus, giving rise to the emission of radiation.

Radionuclide: A radioactive isotope of an element.

Radiotoxicity: The adverse health effect of a radionuclide due to its radioactivity.

Radium: A radioactive decay product of uranium often found in uranium ore. It has several radioactive isotopes. Radium-226 decays to radon-222.

Radon (Rn): A heavy radioactive gas given off by rocks or materials containing radium (or thorium). Rn-222 is the main isotope.

Radon daughters: Short-lived decay products of radon-222 (Po-218, Pb-214, Bi-214, Po-214).

Reactor pressure vessel: The main steel vessel containing the reactor fuel, moderator and coolant.

Repository: A permanent disposal place for radioactive wastes.

Reprocessing: Chemical treatment of spent reactor fuel to separate uranium and plutonium from the small quantity of fission product waste products and transuranic elements, leaving a much reduced quantity of high-level waste. (cf Waste, HLW).

S-Z

Separative Work Unit (SWU): This is a complex unit which is a function of the amount of uranium processed and the degree to which it is enriched, ie the extent of increase in the concentration of the U-235 isotope relative to the remainder. The unit is strictly: Kilogram Separative Work Unit, and it measures the quantity of separative work (indicative of energy used in enrichment) when feed and product quantities are expressed in kilograms.

Sievert (Sv): Unit indicating the biological damage caused by radiation. One Joule of beta or gamma radiation absorbed per kilogram of tissue has 1 Sv of

biological effect; 1 J/kg of alpha radiation has 20 Sv effect.

Spent fuel: Fuel assemblies removed from a reactor after use.

Stable: Incapable of spontaneous radioactive decay.

Tailings: Ground rock remaining after particular ore minerals (e.g. uranium compounds) are extracted.

Tails: Depleted uranium (cf. enriched uranium), with about 0.3% U-235.

Thermal reactor: A reactor in which the fission chain reaction is sustained primarily by slow neutrons, and hence requiring a moderator (as distinct from Fast Neutron Reactor).

Transmutation: Changing atoms of one element into those of another by neutron bombardment, causing neutron capture.

Transuranic element: A very heavy element formed artificially by neutron capture and subsequent beta decay(s). Has a higher atomic number than uranium (92). All are radioactive. Neptunium, plutonium and americium are the best-known.

Uranium (U): A mildly radioactive element with two isotopes which are fissile (U-235 and U-233) and two which are fertile (U-238 and U-234). Uranium is the basic fuel of nuclear energy.

Uranium hexafluoride (UF6): A compound of uranium which is a gas above 56oC and is thus a suitable form in which to enrich the uranium.

Uranium oxide concentrate (U3O8): The mixture of uranium oxides produced after treatment uranium ore from a mine. Sometimes loosely called yellowcake. It is khaki in colour and is usually represented by the empirical formula U3O8. Uranium is exported from Australia in this form.

Vitrification: The incorporation of high-level wastes into borosilicate glass, to make up about 14% of it by mass. It is designed to immobilise radionuclides in an insoluble matrix ready for disposal.

Waste:
High-level waste (HLW) is highly radioactive material arising from nuclear fission, requiring both shielding and cooling. It can be recovered from reprocessing spent fuel, though some countries regard spent fuel itself as HLW. It requires very careful handling, storage and disposal.
Intermediate-level waste (ILW) is sufficiently radioactive to require

shielding, some is categorised as long-lived ILW and this may be disposed of with HLW.
Low-level waste (LLW) is mildly radioactive material which does not require shielding in handling or storage, and is usually disposed of by incineration and shallow burial.

Yellowcake: Ammonium diuranate, the penultimate uranium compound in U3O8 production, but the form in which mine product was sold until about 1970. See also Uranium oxide concentrate. Zircaloy: Zirconium alloy used as a tube to contain uranium oxide fuel pellets in a reactor fuel assembly.

M I N U T E S

International Seminar " A ssessment of the Mining & Chemical Combine I mpact on Population H ealth and Environment"

(Zheleznogorsk, August 7-10, 2000)

Mining & Chemical Combine Zheleznogorsk, August 7-9, 2000	Minatom of Russia, Moscow, August 11, 2000

Arranged by Minatom of Russia and Mining & Chemical Combine

More than 40 experts from 10 organizations of Russia, including the Minatom of Russia, Mining & Chemical Combine (M&CC), VNIICHT, RRC "Kurchatov Institute", Institute of Biophysics, IGCE, RAS IGEM, ISTC, etc., performing the joint efforts for study the radiation legacy of the former USSR within the framework of the ISTC # 245 RADLEG project, took part in the Seminar. Also included were foreign experts – representatives of the International SCOPE-RADSITE project and the RADLEG project collaborators: Prof. M.Goldman (the University of California, USA), Prof. R.Kirchmann (Liege University, Belgium) and Dr. Christian Vandecasteele (SCK*CEN, Mol, Belgium).

Twenty reports were submitted and discussed (Seminar Programme is attached).

The participants of the Seminar reported that:

Recently, the Mining & Chemical Combine, together with specialists from other Russian institutions and with international participation, made significant progress in investigation and monitoring of the radiological impact in the area of the M&CC, primarily in the Yenisei River floodplain and around the "Severnyi" radwaste disposal site. Assessment of inventory of man-made radionuclides in flood-plain deposits of the Yenisei River and the long-term forecasting of the radionuclides entrying into the Kara Sea is being carried out (SPA "Radium Institute" jointly with M&CC). Valuable scientific information gained on radionuclide transfer pathways to man and environment was the basis of development of an original model to estimate the population dose status. Models of radionuclide migration in the liquid radwaste disposal sites in geological formations have been created and estimates of predicted doses have been derived. Future work will also include assessments of the impact of radionuclide exposure on the environment, agriculture, fishing, and water quality.

Databases are needed of normal baseline environmental factors, and of radionuclide behavior and transfer dynamics into the food chain, as well as an evaluation of possible rehabilitation and countermeasures.

A public accessible database has been formed with user's interface (Access/Oracle) both in Russian and in English, as well as a GIS-project describing radionuclide contamination of the area of the M&CC radiation impact within the framework of the ISTC # 245 RADLEG project on the based on the extensive collection of data on the main military and civilian sectors of the FSU radiation legacy. Further planning was developed for the 1 st International Conference "Radiation Legacy of the XX Century: Remediation Problems" (Moscow, October 31 – November 3, 2000).

A series of the meetings of the international experts have been convened within the SCOPE-RADSITE

International project, to discuss problems of radiation impact on the health and on the environment as a result of activities connected with nuclear weapon production over the world.

Minatom of Russia, Federal Department “Medbioextrem”, Institute of Biophysics decided to form a medical and biological register for nuclear facilities personnel, including a corresponding database for population living in area of facilities impact. The implementation of the project will require support from the nuclear industry, as well as from independent Russian and foreign experts representing the RADLEG and SCOPE-RADSITE International projects.

The Seminar participants generated the following recommendations:

• To approve the Proposal for the 3 rd phase of the RADLEG project, “Assessment of the Impact of Radiation-Hazardous Facilities in North-Western Russia and Krasnoyarsk Region on the Population and Environment, including Development of Countermeasures”. The proposal will be developed jointly by RF Minatom, VNIICHT, M&CC, Russian Academy of Sciences, RAS IGEM, and RRC “Kurchatov Institute”.

• The Russian effort in dose estimation, reconstruction, and prediction must include a thorough review and verification of the original data with participation of the M&CC and other nuclear facilities personnel, as well as the international experts (SCOPE-RADSITE project etc.). Furthermore, the assessment methodology and strategy used to develop the Hanford nuclear complex impact areas (USA) appear to provide a reasonable model to follow in the Russian efforts in dose estimation, reconstruction, and prediction.

• To begin forming a medical and biological register database for M&CC personnel and the population within the combine impact areas.

• To convene an International Seminar in 2001 on assessment of the radiation impact (M&CC and analogous objects over the world) at Zheleznogorsk with participation of experts of the SCOPE-RADSITE project, as well as the European Union (Joint Research Center), IAEA, and US Department of Energy.

	Representatives of the SCOPE-RADSITE project:
V.A.Lebedev, Seminar Chairman	M.Goldman
A.A.Iskra. Seminar Secretary	R.Kirchmann

RADSITE contact meeting

10.00 - 13.00 hr., June 14 th , 1998

Venue:	SCOPE IUPAC	Hyatt Regency, New Brunswick, N.J.
Participants:	DoE Experts	Drs. Ph. Bourdeau, Veronique Plocq-Fichelet Dr. Miyamoto
Apology:		Dr. P. Seligman Drs. L. Anspaugh, W. Burkart, M. Goldman, B. Goldstein, E. Stukin, A. Upton, R. Kirchmann Dr. S. Auerbach

1) Approval of agenda, identification of participants

Dr. Ph. Bourdeau, president of SCOPE, opened the meeting and asked everybody present to introduce themselves. The agenda proposed by the convenor, Dr. R. Kirchmann, was adopted and Dr. M. Goldman was elected chairman. Dr. Burkart was charged with preparing the minutes of the meeting.

Dr. M. Goldman outlined the purpose of the meeting to decide on planning and organization of RADSITE. Two major decisions have to be made:
- which generic topics have to be covered in RADSITE, and
- which potential sites will be included

2) General presentation of the RADSITE project

Dr. R. Kirchmann introduced the present status of RADSITE. The RADSITE study is to focus on the global problem of radioactivity released into the environment from processes involved in the production of special nuclear materials for nuclear weapons, and on associated environmental and health effects.

The objectives are:

- to focus on countries having a history of military mining, plutonium production, reprocessing and waste disposal. Therefore the study concentrates on the US, Russia, France, UK, China and to a lesser degree on Japan and Germany. Countries with emerging nuclear weapons programs such as India, Israel and Pakistan might also be considered.
- it is suggested that military rather than civilian activities require analysis and synthesis. UNSCEAR has already considered releases and doses from the civilian nuclear fuel cycle.
- to exchange information among the above mentioned nations.
- to initiate active participation of key institutes and scientists having knowledge and access to formerly classified materials needed for a full assessment of past, present and future exposure situations.
- to assist in selecting appropriate and efficient mitigation activities to reduce present and potential future exposures.

The following principal tasks were identified:

- study of radioactive releases and wastes arising from the special nuclear materials operations
- Exposure assessment of the human populations

Deliverables, publication of results

- A periodic Newsletter
- A comprehensive Radsite publication (SCOPE book) In a discussion to define the goals to be reached further, the following additional specifications were agreed upon:
- RADSITE is to deal not only with accidents but in depth with operational and routine releases in early special nuclear materials activities (Dr. B. Goldstein)
- Activities considered large scale release experiments (e.g. Green Run in Hanford) and situations were experiments on humans were suspected in the media (late or no evacuation after the Bravo test and along River Techa) have to be considered carefully (Drs. M. Goldman, W. Burkart).
- For consideration of remedial actions, both
- limitations of societal resources, and
- the effectiveness of possible options have to be weighted (Dr. Seligman)
- Considering sites in the former Soviet Union in addition to the Chelyabinsk area and Semipalatinsk, Dr. E. Stukin suggested consideration of Krasnoyarsk and Tomsk, two additional areas where plutonium production took place. After discussion of possible merits, the inclusion of naval sites was rejected.
- In response to Dr. Bourdeau's wish to have clear definitions of the objectives, and arguments on the importance of selected topics, it was specified that - contrary to civilian activities - there is a unique need to clarify the circumstances surrounding formerly secret military activities (Dr. M. Goldman). Dr. Seligman considered both societal implications and also the scientific task to learn from unique exposure situations in the past.
- It was decided that mining set up for nuclearmilitary purposes was to be included (Wismut in Saxony, Thuringia), but that occupational exposures would not be considered, i.e. that consideration of health effects would be limited to general populations (Dr. L. Anspaugh).
- Dr. Miyamoto raised the question on how chemicals involved in the diverse industrial processes should be addressed. Although the potential importance of chemical toxicity - and possible combined effects - was recognized, the complexity of these topics is such that it was considered not feasible to consider them in depth in the framework of RADSITE. It was decided to mention these aspects whenever information on the potential importance of releases of chemicals arises. Possible confounders of radiation effects include organic solvents, beryllium, mercury and arsenic.
- It was recognized that activities by IAEA (radiological assessment for Semipalatinsk), and IIASA assessment activities in Chelyabinsk, Krasnoyarsk and Tomsk have to taken into consideration to prevent duplicative work.
- The special importance of exposures still existing or potentially arising in the future through migration of radionuclides in geological structures has to be addressed in RADSITE. This is an original task for SCOPE.
- It has to be accepted that available information and depth of coverage for the sites covered might vary considerably in the final product. Possibly missing information will be addressed in the final assessment.
- An important result of the RADSITE activities will be the flow of formerly classified information among specialists, which by itself might initiate further interaction and an increased understanding of generic issues.

3) Identification of active participants to the RADSITE project

The general structure (draft 2, annex 1) presented by Dr. René Kirchmann lists professionals for the five working groups *Source terms* , *Pathways to man* , *Dose estimates/Health impact* , *Environmental impact* , and *Countermeasures* . The proposed chairmen of the working groups are marked with an asterisk. It is to be considered whether *Dose estimates* should be joined with *Pathways to man* . The members of a proposed scientific advisory committee are in annex 2.

Dr. Bourdeau questioned the need for a steering committee. It was however considered important for coordination, to help facilitate access to classified data, and to help in securing funds for RADSITE.

Both horizontal as well as vertical interaction in the RADSITE organizational chart (annex 1) will be necessary to facilitate interaction among different aspects of specific projects and sites.

The need to nominate a Chinese member to the steering committee was recognized.

4) Potential funding sources

At this stage, an additional planning meeting to take place in Brussels is covered by the EU. An EU concerted action, which could provide travel money for specialists from the EU and the former Soviet Union has been proposed. ISTC (International Science and Technology Center) in Moscow and STCU (Ukraine) are possible funding bodies for RADSITE related activities for members in CIS countries. NATO is to be approached again, as all deliverables to be provided to NATO for the RADTEST project have been completed.

From experience with RADTEST, the SCOPE secretariat suggests a strong project administration to keep the momentum and to meet deadlines for funding bodies.

Further potential contributors mentioned:
- Rockefeller foundation
- Rockefeller Brothers Fund
- Soros Foundation
- other private foundations
- Sasakawa Foundation
- WHO?

Total contributions of about 700 kEcu over 3 years are needed.

5) Planning meeting in Belgium

Fall meeting in November; suggested dates for 2 days conference: 7/8 or 14/15 immediate action needed:
- set up agenda
- make sure that China, UK, and France are represented

6) Varia

Approach proposed group leaders to secure their commitment.
Annex I: RADSITE organizational chart
Annex II RADSITE working group leaders, steering committee, scientific advisory committee
W. Burkart, New Brunswick, 15. 06. 98

Co-ordination meeting SCOPE-RADSITE
Moscow, Hotel “MIR”, 11/08/2000
(Draft)

Objective: Preparation of the Brussels workshop on 04-07/12/2000
Participants: R. Kirchmann, M. Goldman, C. Vandecasteele, T. Yakhnina (observer).

1) Preliminary programme for the meeting:

Saturday	02/12:	Arrival of the participants (APEX tickets)
Sunday	03/12:	Arrival of the participants
Monday	04/12:	AM Plenary session: presentation of key papers on Source terms and Pathways PM Working Group session on Source terms and Pathways
Tuesday	05/12:	AM Plenary session: presentation of key papers on Health impact and Countermeasures PM Working Group session on Health impact and Countermeasures
Wednesday	06/12:	AM Plenary session: presentation of key papers on Environmental impact and Countermeasures side effects PM Working Group session on Environmental impact and Countermeasures side effects
Thursday	07/12:	AM Steering Committee PM Departure of participants

Papers are expected to give the state of the art concerning one specific site in each region. They should be structured as the authors envisage the structure of their contribution to the final report. This will allow the different regional authors for one specific topic to harmonise their individual contribution to the final report.

Working group discussion will be the priority of this meeting and time devoted WG session should not be shorter than 2 hours. They aim to harmonise the individual contributions for the final report, identify missing information, and envisage potential ways ti fill up the gaps.

• Identification of the potential key persons who will act as responsible for gathering and summarising the available information on a specific topic concerning the selected sites in their region.

These persons will be contacted by **CV** to obtain their formal agreement to contribute. Some names need to be still identify:

RK will identify the responsible for “source term” and “Dose estimation - Health impact” in Europe.

RK will contact M. Balonov and **MG** will contact Rusanov to identify a responsible for “Dose estimation - Health impact” in FSU.

Someone for Countermeasure in Japan must still be identify.

Working Group leaders for each topic will be identify during the Brussels meeting among the regional responsible.

	Source-term	Pathways to man	Dose estimation Health impacts	Environmental impacts	Counter-measures
WG Leader	To be define latter among the regional responsible				
ASIA	U. Mishra	Pan Ziqiang Y. Muramatsu S. Yoshida	Pan Ziqiang T. Sugahara	Pan Ziqiang Y. Ohmomo	To be identify (from Japan)
EUR	RK to identify	A Cigna	W. Burkart ? R. Masse	D. Woodhead	G. Collard
FSU	V. Popov	A. Trapeznikov	Ask M. Balonov and Rusanov [Savkin]	A. Trapeznikov	R. Alexakhin
USA	B. Napier	B. Napier	M. Goldman	T. Hinton	T. Hinton

3) Who will participate?

	Papers	Others
ASIA	U. Mishra (SC Advisor) Y. Muramatsu / S. Yoshida T. Sugahara (SC Member) Y. Ohmomo Pan Ziqiang	Mao Yongze (SC Member)
EUR	A. Cigna W. Burkart D. Woodhead G. Collard	Ph. Bourdeau (SC Member) R. Kirchmann (SC Member) C. Vandecasteele (Scientific secretary) R. Masse (SC Advisor)
FSU	V. Popov A. Trapeznikov R. Alexakhin (SC Advisor) NN	V. Lebedev (SC Member) A. Iskra
USA	B. Napier T. Hinton M. Goldman (SC Member)	

4) Provisional budget:

Travel:	FSU:	5 x 400 USD =	2,000 USD	
	USA:	3 x 1,200 USD =	3,600 USD	
	EUR:	4 x 400 USD =	1,600 USD	
	ASIA:	5 x 1,000 USD =	5,000 USD	
	Total:			12,200 USD
Accomodation and subsistence: 25 pers. x 6d x 100 USD:				15,000 USD
Translation:				2,500 USD
TOTAL:				29,700 USD

Hong-Kong ECOSYS-87 study
(Shang Zhaorong,.2001 **)**

2.3.1. INTRODUCTION

A RADIOECOLOGICAL model, ECOSYS-87 (Muller and Prohl 1993), is being used here in Hong Kong:: to evaluate the time-dependent contamination that might occur in food products should a nuclear accident occur at the Guangdong Nuclear Power Station at Daya Bay, and to assess the dose consequence to the local population from ingestion of contaminated foods. ECOSYS-87 was developed at GSF-Forschungszentrum für Umwelt und Gesundheit, Germany. It was developed for German agricultural conditions with the aim of providing a fast prognosis of the radiation exposure to the population due to ingestion after large-scale contamination of farmland. In applying ECOSYS-87 to Hong Kong, two major problems arose:

. The spectrum of food products important in Hong Kong differed significantly from that in central Europe. Many foodstuffs important in Germany could be neglected for the situation in Hong Kong. Other foodstuffs not considered before in the model had to be introduced. Moreover, the growth characteristics of plants had to be modi-fied for the situation in Hong Kong; and

. ECOSYS-87 estimated the ingestion dose assum-ing that all foodstuffs consumed were produced locally. This assumption was fairly acceptable in central Europe, but it was inappropriate for Hong Kong since Hong Kong imported quite a lot of food from distant sources and overseas countries.

Because of the above reasons, adaptation of the ECOSYS-87 was needed for its application to Hong Kong conditions. Adaptation could be broadly divided into two major areas. The first one was the choice of suitable parameters for the various transfer processes of radionuclides in the ecological environment. The second one was modification for agricultural and farming prac-tices typical to the situation in Hong Kong.

The C.B.Poon et al.'s paper* summarizes the adaptation work for radionuclide transfer in the Hong Kong ecological envi-ronment.** Adaptation for the agricultural and farming practices and the application of ECOSYS-87 to Hong Kong are detailed in another report.***.

2.3.2. MODEL ADAPTATION

Adaptation for radionucIide transfer in Hong Kong ecological environment

The climate in Hong Kong differed significantly from that in central Europe. It was characterized by two pronounced seasons, the monsoon and the dry season. The mean annual precipitation in Hong Kong amounted to 2,265 mm; about 90% of the rain fell in the summer months from April to September. The mean monthly air temperature was in the range of I5.8°C (January) to 28.8°C (July) with respective relative humidity of 71 %(January) and 80% (July). In view of this warm climate, farming could be practiced throughout the whole year. Such circumstances were simulated by dividing plants into cold and hot season species; the growth of each one was simulated separately.

Most of the foods consumed in Hong Kong were not produced locally. They came from different sources. Agricultural products and fresh milk came from nearby areas in south Guangdong, whereas livestock were im-ported from more distant sources in China. Other foods (e.g., wheat, wheat flour, potatoes) came from North China or overseas countries. The foodstuffs considered in ECOSYS-87-HK are given in Table 1. It should be noted that some foodstuffs imported from overseas countries (not including China) such as frozen meat or canned foods were not included in the consumption data file because they were quite irrelevant in the ingestion dose assessment as a result of an accident at the Guangdong Nuclear Power Station.

The principal model approaches applied for the estimation of plant food products were described else-where (Müller and Pröhl 1993). Experimental research on radionuclide transfer in the South East Asian ecolog-ical environment has been scarce. This led to the diffi-culty in assigning appropriate values for the model parameters. The choices for various parameter values for the transfer of radionuclides to plants had to be based on limited available data and professional judgment.

* Health Phys. 72(6):856-864; 1997

** Ecological environment in Hong Kong and in South Guangdong are assumed to be similar because, geographically, Hong Kong is part of the Guangdong Province. The adapted model is therefore equally applicable for modeling foods produced in South Guangdong and which are exported to Hong Kong for consumption.

***Food Chain Model-ECOSYS-87, Version HK: Application of ECOSYS-87 to Hong Kong, by S. M. Au, Department of Health, Hong Kong, February, 1994. (unpublished).

- Food production and consumption

A study about the daily consumption of Hong Kong people reports that 180.8g fruit, 35.3g roots and tubers, and 253.4g leafy vegetables are consumed every day per person (WHO, 1988). Therefore, vegetable is the most critical foodstuffs for Hong Kong people.

Table 2.a Estimated breakdown of local vegetable production by type in 2000

Vegetable	Production (tones)	%
White cabbage	383	0.90
Cabbage, Tientsin	181	0.43
Chinese spinach	294	0.69

Water spinach	14,242	33.51
Chrysanthemum, G	92	0.22
Celery, Chinese	1,248	2.94
Chinese lettuce	1,691	3.98
Water cress	5,615	13.21
Swiss chard	261	0.61
Chinese kale	465	1.09
Leaf mustard	135	0.32
Celtuce	916	2.16
White cabbage, green	60	0.14
Matrimony vine	1,835	4.32

Wild amaranth	755	1.78
Spinach	3,614	8.50
Flowering cabbage	43	0.10
Bosella	732	1.72
Indian rorippa	480	1.13
Chinese chives	454	1.07
Pumpkins	153	0.36
Silky gourd	17	0.04
Bringals	45	0.11
Chayote	684	1.61
Cucumber, yellow	62	0.15
Hairy gourd	16	0.04
Cucumber, bitter	255	0.6

In Hong Kong, aquaculture includes inland pond fish culture, marine fish culture. In 1999, the local inland ponds, covering an area of approximately 1094ha, produced 4500 tonnes of freshwater fish. About 99 per cent of the farms are engaged in polyculture (bighead carp, silver carp, common carp, grass carp in combination with tilapia or grey mullet). The remaining 1% practice monoculture of carnivorous species: snakehead, sea bass or catfish. Majority of the fry and fingerlings are imported from the Mainland, Thailand or Taiwan, while there is some local breeding of snakehead and catfish. Some of grey mullet fry may also be caught in local coastal waters. Traditionally, fry are stocked in early spring and most fish species reach marketable size in eight to twelve months.

Marine fish culture involves rearing of marine fish from fry or fingerlings to marketable size in cages suspended by floating rafts usually in sheltered coastal
areas. Common species under culture include gold-lined seabream, brown-spotted grouper, Russell's snapper, mangrove snapper, red snapper, cobia and pampano. Fry are mostly imported from the Mainland, Thailand, Philippines or Indonesia.

Wax gourd	360	0.85
Cucumber, (G &W)	42	0.10
Papaya	22	0.05
String beans	30	0.07
Celery, Euro	87	0.20

Broccoli	85	0.20

Sweet potatoes	19	0.04
Tomatoes	7	0.01
Chinese radish	327	0.77
Carrot	182	0.43
Spring onion	477	1.11
Coriander	212	0.50
Parsley	440	1.04
Chinese leek	62	0.15
Lotus leave	147	0.35
Lettuce, headed	910	2.14

Traditionally, marine cultured fish are fed with trash fish. In recent years, increasing number of marine fish farmers have changed over to use moist or dry pellet feed which significantly reduce pollution caused by fish feed and improves both the feed efficiency as well as fish health. Currently, there are 26 fish culture zones occupying
a total sea area of 209ha. Majority of the licensed farms are small, family based consisting of one to two rafts with average total area of around 250m2. In 1999, the production catered about 5 per cent of local demand for live marine fish (Agriculture, Fisheries and Conservation Department, HKSAR, 2001).

Minutes of the SCOPE-RADSITE Workshop,2 September,2001
Aix-en-Provence,France

(DRAFT)

Within the framework of the International Congress on the Radioecology & Ecotoxicology of Continental and Estuarine Environments (ECORAD-2001) a SCOPE-RADSITE Workshop was convened on Sunday 02 Sept at 15:00 hr in the premises of the Congress Centre.

Present ::R.Alexakhin,E.Falck, T.Hinton, A.Iskra, R.Kirchmann (Chairman), E.Kvasnikova,

Y.Ohmomo (partim), G.Polikarpov (Acting Secretary),V.Popov, K.Wichterey

In attendance: D.Calmet, L.Foulquier, D.Louvat,

Apologies for absence : Ph.Bourdeau, A.Cigna G.Collard, M.Goldman, Y.Kutkahmedov, G.Linden, M. Savkin, S.Sheppard, H.Tsukada, C.Vandecasteele, H.Vandenhove, T.Zeevaert,

AGENDA :

1. Welcome address and objective of the meeting (R.Kirchmann)
2. Progress status of the Synthesis volume (C.Vandecasteele)
   Chap.1.Source-term (V.Popov's report)
   Chap.2 Pathways(A.Cigna's report)
   Chap.3 Dose assessment (M.Savkin's report)
   Chap.4 Impact on Population Health (M.Goldman's report)
   Chap.5. Impact on the Environment (T.Hinton's report)
   Chap 6 Impact Mitigation (G.Collard's report)

3.Appointment of reviewers
4.Future actions
5.Varia

1. Welcome address and objective of the meeting

The Chairman greets the presence of the participants and thanks L.Foulquier who made the arrangements which allow the organization of the present RADSITE Coordination meeting. An overview of the SCOPE-RADSITE Project and the milestones are shown on transparencies.The specific role of the RADSITE members is also reminded.
The objective of the present meting is to assess the progress in the preparation of the Synthesis volume and to make recommendations to improve the exchange of informations. The Chairman distributed a CD-ROM containing the Proceedings of the RADSITE meeting held on 04-07 Dec.2000 at the SCK-CEN Headquarters in Brussels. He underlines that some of the scientific material presented at this workshop could contributes to the synthesis volume. It is the role of the Chapter's leaders to identify these relevant parts.

2.Progress status of the Synthesis volume

Chap.1-Source-term

V.Popov presents the new material received recently

-1.3.“Electrostahl”

V.Popov comments the following tables:

Table 1 : location of the facility; period of activities (until 1996)
“ 2 : contaminated areas (land,water) resulting from the activities (until 2001)
“ 3 : doses exposure (3 levels) around the site.

-1.6.Hanford

V.Popov comments the contribution sent by B.Napier concerning this source-term.

-1.9.Marcoule

V.Popov indicates that he received no contribution related to this site.

R.Kirchmann underlines the necessity to get as soon as possible data about previous releases (needed for dose reconstruction).He mentions the complete set of data related to the Sellafield site that he received from BNFL.

-1.11.NW Russia

This region is one of the two regions selected for studies within the framework of the Proposed RADINFO project. V.Popov presents a map where the regional radioecological cadastre of the North-West of Russia is shown. A table describing the thirteen enterprises and the source of radiation hazard in this region is also shown (SNF, North Fleet etc.).V.Popov indicates that all these radioactive material wil be later on transported to the Mayak facilities. He concluded that there is noactual risk of radiation exposure but great attention must be paid to these problems in the future , the major one being the transport of highly radioactive material on long distances from these sources to Mayak. A.Iskra comments that a specific project of MINATOM (RADTRANS) is under consideration.

Chap.2-Pathways

R.Kirchmann informs the participants that he recently received from the chapter's

Leader, A.Cigna, the following contributions:

-2.1.Wismut

K.Wichterey sent a contribution on :

a)section 2.1.1 Atmospheric pathways (Inhalation of radon-222 and dust)

b) " 2.1.2 Aquatic pathways

c) " 2.1.3. Terrestrial pathways

She also provided a flow-sheet showing the relevant pathways to be considered.

2.6.Hanford

B.A.Napier provide a contribution on the Environmental Pathways at Hanford and a list of relevant references

2.7.Kalpakkam

A report on "Environmental Radiation Levels Around Major Nuclear Sites in India" was received from U. Mishra. This general report concerns several chapters so it will be more appropriate to use it in the chapter 7."Synthesis". The chapter's Leaders are invited to extract the relevant parts to include in their own

Chapter. 2.8.Krasnoyarsk

A well documented report on Krasnoyarsk Mining Chemical Enterprise has been provided by E.Kvasnikova. (see **Annex A**) The sections covered are:

- Global fallout in the valley and catchment of the Enisey river
- Radionuclide composition of the water of Enisey river
- Data on the fish contamination
- Contamination of the bottom materials and of the soil of the flood-plain
- Spatial redistribution and vertical distribution of radionuclides in the soils of the flood-plain
- Spatial redistribution and accumulation of radionuclides in the estuary zone of the Enisey river
- 21 references are cited
- Fig.1.Cs-137 contamination of the Enisey catchment as of 1999
- Fig.2.Distribution of Cs-137 in one of the fascias phases of the Enisey valley
- Fig.3 a/b/c/d results of airborne gamma spectrum survey around four settlements
- Fig.4 Gamma emitting radionuclides distribution in the soil of the flood-plain (Island Belyi)

Chapter 3.-Dose Assessment

Three contributions were reported by E.Kvasnikova at the request of the chapter's Leader, M.Savkin, concerning respectively the following sites: -Hanford, Krasnoyarsk and Sellafield.

-3.2.9. Hanford

The primary thrust of Hanford Environmental Dose Reconstruction (HEDR) modeling effort was the preparation of a complete system by which individuals may receive estimates of their dose from past Hanford Site operations. The terrestrial dose model, CIDER [Farris et al.1994a], calculates dose for four pathways: submersion in contaminated air, inhalation of contaminated air, irradiation from contaminated surfaces, and ingestion of contaminated farm products and vegetation. The CIDER code treats people differently as they age, including prenatal and nursing periods. The Columbia River Dosimetry (CRD) [Farris et al.1994b] model calculates dose via water immersion, drinking, and consumption of resident fish, game birds, salmon, and ocean shellfish.

The detailed report is available in **Annex B** .

- 3.2.10. Kalpakkam

The critical groups at the two coastal sites Tarapur and Kalpakkam are fishermen whereas at the remaining 4 places, they are villagers living within 15 kms radius.
For fishermen, the main diet is fish and rice. At other places, it is a combination of rice, wheat and vegetables. However, the dose due to ingestion is negligible and the critical pathway for all the sites is inhalation and immersion dose through releases of radioactivity through stack.
The critical isotopes for Tarapur are I-131 and Ar-41, Kalpakkam and Rawatbhata are H-3 and Ar-41 and for Narora, they are H-3 and Co-60, and for the Kaiga and Kakrapar it is H-3.For Narora, Kaiga and Kakrapar, Ar-41 is negligible as nitrogen has been used as a cover gas instead of air used in earlier reactors.

- 3.2.11. Krasnoyarsk (M. Savkin, Y. Karelin)

Dose assessment to the population from the main pathways was carried out according to valid methodics on the basis of the following data:
(I)routine control of the parameters of radiation condition in sanitary and supervision zones provided by the Environmental Protection Lab of the MCC and Industrial-Sanitary Lab of Medical-Sanitary Division (see **Annex C** Table 1);
(II)research control carried out by the specialists of different research institutes in the area of possible impact from the MCC [2-5].

-3.2.13. Sellafield

The report (see **Annex C**) presents collective doses to the UK and Europe and the annual doses to typical individuals residing near each nuclear site. Discharges for 1975, 1985 and 1993–1995 have been selected to represent three decades of operation. Average annual discharges over the period
1993–1995 are taken to be typical of the situation in the mid-1990s. The collective and individual doses are used to give a holistic view of the radiological impact of the routine discharges from the UK nuclear industry.

REMARK: D.Louvat underlines the fact that in France the Dose assessment Methodology is different from the other countries.

Chap.4. Impact on population health

R.Kirchmann regrets that he did not received in due time the chapter's Leader (M.Go) report.

4.2. Health studies

4.2.3 Elektrostal

V.Popov indicates that there is no data actually available but some information could be provided in a near future.

4.2.4 Oak Ridge

A report sent by M.Goldman have been received during the week of ECORAD

Conference This document entitled” Tennessee Department of Environment and. Conservation”-DOE Oversight Division- Status report to the public- Dec 1999, contains a section dealing with the Heath Studies performed at ORNL.This document PDF will be available on the RADSITE Website in the directory “TECHDOC” section “other”.

4.2.5. Savannah River

Concerning the health situation of the population T.Hinton mentioned that the workers of SRL are in

a better health condition that the local population.

4.2.8. Krasnoyarsk

R.Alexakhin comments that the health situation of the population is the subject of special discussion.

4.2.10.Sellafield

R.Kirchmann informs the participants that he recently received from S.Haywood the Fourth Report of the Committee on Medical Aspects of Radiation in the Environment (COMARE, 1996).
This report deals with the incidence of cancer and leukaemia in young people in the vicinity of the Sellafield site, West Cumbria: Further studies and an update of the situation since the publication of the report of the Black Advisory Group in 1984.

Chapter 5 : Impact on the Environment

T.Hinton, chapter's Leader, presents data on the levels of biota contamination at Savannah River site. But the end point is the effects on biota which could be affected locally it is why the T.Hinton's intention is to use an official model recommended to predict the radiation effects on the various components of the biota and to apply it to all the sites studied in the SCOPE-RADSITE Project.

This declaration is unanimously approved by the participants.

R.Kirchmann recommends to take into account the Woodhead's publication actually in Press (JER) dealin with the observations made after the Chernobyl contamination..

Chapter 6 : Impact mitigation

From the general discussion, it is concluded *that more clarification is needed* for the implementation of this chapter.
It is suggested that the chapter's Leader ,G.Collard, meets the Scientific Secretary to discuss this problem.

3.Appointment of reviewers

R.Kirchmann submitted for discussion a draft list (see **Annex D**) of well-known colleagues who would be asked to play the important role of internal reviewer either of specific chapter or of the whole synthesis volume.

After exchange of views this proposal was accepted: the Chairman will approach each potential reviewer to get their individual agreement.

4.Future actions

a) The participants agree with the Chairman's proposal that all the data available must be sent to the respective chapter's Leaders before

the 21 December 2001 (deadline).

b) The next steps of activity will be:

- collection of the missing data (to fill the gaps),
- harmonization of the sections and chapters,
- drafting of the document,
- submission of the draft of each chapter to the Editorial Committee **before June 2002** .

5.Varia

A.Iskra presents to the participants the information concerning the main results of the ISTC # 245 RADLEG Project and a newly proposed # 2097 RadInfo Project.

From the presentation it appears that the goals of the RADLEG Project were full-filled: a sophisticated computer-based data system for the evaluation of the former USSR radiation legacy had been created. The innovative character of the foreseen RadInfo studies was underlined i.e.:

-formation of meta-database;
-creation of regional and subject-oriented radioecological cadastres;
-systematic and detailed assessment of the radioecological situation in two regions of particular interest for RADSITE (NW Russia and Krasnoyarsk region);
-working out of special recommendations on countermeasures for mitigation of radiation impact on the population and natural environment.

The workshop's participants approved the proposal for a new ISTC # 2097 Radinfo Project, pointing out that it is completely coordinated with the SCOPE-RADSITE Projects's goals in the part of comparative analysis of environmental impact of radiation-hazardous objects in the European Union, USA, Former URSS and Asia.

It was also suggested to consider the issue of introduction of the radiation risk assessment, linked with spent fuel nuclear materials transportation within the limits of the two regions of interest, in the list of the newly proposed project's priorities.

The Chairman thanks the Organizers of the ECORAD Conference for the hospitality in their premises and the participants for their respective contribution and vivid discussion .

ANNEX A: E.Kvasnikova's report
ANNEX B: B.Napier's report
ANNEX C: M.Savkin's report
ANNEX D: Draft list of potential Reviewers

Minutes Steering Committee meeting, Brussels 07 December 2000

Venue : SCK-CEN Headquarters

Present : Philippe BOURDEAU (Chairman), F.A.BALOGUN , Marvin GOLDMAN , Anatoly ISKRA, René KIRCHMANN, , Umesh C. MISHRA, Christian VANDECASTEELE(Scient.Secretary).

Apologies for Absence: Eberhard FALCK(IAEA), Valery LEBEDEV, Mao YONGZE, Roland MASSE, Rudolph ALEXAKHIN, T.SUGAHARA Sir Frederick WARNER

In Attendance : Petr BENES (IUPAC), Eduards DEKSNIS (EU), J.INABA (IES), , Jiandong LU(MoD), Victor POPOV (KIAE), Véronique PLOCQ-FICHELET (SCOPE), Mikhail SAVKIN(IB),

AGENDA :

1 Approval of the Agenda
2 Work plan 1999-2000 : Progress status (Sc.Secr.)
3.Perspectives 2001-mid 2002 : Program/Funding

a) EU Branch (RKi)
b) ASIA Branch (UMi)
c) US Branch (MGo)
d) FSU Branch (AIs)
e) Collaboration with related projects: IAEA (EFa), IUPAC (PBe).

4.Outline of the Synthesis RADSITE report (Sc.Secr.)

a) Content
b) Contributors
c) Publication Form (Book ? CD-ROM ?)

5. Any Other Business

The meeting is open at 09 :45 Hr, the discussion is recorded on tape which was eventually typed by J-P Verecken, translator-interpreter.

CHAIRMAN :

First of all I must apologize for not attending your meeting. I've been abroad until last night. You have all I presume the draft agenda of this Steering Committee meeting. Veronique will come this morning. It's a good idea she be here and have direct contacts with the evolution of the project and give us some administrative and publication requirements as SCOPE has a new publisher.

1.Approval of the agenda . Do you have any question before we can adopt it?No? The agenda can be adopted. The first item is the Program Status for last year presented by the Sc. Secr., Christian.

2.Work plan 1999-2000 : Progress status (Sc.Secr.)

Progress was made since the last time I reported when we were in Beijing in April 2000 (22nd Scope Open Ex.Co.). I presented the status of the RADSITE Programme. I think the

most important comment we had is that we must first concentrate on the production of the Report and communication of the results to a large non specialized public. On top of all the other target are people like politicians, etc…we should also try to add informations which could be understood by the public at large. During this meeting I had contacts with people from Asia, we had some problems since only Umesh was only actively participating in this program. We had a name (Mao Yongze) who attended the preliminary meeting we had here in 1998, at the Academy of Sciences. But since then it has been very difficult to find someone to be involved in this program from China . During this meeting, we have the pleasure to welcome Mr. LU Jiandong who contributed actively to the production of the Report. I have also heard in Beijing that there are some problems concerning the financial support for the meeting to be organized next year in the U.S.A. Mr. B.Goldstein proposed, in collaboration with Marvin and Freddy, to host the meeting in New Jersey in his Institute. This time we 'll try to organize a visit to Savannah.

The next step was the participation of René Kirchmann to the International Conference “Radioactivity from Nuclear Explosions and Accidents” in Moscow. René was there as a member of the Scientific Committee meeting organized by the RAS, MINATOM, Federal Service of Russia on Hydro-Meteorology and Environmental Monitoring, the Institute of Global Climate and Ecology, the Kurchatov Institute, the Institute of Biophysics and the Institute RIRAE (ALEXAKHIN). There were 400 participants and 200 oral presentations , the proceedings are expected at the beginning of next year..

Then we had the pleasure to be invited, René Marvin and myself, to go to Krasnoyarsk-26 for a 3-days meeting where we were able to visit, not the nuclear reactors themselves, but the environment and we had a cruise on the Yenisseï River to see the type of environment there. During the Seminar in Krasnoyarsk on the “Mining & Chemical Combine operations impact on the population health and the environment”, 20 Reports were submitted and discussed. These reports concern the monitoring of the radiological situation in the area and, in particular in the flood-plain of the Yenisseï River. Back to Moscow on Saturday, we were invited to a meeting with the Deputy Minister Valery Lebedev who is taking over the job of N.Egorov , who left us last year.

In September we had a meeting in Munich to study the remediations achievements after milling. This meeting was sponsored by BsF and by DFG : there were 20 participants to this meeting as a satellite meeting of a major Conference. For the RADSITE meeting, there were several experts from Europe, few from the FSU and representatives from the USA, Asia and Canada. In the present situation, Risk Assessment and Environmental Impact that have been applied to these mining and milling sites as well as site-specific cases have been studied by Cogema, by Wismuth, and US people. The program of this workshop has been published, but there isn't a copy for all participants. If you want it I can send it to you (e-mail); it is a book with the extended synopsis of the situation; a synthesis of what has been discussed at that meeting has been presented during the Conference Radleg-2000 in Moscow, in last November.

Radleg 2000 is a short name for the Radiation Legacy of the 20th century and was co-organized and sponsored by MINATOM, the Russian Academy of Science; the VNIICHT ;

IAEA, the European Commission. We got a contract with SCK-CEN and the EC to help the organization of this meeting (12,000 USD). At this meeting there were 250 participants from 20 countries and international organizations. We had more than 100 posters and 20 presentations; the Book of Abstracts is available, although we received it rather late during the Conference and the Proceedings will be published in May 2001.Anatoly will be ready to give you some more details.

I remind you of the existence of a Website on which René and his grand-son are working, and the quality and accessibility of the site will be underlined. Concerning the future, we have in mind that we will find a slot during the big ECORAD 2001 Conference in Aix-en-Provence in September (beginning) and finally we have still some possible meeting which would take place, if Marvin can get funding available, in Savannah River, and in May 2001, the meeting announced by Anatoly in Krasnoyarsk-26 (Zhelenogorsk).

This is all I have to say except for the contents of the Final report (Item 4).

(Arrival of Véronique PLOCQ-FICHELET, SCOPE's Executive Director)

Chairman : Thank you Christian. Véronique, we are glad to have you here! Comments to the WORK-PLAN put to you by Christian? No? We move to point 3.

3.Perspectives 2001-mid 2002 : Program/Funding

a) EU Branch (RKi)

KIRCHMANN : For the program, we tried to develop the aspect of organization first, and the difficult point remains the funding. It is not a long term or medium funding. We must find some money to organize the specific meetings we want, but until now we hope that for the future it will still be the same procedure : we had twice a support from the European Commission for a duration of 1 year and now for 1 ½ year for the European Branch to organize WG meetings. For the future, we shall rely on using e-mail communication. This week, the meeting has to identify the participants, contributors and to arrange the communication and the exchange of information in order to prepare a draft for each W.G. This draft will be submitted and discussed at the meeting in Aix-en-Provence at the beginning of September 2001, as Christian already indicated, in order to identify the missing parts or complementary informations.

So that in 2002 we shall be in the process to produce a digital report and also a hard copy of the report : Mrs Plocq will give us more useful explanations about the policy of SCOPE in Publication matter. Concerning the contribution of the European Branch, after the meeting this week, we shall see with the WG Leaders of the European Branch, if it is necessary to organize a small co-ordination meeting and to discuss it with the contributors to that groups in order to have better informations available for Aix-en-Provence. This is almost all I can say about the European Branch activities. The next 9 months will be, I hope, very active and each Chairman of Branch is invited to consult with the WG leaders of his Branch, and to stimulate the discussion, so that there will be no problem as regards the transmission of informations and to ensure a matricial exchange during that period.

CHAIRMAN : Thank you. Any question? OK. We move to the Asian Branch.

Dr.Mishra do you wish to report?

b) ASIA Branch (UMi)

KIRCHMANN : Just a remark. We have not yet found someone willing to chair the Branch, but in the frame of your activities, in Asia, you could indicate your views about the near future, to be ready for Aix-en-Provence.

MISHRA I was not able to get much information about Asian sites. As regards India, if you see the programs discussed during these last 3 days, I am not sure if any Indian site falls in the scope of our programme.

Uranium is not only used for weapons but also for electricity generation in nuclear power plants and research reactors which are peaceful uses and hence mining of uranium does not fall in the scope of our meeting (unless it is done exclusively for military application as in the case of Wismut). Therefore, as far as mining and milling are concerned they are essentially the same for military and peaceful applications. We have indications from Chinese presentation about 17 accidents. We don't have details if they involved nuclear plants or other facilities like mining and/or mill. So we have to get details to decide which accidents and operations fall within the scope of our mandate..

As far as India is concerned, I feel that I have all information. We have no nuclear plants for military applications. This I had mentioned at the last meeting also. We have no separate plants for weapons we produce and we did not have any accident involving radiation or any contaminated site. First of all there is no comparison with Big Powers in the sense that we produce nuclear weapons for defence and not for aggression and hence the number required for us is rather small. Our main programmes are R&D for peaceful applications of nuclear radiations and for power generation. Therefore, there is no facility earmarked for weapons. Our nuclear weapons are under the Ministry of Defence and we do not decide on the use of nuclear weapons. The Defence Ministry decides. Once again I wish to state that there is no plant or facility which I can call "military plant". We follow the same principles of radiation protection as used in nuclear power plants, for weapon production as well.

We have 12 operating Nuclear power plants and none of them can be called "military" reactors, unlike developed countries where some reactors have been used for the production of tritium and fissile materials (Pu). They did not follow IAEA safety norms and this has resulted in contaminated sites. Remediation of such contaminated sites are to my mind the most important task for SCOPE-RADSITE programme.

Next, we can look for information for power plants and waste management systems which are not yet covered by IAEA norms and which produce materials for nuclear weapons and for any plants which are still operating for military purposes, we have to look at the discharges from these plants. As far as India is concerned, we have 3 reprocessing plants, one at Tarapur, one at BARC, Mumbai, and the third one at Kalpakkam near Chennai (now called Madras) and all 3 plants follow IAEA norms of radiation protection and safety. They have been reported at IAEA meetings and in each of these places we have extensive measurements to show that there is no contamination or high activity anywhere.

So, to my mind and according to our Agenda, there are 3 things on which we put question: marks and need information. If after getting the information, the Committee feels that the plants/activities do not come under our purview, they should be deleted. First for China, we need details about the accidents reported here and if they occurred in any of their military installations then they fall in this category of our interest.

Second for India, if we get information from any source (as far as my information is, there is no such site) about environmental contamination in the vicinity of any of the Indian plants or about their radioactive discharges, then it should come under the purview of this Committee. Otherwise, we will be only diluting the issue and not give relevant information.

The third point which should be considered is that do we want to consider the entire nuclear fuel cycle including mining/milling. To my mind, mining/milling is not a high priority for this Committee. Most sites are not like Wismut which was used primarily to get fuel for weapons and even here the contamination problems will obviously be tackled soon and there is no other major mining/milling area of the world having important concern from the contamination point of view. Further, contamination problems associated with mining or milling are not of such explosive nature which could result in high radiation exposures of large population groups. This is all I wanted to say.

CHAIRMAN : Thank you very much.Comments?

KIRCHMANN :I am a little bit surprised . At the beginning we thought about Tarapur because the site was quoted to make a comparison with the other installations for the reprocessing of fuel, and afterwards, i.e. after your explanations the situation is unclear..

MISHRA: There is an IAEA Tech Doc which gives all information about Indian fuel reprocessing plants and it has been referred in my text of the paper. It also gives information about 3 more plutonium plants which we propose to build. Plutonium produced in power plants for electricity generation is generally "dirty plutonium" which is not very efficient for making weapons.

KIRCHMANN : We needed these informations at the beginning, to select the sites. But after the discussion here, it is very important to identify the sites and to have a comparison available.

MISHRA: We can provide information for all the 3 sites; One reprocessing plant at Kalpakkam (near Cheenai) started operation only 6 months ago And we are constructing 3 more reprocessing plants : 1 in Tarapur and 2 in Kalpakkam. Because our nuclear energy program is expanding very fast. 2 New nuclear power plants will be soon in operation, one at Kaiga and the other at Kota and now we are building two more 500 MWe plants at Tarapur and hope to build 4 more at Kota and 6 more in Kaiga. This is the program for the next 10 years. We are getting two 1,000MWe VVER type power plants at Kodamkulam (Southern tip of India) from Russia. Our plans are to have 20, 000 Mwe installed nuclear power by the year 2020. Present installed capacity is slightly over 2000 Mwe.

KIRCHMANN: I have also another info. I've been three times in a scientific Committee for the examination of PhD theses. Around the new facilities, you have a high level of natural radioactivity and the quality of the studies is very relevant as a source of information for radioecologists.

MISHRA : Only Kalpakkam, near Madras (now called Chennai) has some monazite deposits and hence is in slightly higher natural radiation background region. Our real high natural radiation background area is south west coast of India in Kerala state. The natural radiation dose that the people are getting at some places in monazite areas of Kerala India (High Background Region) is about 10 times what is permitted for occupational workers under ICRP-60 and these people have lived there for generations.

Therefore, we had initiated a very long term study by awarding a research contract to Regional Cancer Centre, Trivandrum (now called Thiruvananthpuram). This is a highly specialised centre for cancer detection

and treatment. They have covered one of the high natural radiation background area fully (about 300,000 people). Each person has been medically examined by this hospital and the people welcomed it because they got a chance for early cancer detection on the population. In addition to medical check up, internal/external dosimetry and the entire area has been radiation mapped. They found that in this area the cancer incidences are lower than the country average, the longevity is higher. We do not think natural radiation has anything to do with these observations. It is only that people have high education and personal hygiene standards and are more enlightened and lead a better life here.

Now we wish to carry out a similar study in another high natural radiation background area of the south India where the population is smaller but the radiation levels are higher by a factor of upto 10. We intend completing this over the next 2-3 years. We also have a joint program with Dr. Sugahara from Japan and our Chinese friends to pool all the data from India and China to see if we can find any adverse effects of nuclear radiation exposures, To observe statistically significant radiation effects, we do not have a sufficient population anywhere in the world . But if we pool together data from China and India, we may observe some effects. These two countries have a good amount of data and Dr. Sugahara is trying to encourage both India and China for doing this. In China, the radiation level are lower than in India but the population is larger. So, pooling the data and studying it for a number of years may compensate for the lack of available population.

In India we are keen to have more nuclear power as we do not have large reserves of oil and gas and we believe that nuclear power is a clean source. Since we have greater stakes in nuclear energy, we are interested in knowing if we get any harmful effects at permitted levels of radiation exposures. In India, we are monitoring every nuclear energy worker over his life-time for radiation dose and any harmful effects. We have also been doing medium-term studies in cancer hospitals in Bombay and given research contracts to them. They found that cancer incidences in the occupational workers are less due to better health care and early detection. A long term study will be made for the next 20 years.

CHAIRMAN : The Candu reactor is still in operation ?

MISHRA : The new reactors we are building in Tarapur are Candu type (500 MWe each), designed by us. The two present reactors are about 200 Mwe each, They were built by USA and are BWR type.

CHAIRMAN : Is it a Candu technology ?

MISHRA : Yes and No. They are Candu type but designed by us. They are natural uranium, heavy water type as we do not have facilities for large scale enrichment.

CHAIRMAN : You do not enrich it, but it produces a lot of plutonium, I understand?

MISHRA : Yes, and we need it for fast breeder reactors of second stage; we want to exploit vast reserves of thorium by converting it to U 233. Unfortunately for us, there are only two countries interested in thorium technology, one is Japan and the other is India.

We have a good co-operation with Japan on Thorium technology because we see a long term future for us in Thorium (converted to U 233 and used as fuel). U-233 has an added advantage. When you burn it in power plants you produce very much less long lived trans-uranics, so the radioactive waste problems with U 233 reactors are much less than with U 235. U-233 reactors are more difficult to control as compared to U 235 reactors. So, to get an experience on that, we have built a small reactor

(catted KAMINI) which we are using for neutron radiography. The operation of this facility will give us some experience.

CHAIRMAN : These new units which you are building now, are light water?

MISHRA: No, except for the two units operating at Tarapur which are BWR reactors, all others are 235 MWe Pressurised Heavy Water Reactors (PHWR's) of Candu type. At Tarapur, we are building 2 units of 500 MWe PHWRs. Two 1000 Mwe plants which we are getting from Russia are LWR type using enriched uranium (to be supplied by Russia).

CHAIRMAN : Thank you. More questions?

INABA : I would like to talk about a situation in Japan very briefly. In Japan the nuclear program is rather active. Currently we have more than 50 power reactors and one third of our electricity comes from them. More specifically we have 51 NPR in operation, 4 under construction and 3 in planning stage, which means we are going to expand our program a little bit more. But we do not have enough resource for nuclear fuel, uranium. For more efficient use of uranium we would like to establish a recycling system of the nuclear fuel. And hence, we have constructed a prototype reactor of FBR, Monju in Turuga, which is right now in preparation for operation. We are also constructing a reprocessing plant in Rokkasho-mura, a very northern part of Honshu, Japan. Needless to say, all these activities do not have any relation to military purposes including defense. Actually all our nuclear activities are strictly inspected by the IAEA.

Therefore, I think we do not have any specific program to be reported to RADSITE. If you are interested in any stage, any plant and any activity of our nuclear program, however, I am happy to provide information about them in RADSITE.

As far as dose reconstruction and retrospective dosimetry are concerned, I think we have a good capability. I can give an example. Many scientists in Japan have been involved in a dose reconstruction program for people exposed to atomic bomb radiation in Hiroshima and Nagasaki, that is a very important program since it provides better estimates for risk coefficients of radiation. I think these expertises established during the program are applicable to other cases.

CHAIRMAN : Thank you Dr INABA.

(Arrival of Dr E.Deksnis, EU)

You are welcome. Please, Introduce yourself.

DEKSNIS I work at the European Commission, in particular on the ISTC Program related to the former USSR. We are working on the terrestrial and marine aspects of the fuel cycle and military use in the Former Soviet Union. So, I think that any status here would be of interest for us.

CHAIRMAN : We are pleased to have you; this meeting will give you a chance to provide and get relevant

informations

Marvin, could you give us a report?

c) US Branch (MGo)

MARVIN : The US Branch has got a good scientific and technical start, in a rather rocky financial support. This is one of the hindrances we had in the commitments of our team and, as you see here, some of our colleagues are coming on self-funding from their Institutes. But I am optimistic that we 'll ultimately get that problem of financing solved, probably by touching things together. That's the bad news.

The good news is that in our activity for RADSITE, most of the information that is wanted exists and it is more a matter of collating, editing and summarizing than generating *de novo*. As you have seen from the presentations given this week, there is very rich database on almost all the parameters; I'm pleased that there are two younger colleagues who are participating for the first time and are enthusiastic about what they are doing, but it is their job and I am rather optimistic about how it is going to proceed.

We're probably going to make some small changes in the names associated with this, and include both Hanford reactor site, Savannah River on the production side, and on the enrichment side at Oak Ridge which was not represented at this meeting, but we now have a better feeling for it. It is more important to take one site or two and given you a suggestion of an overview of the workplan going through this cycle and showing how the source-term, the pathways, the dose estimate, environmental impacts and possible remediations are handled in these two examples. I presented a format the other day, with a mass of organizational charts showing one way of putting these matrixes together, which are adaptable to our activity.

I talked to Tom Hinton about hosting the next meeting at Savannah River and he has offered that they do have facilities and they probably can support it, and I have additional monies to handle the problem of foreign visitors. I think we'll receive some contribution from industry, from the 2 big laboratories and maybe from Oak- Ridge and I'm still beating up for the Department of Energy. The transition from one President to another : we may have a new Congress and it is not clear how this might impact at the level we are concerned with, but I'm still optimistic, so I do not see that the funding problem is going to prevent this from contributing in a solid way. I shall try to get copies of this format on the Web page and we'll mail this to all of you.

As regards nuclear energy, today it doesn't seem to be expanding. We have built no new reactor since 1978 and there is for the first time a couple of the olders reactors that got their licence renewed for further life. I expect there will be a decline and as the energy crisis becomes more evident there will be a re-emergence of this. The hardness against nuclear energy is softening a bit if we do not have any major catastrophy to contend about anywhere in the world, it may be helpful. In my opinion, the United States do not have an energy policy in which we could put nuclear energy. They have a strategy to get through the next year and I do not expect that this could continue for too long. Once there will be a national will, things be clearer.

There is something we are most interested in : there are some remediations going on and I showed you how the part of our Government called "Environmental Remediation" in the Department of Energy handles the military sites and their ultimate disposal. And the budget to do this is 6 billion USD every year. Yet there has not been progress. Today the reasons for this are very obvious and there is a lot of activity ongoing.

The business of the linear threshold hypothesis is killing nuclear energy. I have an opposite view : whether

it's there or not, the impact of small doses, whether threshold or a small coefficient is still sufficiently small and does not make a lot of difference. You know, it's the emotional baggage that goes with it… One additional element is that energy employees who were involved in the nuclear weapons enterprise in the earlier years and who latter in life succumbed to some disease, will now be compensated by the American Government to 150,000 USD each. But the legislation is not clear if you have to demonstrate that there was an associated dose that went with this. So there is a rather fuzzy or not clear understanding how this will be implemented. It could set a very dangerous precedent, and I warned you at one time that this is something we'll have to contend with.

The appearance now of diseases related to beryllium, which was very much involved in the weapons program and which is very much a toxic material; and now handling the case beryllium you must also include radiations. One drags the other and we'll have to see how this transpires. I have a copy of this, if you want to look at it.

My conclusion is that I think our team is now functioning and I am very pleased with the progress that we made at this meeting, and we have some momentum that we must take advantage of we can talk about that the moment we'll get to our reviews. Any questions? Thank you.

CHAIRMAN : Thank you Marvin. You are feeling much more optimistic about this project. We are now on a good footing.

KIRCHMANN : Just a comment about the problem you mentioned just now. I was two years ago asked by Dr. Buldakov questions about a study on beryllium made in Western Europe. But I was not able to find something… Do you have any information?

DEKSNIS : The project I worked on was made 2 years ago and at that time we took advice from the safety authorities… (inaudible)… these were companies which were privatized .

GOLDMAN : There is a beryllium study in the States being sponsored by NIOSH, the National Institute for Occupational Safety and Health located in Cincinnati, Ohio, and the Deputy Assistant Director for Environment Safety and Health is an expert. He is also involved in the US-Russian studies on radiations, and is tremendously involved. I'll try to get some more informations on that if you are interested.

CHAIRMAN : I think there was study in France, in the non nuclear field, on beryllium. I could give you the references, but that dates back… OK, so shall we move to the FSU Branch? Dr. ISKRA, you shall report?

d) FSU Branch (AIs)

ISKRA : I'd like to say that Deputy Minister Lebedev could not come this time but he is very thankful for the efforts made for the preparation of his visit. According to a decision of the Minister Yevgeny Adamov, Mr. Lebedev's visit is planned to take place in January next year. And the same subjects are proposed to be discussed during his official visit including issues linked with decommissioning of nuclear submarines , and other nuclear installations in Russia. We'd also like to appreciate the very important contribution of the European Commission and of the Centre d' Etude de l' Energie Nucléaire to prepare and organize

meetings held in Krasnoyarsk and Moscow. In the opinion of Russian specialists these meetings are of great importance. Of importance is the working out of some rules, recommendations for the decommissioning of nuclear objects and the remediation of affected sites. In December a meeting of the National Organizing Committee will take place, and such issues as environmental impact of activities connected with the decommissioning of nuclear submarines and weapons disposal are suggested to be discussed in the next meeting in 2001.

Last point : during the Moscow RADLEG Conference, Mr E.Deksnis and Mr Uwe Meyer (ISTC Deputy Director) visited the Kurchatov Institute and the database was shown to them and they made some remarks about the future workplan for the upgrading of the database, and technology was discussed on that occasion. Several institutions belonging to MINATOM and the Ministry of Emergency situations applied to RADLEG and asked to have access to the RADLEG data. Mr. Lebedev visited on November 3 the ISTC and met the Director General Mr.Kroening and they discussed the issue of an efficient co-operation between MINATOM and ISTC. In accordance with the recommendations given by Mr. Kroening and Uwe Meyer, their work is planned to be organized within the frame of a new project, not RADLEG , and now they are preparing proposals for a new project and the Ministry of Atomic Energy of Russia is ready to support this work.

CHAIRMAN : Thank you. Any question?

KIRCHMANN : Just a comment to say that the co-operation RADLEG-RADSITE is now two years old and we are very interested in some aspects of this program in co-operation with our program. We went to Krasnoyarsk and in this framework Russian colleagues contribute and will continue to contribute with the informations we need for our program. This is very important.

CHAIRMAN : But you have assurances to use the informations?

POPOV: Maybe Representatives from two other Russian organizations, Instiute of BIophysics and Kurchatov Institute, may also say some words?

CHAIRMAN : Go ahead.

SAVKIN : Thank you Mr. Chairman.

Retrospective analysis of radiological legacy of the former USSR nuclear defence activities is one of the “hot” problems with both the Ministry of Atomic Energy and Ministry of Public Health Care of Russia. Medical & Dosimetric Registries for nuclear workers, which have been involved in these activities, are one of the most important tools for systematic investigation.

A month ago the Institute of Biophysics organized its Branch at the Siberian Chemical Combine (Tomsk-7) and provided scientific support for Medical & Sanitary Division in Krasnayarsk-26 with the aim of creation of a Medical & Dosimetric Registry of the Mining and Chemical Combine. Prospectively, results of these studies will be used in the national radiation legislation. The next radiological issue is working out of criteria

for decision making in the case of accidental dispersion of plutonium. Consistent collaboration and transparency of national and international bodies are required in this area. Many years ago US emergency criteria had been adopted for Palomares accident. After the Chernobyl accident very strict (may be excesively) radioecological scriteria for plutonium contaminated lands were applied. Nevertheless, this problem is important taking into account large-scale nuclear weapons reduction.

Irradiated nuclear fuel management requires not only technological development but also amendment of the Environment Protection Law and intense PR activity.SCOPE-RADSITE program will have positive role in this policy.

CHAIRMAN : Thank you for bringing this information to us.

MARVIN : One more point which I negliged to introduce concerning the activities of RADSITE. Many labs are now developing a new technology called "molecular epidemiology" which is not simply biological dosimetry, but sensitivity and responses at the molecular level and in some of the questions we have raised about the incapability of traditional epidemiology to really distinguish smaller factors in large populations, this approach holds the promise over the next decades of possibly filling in a such a way. We must do our planning so that it will quietly go on and not a major activity yet, because this tool is still being developed and what is taking place today is very encouraging. So, it's like the Genome Project. You still do not fully comprehend what it will do, but the kinds of questions we have raised here have relied on more empirical evidences. A more basic and fundamental tool will be available even before the end of our project. I wanted to alert you to this.

CHAIRMAN : Thank you. If there are no further comments, we may ask Dr. Benes, on behalf of IUPAC to tell us about potential cooperation with RADSITE.

e) Collaboration with related projects: IUPAC (PBe).

BENES : Thank you Mr Chaiman. During the last 3 days we listened to very interesting reports on the migration of radionuclides and we note that chemistry plays an important role in migration. Now, I'd like to speak a bit about chemistry and the possibility of taking some advantage of co-operation of interest for IUPAC. You all have been informed about IUPAC. It is International Union on Pure and Applied Chemistry with more than 100 countries participating. The work of IUPAC is mainly based on projects which are not ordinary research projects but should enlarge the existing chemical knowledge by its critical evaluation. I should like to say a few words about the nature of the projects.

Projects should be related to the needs of the chemists worldwide, not just in a country or region. They should contribute to the role of chemistry to satisfy the needs of mankind and this should best be approached by an international team that IUPAC can assemble. Typical projects are the projects on international nomenclature, symbols, terminology and conventions; then there are future-oriented projects important for the position of chemistry and for the needs of mankind. Then, there are compilations with the critical evaluation of data and projects on the unification of approve experimental methods, which is also of significant importance for this RADSITE Project.

Of course, there is also a critical evaluation of the state-of-art of chemical problems. You may have heard

that IUPAC is organized in Divisions and Commissions, and there is one Commission which is especially important for RADSITE : "Commission on Radiochemistry and Nuclear Techniques". I want to refer here to a few projects which were already terminated by this Commission and which might be of some interest for RADSITE.

he first one was entitled "Speciation of Radionuclides in the Environment" published in 1995 in Radiochimica Acta; there is "Nomenclature for Isotopes, Nuclear and Radioanalytical Chemistry" which is now being prepared in electronic format; there was a project on “Radionuclide Migration in Groundwaters. Review of the Behaviour of Actinides” published in Pure and Applied Chemistry; then there was a project on the “Release of Cesium 137 from Freshwater and Estuarine Sediments”, of course something very important concerning the redistribution of Cesium from sediments; and on the “Determination of α-emitting Radionuclides in Diet: Review and Evaluation of Analytical Methods for Artificial and Natural α-emitting Nuclides in Food and Human Tissues”. This was already published and it can be used for the preparation of conclusions or for a RADSITE report.

We have now only one running project which might be of some importance for RADSITE and that is on the effect of natural organic matter on the migration of radionuclides, which is sometimes very important, especially in ground-water migration, where the migration is facilitated by the formation of colloidal forms or the complexes of radionuclides with humic substances.

IUPAC will be completely restructuralized beginning 2002; all Commissions will be cancelled and the work of IUPAC will be based on projects aimed at the improvement of chemical nomenclature, evaluation of chemical data and methods and on the critical assessment of the state-of-the-art of selected chemical topics. But, what is very important is that IUPAC will encourage submission of projects from outside its Commissions and we, in the Commission for Radiochemistry, consider a project dealing with the radiochemical aspects of radioecology, we would like to propose it as a critical evaluation of speciation and migration of artificial radionuclides in the environment, and we would like to seek some contributions and possibly some coordinator for this kind of project. We are discussing this with professor Myasoedov. I do not know whether he mentioned that at RADSITE, but I would like to ask you now to help us with finding people who might, from this circle of participants, contribute to such a project. That's for the future. Thank you.

CHAIRMAN : Thank you very much. SCOPE has always appreciated very much the co-operation with IUPAC, IUPAC being one of the Unions is in a way one of the many fathers or mothers of SCOPE.

PLOCQ-FICHELET: It's one of the founding-mothers….

CHAIRMAN : Right; so this is all for the good, I mean this other area in which IUPAC could work. It's very good that you take an interest on see what specific area you can tackle jointly or in your context with the project. Thank you very much.

MARVIN : As someone who had not so much background, could you tell me what is the basic strategy or rationale for restructuring IUPAC, which you mentioned. Is it just cost/ effective or evolution of thinking?

BENES : The activity of IUPAC is not efficient enough. Therefore, this restructuring could improve the efficiency and update the projects to the needs.

CHAIRMAN : O.K. Any questions or comments?

KIRCHMANN : Just a comment. I suppose that IUPAC people will be present at ECORAD 2001 in Aix-en-Provence when we will meet; this will be an opportunity to do ecology and ecotoxicology and to discuss the collaboration with others. And as Christian already mentioned, we will have at that time a co-ordination meeting. Working Group members will be invited to intervene.

CHAIRMAN : O.K. If there are no further comments, I move on to Point 4, "Outline of the Synthesis/RADSITE Report". This will be presented by the Scientific Secretary, I presume?

4.Outline of the Synthesis RADSITE report (Sc.Secr.)

a) Content

SCIENTIFIC SECRETARY : Something was missing on the Agenda. I haven't much to say about, except that during this meeting we succeeded to establish in a certain way the skeleton of what will be the Final Report. And you got a draft already distributed where we have divided the document into different topics starting from the source-term, the pathways, then the dose assessment, the impact on the population and the impact on the environment and the measures. And finally we are also supposed to have a synthesis at the end of the document together with a sort of Executive Summary at the very beginning of this document.

In this document we have also tried to identify all the potential contributors taking into account their specific knowledge about the different sites, and all these people will look at the different chapters. They have been identified and associated with the different items. I do not know if the newcomers would like to go through this document and if there are remarks or questions concerning the Final Report before we start the discussion about the publication(s).

CHAIRMAN : Véronique? Marvin ? Comments?

GOLDMAN : During the three days we got informations arranged in-depth , which is usually the case at the beginning of our program, but there is one area which proved to be an obstacle to doing this : the fact that there is no uniform declassification of the information that is essential, and our charter requires that we work only with unclassified material. Different nations have different progress in declassifying the kind of information that is necessary.

So, in particular, we may have a difficulty with information from France and China on this, and it may well be that some of this is simply semantic or language communication, some may be political problems which we cannot solve today. But we must be aware that this could be an issue and try and, parallel to our work, try to see what we can do to minimize

that from becoming a bigger problem. I don't have a solution, just to recognize that this could be an issue…

CHAIRMAN : Thank you

DEKSNIS : I apologize. My colleague, Mr Cecile was unable to participate, but he is aware of the problems in the North-West Russia and I think he would have liked to raise the issue of how important the problem is, seen by the Europeans, in order to have a good a solid basis for our activities in this area. And I believe it is extremely important to take note of the interest of European Union, in order to have a good a solid basis for our activities in this area. And I believe it is extremely important to take note of the interest of European Union to try to obtain the maximum amount of declassification. One should recognize that this is an important problem-area . What I want to say is that it is extremely important to encourage the maximum effort, quality and make transparent, this is something that will come up in other discussions than today.

GOLDMAN : I do not know what influence an organization such as ICSU may have in encouraging an acceleration of this declassification. I'm not enough in the global level. That's why I raised this issue.

CHAIRMAN : I had one question, perhaps. I am impressed by the breakdown and by the identification of the contribution. If you have to make out a percentage of the total material that is already on hand, what figure would you say?

KIRCHMANN : It is related to the sites, first. Half??

GOLDMAN : More than a half… there is something like 60%

CHAIRMAN : That is very encouraging.

GOLDMAN : Maybe 450 pages ?

KIRCHMANN : And also we have experienced in previous RADTEST or SCOPE projects that, at the beginning, France was very reluctant to provide materials. Once we had started the project and they saw how it was working and the purpose of the project, they provided that type of good material, and I think it's probably the same process here. Not to give too much but not to give too little, they have to make a compromise, and we have contacts. But, experts are note allowed to provide directly material, of course, but they can provide sources not too well known and which could help you too to identify good documentation and information.

This is a way and even I hope that some book such as the "Déchets nucléaires militaires français" could make a balance about what could be available and with reference to a report we might ask to have a copy: For example, in Marcoule, at the request of the Department du Gard, they requested the Montpellier University to do a study about the epidemiology and it was the IPSN, Institute for Safety and Nuclear Protection, which was in charge of that, and this report was afterward reviewed by a consultant office (SENES). The original report was produced in an official way, but the external reviewer made some very pertinent remarks as a Canadian. And we might proceed in the same way for Marcoule. The French participant to this week

meeting, Michel CHARTIER, said that there is a lack of scientists in IPSN and they all focus on La Hague for the time being; it is a priority for them, not Marcoule. But we have to take into account this kind of situation.

CHAIRMAN : OK. On the item b) do you want to say a few words? We are on a) now… a) and b) together.

SC.SECR. Marvin made a good point in asking what could be the title of this report. I think the title will be chosen taking into account on what we will put the emphasis in the conclusions. So, we could highlight one or another point.

GOLDMAN: But the working title could be the description of this project, what RADSITE says, that's a good work…

PLOCQ-FICHELET : I first want to say that I commend this Group and at the same time I am very pleased to note that there is an Executive Summary and a Synthesis chapter. This is certainly not the same thing, and this is something that SCOPE is really trying to encourage, to have not only a science and synthesis volume but a chapter to provide the salient points, so to have an Executive Summary more addressed to decision-makers and to give the public more recommendations, suggestions, options for action.

GOLDMAN : We were also talking about the possibility in view of what we saw this morning, of having not a Press Release but an Executive Summary, written in a fashion which is even more related to the general public and decision-makers. So I see a three-tier approach. But this must be at the very end… a stand alone summary.

KIRCHMANN : In the same framework as has been done with "Planet in Jeopardy"..

PLOCQ-FICHELET: Something different ! This was a popular volume, and not very good one.

GOLDMAN : We agree to the revision.

CHAIRMAN : O.K. On the matter of publication…

c)Publication Form

SC.SECR. : On the matter of publication, we have taken into account the publication(s) of SCOPE in the field of radiation protection and we started on one of the two volumes, the smallest one, and "Environmental consequences of a nuclear war". This was the wrap-off program, and the very last book published with RADTEST, and Véronique will correct me if I say silly things. I guess that the contract for publication between Wiley and SCOPE has come to a halt and that there was also a problem because the price of these books for a large diffusion was rather high, so that many people could not afford to buy this kind of book, and now we have also from SCOPE a book which has been published by Island Press and, I think, at the risk of the publisher..

PLOCQ-FICHELET : This book is something entirely different. This is not on the nuclear aspects, but on biodiversity. This is a popular volume which was a distillation of one of the volumes in our series written by some authors working together. This one has been published by Island Press .

Christian is right that we have terminated our contract with WILEY &Sons except for the last book on

Radioactivity from Nuclear Explosions. This one is still sold by WIley until the end of next year but all the other volumes are available nowadays from the SCOPE Secretariat;(that is what remains of the stock,)and are available on website. Those who want access to past volumes can go on a website and unload these books.

We are now discussing with Island Press, which is a publishing house, and the price is established in the U. S.A.. It's a non-profit organization, so they want to produce books on the environment and distribute them and, secondary, to make money out of it; they have a much more aggressive marketing policy than Wiley. This is not difficult since Wiley is entirely passive. So, we are discussing with Island Press first of all on the publication of our science volume, take on the SCOPE Series, but also other derived outputs like popular volumes, again written by science authors under contract or, like in some cases, textbooks or practioners' manuals and publications more directed to practioners and/or decision-makers. They may also want to take on some of our intermediary publications, the books that are produced within the course of a project, but which are not a final synthesis, etc. And we are thinking about having at least the science volumes published as paper version and electronic version. That means we'll have a much wider publication, more productive. Again with a publisher which guarantees a much wider distribution of our results.

There are obviously some constraints as well which did not exist with Wiley : which means that, in this case, the publisher will want to be involved at an earlier stage than before in the preparation of the volumes. They do not want to interfere with the science, but they certainly will want to have a say on the style, on the pallatability of what is written and they will be available to tell you "we have read your chapter, but sorry, this is not clear enough!!. They will not say "that don't make sense", but "please explain it better! etc." There is also going to be a size constraint which is all for the best, because this is something that SCOPE has been trying to enforce over the past 10-15 years with various degrees of success. Basically, we want books in the 250 pages range, with the provision that annexes may be put on a website. But what should be in the book will be really a synthesis of the chapters themselves.

We will insist on having an Executive Summary, but I see that this is something that is been taken care of by your group already.

What we would need from your book, is a more detailed outline of the future book and this is a good start but you'll have to explain. In other terms, this is clear enough for somebody who is already involved in a project, but not something I can send to a publisher. I want a synopsis.

GOLDMAN : What is the approximate cost of a 250 page volume from ISLAND Press? What is you guess?

PLOCQ-FICHELET : I would guess it will depend from the topic and if they can sell such a book easily or not. A popular volume like the ??? volume is sold at 20-25 USD. I think that for the science volumes, we are going to be again in the 50-80 USD given again what is their expectation on how easily this can be distributed or not.

GOLDMAN: What was RADTEST Cost ?

PLOCQ-FICHELET : Everything I can say is that it changes all the time and the price is different in Europe and in the USA, but I assume that in the US it is probably 200-280 dollars.

KIRCHMANN : One hundred pounds (UKP) was mentioned on the Flyers

PLOCQ-FICHELET : Probably more…

GOLDMAN : Has SCOPE considered putting things like this on a paperback?

PLOCQ-FICHELET : Right now it only published for a collection

GOLDMAN : For your future?

PLOCQ-FICHELET : Island Press considers this on a case-by-case basis. We produce hard-cover, soft-cover, almost at the same time.

SC.SECR. : Any possibility to produce a CD-ROM? Which is a rather cheap way of diffusing informations. But for SCOPE and for many people who are interested, hard copies are advisable. Now, we are close to the 400-500 pages probably, with all the stuff, so we will have to consider that we need to synthetize the material outcoming.

KIRCHMANN : It is possible to imagine that you have a CD-ROM in way produced by scientists, and then, to adapt the style and to improve it to have 200-250 pages. You have two types of documents : one less documented, popular; but also a more documented volume.

MISHRA : Usually they sell a book first and the CD-ROM comes afterwards, if it has high demand… Books are more expensive and are mainly sold to libraries.

Once you produce a CD-ROM, the demand for the book will be down, What you propose is to have a CD-ROM with much more material than the book. Obviously, it will be much cheaper. Most of the people want to buy book if affordable as ir is more convenient to read.

CHAIRMAN : But, Véronique, have you approached Island Press on this issue?

PLOCQ-FICHELET: They know that this project exists and its importance in a time in the future. But right now we are discussing the general issues and there will be separate agreements for each volume.

CHAIRMAN : But you don't have any concrete project signed yet?

PLOCQ-FICHELET : We are on the verge of signing it. We have already agreements for separate volumes, but we are still discussing the terms of the general agreements. And I think you got a copy of the draft agreement.

CHAIRMAN : But you have already negotiated separate agreements…

PLOCQ-FICHELET : On two volumes, yes.

CHAIRMAN : So it is a trial, and we'll see how it works.

GOLDMAN : You need from us an expanded outline? My impression is that the scientists will need this and sign. When do you need this from us? Twenty years?

PLOCQ-FICHELET : This month or January, this will be perfect.

GOLDMAN : We'll do that!

CHAIRMAN : I see your initials are already indicated.

PLOCQ-FICHELET: By the end of January would be perfect because we're having a meeting of the SCOPE Executive early February and there will be a representative from ISLAND PRESS at the meeting, at least for a part of the meeting. So that is taken care of.

GOLDMAN : The names that we have assigned may be temporary, but at least we'll try to made an assignment for each section although that might not be final, but that will show you how far we've got.

PLOCQ-FICHELET: Any publisher will need to have an idea of what you do and why it is important and interesting in that perspective.

GOLDMAN : . We have already made our philosophy, but we'll dot that.

CHAIRMAN : The source term is what we need to begin with.

SC.SECR. : I think that at the end of the day, we'll have to regroup things by type. Consider what is dealing with uranium mining and milling, because you will have almost the same type of source, almost the same type of risk and this associated with the same type of radionuclide. And we'll consider production and reprocessing and maybe afterwards the wastes. But in this case all the different sites that we plan to consider can be regrouped under other larger items.

GOLDMAN : I'll make a couple of paragraphes and call that a "Zero Draft" but the Executive Summary will have no numbers, but it will conceptually walk you through what we're trying to do.

PLOCQ-FICHELET : The structure of the book : probably we'll need when we'll go to ISLAND PRESS with a proposal for a new book is something that will tell them why it is important, why it is interesting and where is the prospective'public.

GOLDMAN : The same question we ask when we are seeking funding.

CHAIRMAN : OK. Is this the end for the publication? It would be good to form a, what is the right term in English?

KIRCHMANN : Editorial Committee (?)

GOLDMAN : I think the Editorial Committee, for the moment, is the Steering Committee, rather than create any more body. Maybe the four of us… I welcome any volunteers… Thank goodness for electronic help! (inaudible)

CHAIRMAN : OK. You will take steps to implement those recommendations about the story-line, the table of contents…

GOLDMAN: Publications then ?

MISHRA : Two years from now.

SC.SECR. : The program is going on until 2002.

GOLDMAN: Christmas 2002 is the target.

PLOCQ-FICHELET : For the manuscript? (inaudible) electronic form?

KIRCHMANN : We'll have another solution. It's too heavy to produce hard copy for the people. We are working electronically.

GOLDMAN : We're talking about two different things. Your work will be done and we'll deliver it to the publisher what I call a "camera-ready" copy. Then there is a delay until the publication appears. This we cannot control but I think what were…. Our work is completed… do we give this to the publisher and we agree on what it is, how long?

PLOCQ-FICHELET : The production : once we have agreed on a manuscript, it's 6 to 9 months.

GOLDMAN: Six to nine months?

PLOCQ-FICHELET : Realistically, but it's the same with all publishers. It generally shortens the time if we can determine the scope in advance and respect that calendar. It's always the same : if we can tell the publisher enough in advance; "you'll get our manuscript prepared and reviewed, finalized, approved by such a date", then they can do their publishing plan for 3 months, and it goes on smoothly. If you miss your deadline, then…

SC.SECR: You loose the slot!

GOLDMAN : We have not really discussed when we think we will have ,let say, our book done. I realize it's editing…

PLOCQ-FICHELET : And also there needs to be time for an external reviewer, which will be probably from now on an external reviewer chosen together by (inaudible) and the publisher.

GOLDMAN : And what time do you need for that?

PLOCQ-FICHELET : Probably 2 months, and the manuscript comes back to you with the remarks…

GOLDMAN : Before we finish, it's a whole year… when you include reviewing and publishing… But the product that goes to review will be prepared by one. I think that was your question.

SC.SECR : Well, we have decided that we should prepare the first draft, the draft "zero" within… for the middle of next year, and to have some criticisms.

GOLDMAN : Maybe nine months, we'll have enough meat to have a loose leaf to say "this is our draft".

PLOCQ-FICHELET: With that first draft already, we can already discuss with the publisher.

GOLDMAN : Even if it's not complete…

SC.SECR : But it will appear around mid-2001 already.

GOLDMAN : So it looks like one year to have our work + 1 year out of our control until it comes out, that means two years… But that means than your collaborators and contributors must not delay the things you promised.

KIRCHMANN : It is a hard job, but we did that for RADTEST. You have to be prepared and ready. I've been enough in the system!

GOLDMAN : In an activity like this we're not dealing with contractors but mainly with volunteers, and you're always gonna have the same problem, and we've got to avoid the threat or the risk of giving it to two or three people. But I think we're optimistic, right now.

KIRCHMANN : We have first to have a contribution from each contributor and a Rapporteur. And there is still a lot of hard work to do. I hope that with the new Publisher there will be a more modern or simple way communicate.

PLOCQ-FICHELET : Ask a Company which has an agressive policy and much better prices, so the prospect of a better distribution of our results.

GOLDMAN : What kind of editing assistance does the publisher provide? Or just the usual… I'm just unfamiliar with what your expect.

Sometimes you have a technical scientific writer who works with the production of the book and reacts simply to what is given to him. I do not know whether there is some help available as we get to the final stages of this.

PLOCQ-FICHELET : I do not know, we have to see exactly because our contact with ISLAND PRESS has been only for this (??) volume. So we have to see how that works for sciences volumes. This is also something new for them. So we are going to learn together.

GOLDMAN : One other thing that can, reduce your concern would be if there was a Science writer. I'm using a quotation, a sort of "walking" through "with this thing"… I'm not saying it's one person, but so that you do not have so many writing styles.

KIRCHMANN : We did the system in IAEA when I was there in the 80's. Then, there was a scientist, an English one, who knew English of course (!) and the work was not satisfactory, and the Head of Publications had to take the material and re-write again and up date before publication.

MISHRA : IAEA also has an Editor who reads your manuscript…

KIRCHMANN : It was a joint effort on waste management, by the way. The system "Scientific Writer" did not work and this was disturbing, because he himself, in some sense, interfered and made some politics.

GOLDMAN : This can create a problem. If you have an English Editor who is not necessarily a scientist but who understands that some sentences need a verb and if some piece of English does not make sense, at the beginning rather than, at the very end, this accelerates the product.

PLOCQ-FICHELET : If you really think that would be useful and necessary, you will have to meet the cost in your project. Frankly? I would have the same reaction than René. It's the same thing when you have people who produce a contribution in their own language and then have it translated into English. It looses quite a lot because the translator may be an excellent 1st class translator but does not have the level of science necessary to fully understand what is really the meaning of the text, and we would get exactly the same type of result, something that will erase the salient points we want to highlight.

CHAIRMAN : . Enough on publication? You need to have a group of 2-3 people.

PLOCQ-FICHELET : I would like to say that among the 2 or 3 editors of the volume, you must absolutely have some person with English as a mother tongue.

CHAIRMAN : Even an American will do!

GOLDMAN : What did Churchill say : "Americans and British are separated by a common language!"

CHAIRMAN : We close the chapter on publication? So, this is hard, we know it by experience, editing books. Any other item that you want to look at?

5. Any Other Business

KIRCHMANN : About the next meeting to be held in Krasnoyarsk. Is there a date fixed for this workshop?

ISKRA : Preliminary it's planned to be in May, but this should be specified a bit later.

CHAIRMAN : Nothing else to say?

I wish to thank the SCK-CEN, Nuclear Study Centre of Belgium, for making these facilities available for organising the present workshop. It helps that the Scientific Secretary of the project is one of the officials of that Centre. It has been extremely convenient and practical. Our thanks addressed to the Secretariat and also to Christian for all these arrangements made in a very pragmatic and efficient way.

KIRCHMANN : We'll send an official letter to the General Manager of the SCK-CEN

CHAIRMAN : I think we must also give our thanks to the European Commission which has been helping this project along in various ways, and give our regards to MMr. GAMBIER and CECILE. And I thank also all the participants.

SC.SECR. : Thanks also to ONDRAF-NIRAS.

CHAIRMAN : ONDRAF is the Waste Management Association together with the Federal Agency for Nuclear Control which has also contributed some funding. And I thank you all for your participation and those who have already left. I think that we can close the meeting.

GOLDMAN : Before we close it might be that these two workshops could be deadlines for us to achieve a couple of what we call "milestones" in the production. We already agreed to have an expanded outline by the end of January. I'm thinking of a sort of timetable and I'm also warning you that I think we will have a monthly electronic roll-call enabling the contributors to assess the status of their work, and I don't know what you're ideas are and how to stimulate this since we are only volunteers, we can't do anything by request. But certain countries have sent suggestions on how we may make this as less painful as possible/ Any suggestions?

Well then! Be prepared for short telegrams from Christian..

12:00 Hr :End of formal meeting.

SCOPE-RADSITE

Initial Workshop on:

Radioactivity from Military Installation sites

&

Effects on Population Health

12 November 1998

Palace of the Academy of Sciences, Brussels, Belgium

Minutes

Present: Ph Bourdeau (Chairman), M. Goldman, R. Kirchmann, A. Iskra, Y. Mao, R. Alexakhin, R. Masse, U. Mishra

Apologies for Absence: Y. Onizuka, Sir F.Warner

In Attendance: B. Myasoedov (IUPAC), ? Kovalevsky (STCU), E. Stukin (IGCE), J. Sinnaeve (EU), S. Kaiser (EU), V. Plocq-Fichelet (SCOPE), V. Tysplenkov, C. Vandecasteele (Scientific Secretary), J.P. Vereken (Interpreter)

1) APPROVAL OF THE AGENDA

The agenda for the meeting was approved.

It was noted that this is the first meeting of RADSITE, and hence the importance of defining the capacity of those involved was noted. The need to try to put together a unified programme, in view of the range of expertise that exists within various fields was mentioned. The RADLEG structure comprises 4 branches: US,

AVM branch, FSU branch and EU branch. In each branch there are experts in fields ranging from the source term, to the exposure of population, going through pathways and dose assessment and countermeasures. It is expected that in the future, after reviewing all existing studies, in a critical scientific way, that recommendations may be made for governmental authorities. It is considered a timely, and ambitious project, with results three years hence.

2) FUTURE PROGRAMMES OF THE RADSITE BRANCHES

a) FSU (ISTC #245 RADLEG)

Dr. Iskra reported on FSU programmes, noting that a first meeting relating to RADSITE occurred in Moscow, involving various organizations connected with the project. These discussions are reported in the summary report of the meeting. A Memorandum was signed by the appropriate FSU authority, and there have already been meetings with Profs. Kirchmann and Goldman. For the initial meeting sub-committees were established as a model. The mains lines of work include: the study of various matrices which have been prepared for the EU, US and other branches, and the most representative facilities will be selected. The same will be done for the case of China. These facilities will be studied and the methodology applied. Another aspect for study within the RADLEG project are those relating to radioprotection. These aspects will be mentioned within the framework of the symposium. Up to now information relating to 600 disposal sites for radioactive have been collected with regard to the FSU. It is being attempted to determine he impact of this radiation on the environment historically. The representatives of the Ministry of Public Health have the possibility to intervene in this issue. There is also a detailed record from Drs. Stukin and Alexahkin relating to these matters. Dr Iskra noted their interest in organizing an international Scientific Symposium in Russia, in September 1999 (a RADLEG symposium). All interested organizations will be invited to participate. This will be supported by the Ministry for Atomic Energy, by the Russian Academy of Sciences and other institutions. So far 40 institutions have agreed to participate.

b) USA

Prof. Goldman reported that he is presently beginning to organize the North American programme. He noted also that decisions about US budget are now being completed and consequently funded decisions are not yet completed. Contact has been established with Lynn Anspaugh, Ward Whicker and Stan Auerbach, and it is hoped that the group will be formulated in the next few months. Contact with the US Department of Energy has been established, and they are supportive, but have not yet done anything specific as regards funding. It will be attempted to summarise the consequences for the environment in the US nuclear military facilities, which number more than 130. The more significant facilities will be concentrated upon and an overview will be provided during a subsequent presentation. Prof. Goldman noted the welcome first opportunity for cooperation, to have an independent, non-governmental, organization review this topic. Appreciation for forthcoming work was expressed. The hope that the end-product would provide some general rules for all countries to agree to was expressed, including how to represent past-events, the current status of facilities, and the options for remediation and future action.

c) ASIA

Dr. Mishra noted that as far as India is concerned there are no military installations where radioactivity is involved. However there is a strong belief that those countries with nuclear weapons programmes must be involved in early stages. Radioactive waste was not treated and dispersed in the same way as it is treated today, and this has resulted in contamination at several sites. Since there is interest for power generation, these reports about contamination are providing material to anti-nuclear groups, with regard to preventing the

growth of nuclear energy, which is very important for countries like India which do not have any other materials for electricity generation (apart from coal), and it is one of the lowest in per capita electricity consumption. For industrial growth and sustaining a large population it is necessary to increase this per capita electricity consumption 10 times over the next 20-30 years. Hence India would like to learn from this group what steps should be taken in order to avoid mistakes that have occurred in the past.

On behalf of CAST's SCOPE China, Prof. Mao noted that previous involvement in the RADTEST had occurred, and expressed interest in RADSITE. An ad-hoc meeting of the China group was held before Prof. Mao left from Beijing, involving Vice-Chairmen and the Secretary General of CAST's SCOPE China, Prof. Liu. Ideas for involvement in RADSITE were discussed, and the draft paper for this workshop to be presented by Prof. Mao. There are four parts in this paper relating to foundations of nuclear cycle facilities in China, nuclear test cycle facilities, environmental protection in the nuclear industry for the purpose of national defence and finally environmental evaluation and the impact of nuclear industry on the environment. Their group discussed this paper in detail and agreed the content. This is a general overview for the initial workshop. Further efforts to collect more material, including in quantitative detail, can be made (e.g. source term, dose evaluation and impacts on the environment). Following discussions, cooperation was agreed with their Chinese Society for Radioprotection (Prof. Pan) so further contact is envisage with this organization.

d) EU

Prof. Kirchmann reported that the European Branch's the main objective is the preparation of a concerted action in the 5 th Framework programme of the European Commission. It was attempted to obtain some information from the EU authorities, but these are either not for general disclosure or, more likely, they are not yet well defined. Regret was expressed that representation from the EU (Dr. S. Kaiser) would not be possible until later in the day. It was noted that there must be clear ideas of what is needed for inclusion in the proposal. This is one of the reasons for the working party, next Saturday, with ISTC. Prof. Kirchmann noted that more details about SCOPE-RADSITE would be presented later during the meeting.

e) IUPAC

The representation by IUPAC was welcomed, and the late Prof. Koptyug's role in this organization (and in SCOPE) was noted. He was particularly involved in developing the relationship between IUPAC and SCOPE. Dr. V.Myasoedov note that IUPAC is an important organization for chemists, involving over 100 countries. IUPAC covers different aspects of modern chemistry, including environmental radioactivity. As an organization, it has seven different divisions including; physical chemistry, organic chemistry, inorganic chemistry and, perhaps of most relevance to RADSITE, that of analytical chemistry, chemistry of environment. In the division of analytical chemistry there is provision for radiochemistry and nuclear technology. The main purposes of the Radiochemistry Commission with regard to RADSITE are: environmental radionuclides (including determination, speciation, behaviour and remediation). Radiation technologies associated with radioactive waste include radioanalytical methods and nuclear techniques for the determination and speciation of elements and isotopes in various matrices. This Radiochemistry Commission now elaborates a lot of their projects which are quite closely related to RADSITE projects, namely, determination of very low levels of radioactivity, speciation of trace elements in the environment by radioanalytical methods, radionuclide migration in ground water (review of the behaviour of the most dangerous actinides), and different aspects of behaviour of chemical species in environment (as covered by division 6, Chemistry and Environment). IUPAC is quite interested in active participation in the RADSITE programme and the need for coordination was noted.

f) IAEA

Dr. Tysplenkov noted the IAEA's division of Nuclear Fuel Cycle and Waste Technology, which belongs to the Department of Nuclear Energy, which has various activities in related fields including with reference to environmental remediation and restoration. IAEA is interested to maintain contact with all groups responsible carrying out work relating to environmental remediation. He reported also on his recent attendance at a NATO Advanced Research Workshop on remediation of military sites (held in Poland), which is closely related to RADSITE interests. It included representatives from several countries (US (Doe), Los Alamos, Russia, Ukraine, Hungary, Czech Republic). The main purpose of their meeting was to identify main areas of collaboration between different organizations (in particular Los Alamos and Kazakhstan National Nuclear Centre, and the Ministry of Emergency Situation in Ukraine and Los Alamos). During this ARW an earlier Estonian meeting was noted. The need to avoid duplication of efforts was emphasized. A similar NATO ARW was held some three years ago on Actinides and the Environment (involving LLNL). The involvement of PNL was also noted.

3) NATO ARW

The possibility of interesting NATO in an ARW for RADSITE was noted, in view of their activities in this field. Prof. Kirchmann reported on his contacts with Dr. Veiga da Cunha (NATO Scientific Secretary), who unfortunately is involved with Symposia elsewhere at the present time. However he has expressed interest in RADSITE, and he will be kept informed of RADSITE's evolution. In the past NATO supported two RADTEST ARWs in Vienna and Barnaul, which is why it is hoped that NATO will support an ARW next year within the framework of the current RADSITE programme. In this connection it is necessary to consider the proposal, date and location (including administrative support from the University of Essex, where there are problems in so far as the SCOPE Unit located there will terminate (from 1 January 1998). It was noted that the Essex Unit has had extensive experience of preparing the detailed proposals that are required by NATO. Following on from this, the need to identify a willing participant assist with organizing such a NATO ARW next year was noted. Prof. Kirchmann suggested that ideally this will involve *big* nuclear science in a *big* nuclear power country (e.g. US, Mayak etc.). It is hoped that this RADSITE meeting will enable identification of a relevant organization.

4) PUBLICATION OF THE INITIAL WORKSHOP PROCEEDINGS

It was recalled that when a RADTEST meeting was organized in Brussels and Liege, proceedings were not produced at that time, but rather material provided an input to the synthesis volume. However, in retrospect this is not considered to be a wise decision, in view of the delay in publication of the synthesis volume (envisaged next year). Hence there is not wide access to material prepared at that time. Consequently, with regard to the present workshop it is considered necessary to examine possibilities for publication (and a tender has been provided by Elsevier). There are two difficulties in this regard: the amount of money necessary and editorial matters relating to the provision of camera-ready copy. Another solution could therefore be to put material on the RADSITE website, which has recently been created. This could be useful mechanism for advertising the programme and putting information at the disposal of interest parties. With regard to the general policy of SCOPE, the Executive Secretary (Ms Plocq) noted that the role of individual publishers with SCOPE was irrelevant to proceedings, because SCOPE publishes in its series only final synthesis volumes. Hence intermediate publications, such as proceedings, are welcomed but are not published within SCOPE's series. It was nevertheless noted that SCOPE's agreement with Wiley has been terminated (after more than twenty years), and a new publisher(s) are being sought and the matter will be resolved by the time of RADSITE's concluding synthesis publication. With regard to disseminating results of the present meeting, she advised delaying a decision until the material provided has been assessed, as this may provide a clearer view of the best way to publish it. The need to remember that the project is in its initial

stages was noted, and by definition it was noted that proceedings are an intermediary and short-lived publication. Ms. Plocq recommended that the proposal by Elsevier is probably not appropriate for this relatively short-lived material, in terms of money and effort required. The idea of utilizing a web site was considered to be very appropriate, and was welcomed as a first-step. In addition the preparation of a reviewed article for a journal was proposed, which would publicize the project to a wide audience and provide a strong focus for mobilizing participants at an early stage.

5) VARIA

Prof. Kirchmann noted the need for official participation by RADSITE scientists in international symposia. In this connection, next year's March meeting (in Montreal) involving DGXI was noted with reference radionuclides in the Arctic. Information about symposia was invited, for provision to Profs. Kirchmann, Bourdeau and Goldman in order to inform those involved with RADSITE. This information will be made available, to enable decisions to be made regarding involvement and presentation of the achievements of the project.

It was noted that for RADSITE it was proposed to use the Essex SCOPE Unit to disseminate information, however its closure means that an alternative method needs to be identified. It is therefore proposed to use the web for this purpose, and to launch a newsletter via this.

Ms. Plocq advocated that the meeting should be used to update and complete the project document for RADSITE. The initial project document was appropriate but is now more than two years old and there have been many developments including in the workplan. Consequently, if interest in the project is to be attracted (both financial and scientific), a single document is needed. This should provide in significant detail the rationale for the project, the objectives, contents and programmatic and organizational aspects. At the SCOPE Secretariat a meeting was hosted three weeks ago, involving French scientists who would like to involve their community, but a background document is required for this purpose.

Dr. Stukin mentioned a few important questions regarding how to progress with RADSITE. It was noted that the initial stage of RADSITE is underway, and with regard to the FSU there has been progress, but some republics of the FSU are lagging behind. The need for other colleagues to take an active role in the project was therefore emphasized, in order that active participation at the minimum should involve Ukraine, Kazakhstan and Uzbekistan. The need to think about the completion of the RADSITE document needs to be considered in order to achieve the task was mentioned. Regarding the organization of a Seminar in September 1998, under the auspices of RADLEG, it was suggested that a joint seminar with RADSITE might be envisaged.

L.J. Appleby: 10 th December 1998

MEMORANDUM

of meeting N.N.Egorov with M.Goldman and R.Kirchmann

Moscow, Minatom (Staromonetny per.) October 14, 1998

Participants:

Prof. Marvin Goldman	University of California, USA
Prof. Rene Kirchmann	University of Liege, Belgium
Dr. N.N.Egorov	Deputy Minister, Minatom
Dr. Uwe Meyer	Senior Project Manager, ISTC
Dr. A.A.Iskra	ISTC Project 245 Manager, VNIICHT
Prof. V.I.Velichkin	Deputy Director IGEM RAS
Dr. E.D.Stukin	Chief of Laboratory, IGKE
Prof. V.A.Logatchev	Chief of Laboratory, IBF MH
Prof. V.B.Georgievskii	Chief of Laboratory, Kurchatov Institute
Dr. O.G.Lebedev	Senior Research Officer, Kurchatov Institute

Agenda of meeting: about possible participation of Minatom and other Institutions of the former USSR in the International Project RADSITE.

The International Project RADSITE (radioactivity from military installations sites and effects on environment and population health) comprise a preparatory and a completion phase. The year-long preparatory phase (June 1988/1999) will seek to clarify goals and assure input, establish RADSITE within the SCOPE structure, and secure a sound financial basis for the project. The three-year completion phase (June 1999/2002) will be concerned with collating synthesizing information for wide dissemination.

A discussion has taken place between representatives of the project RADSITE M.Goldman and R. Kirchmann, from one side, and N.N.Egorov - from other. A brief content of discussion is given below.

Goldman:

I ask you to lead the work on the project RADSITE in the states of the FSU, to help in obtaining information on the radiation situation in the archives of Minatom' enterprises subordinated to you (both at the present time and in the past years for reconstruction of contamination situation, estimation of doses and dose rates), help to overcome the interagency barriers in requesting the information to the other authorities of the former USSR. The enterprises Mayak, Siberian Chemical Combine (Tomsk), and Mining Chemical Combine near Krasnoyarsk (Zheleznogorsk) are of greatest interest for the project. In the framework of this project we shall study the impact of the radiation sources not on facilities staff, but only on the population of surrounding areas. We are seeking financial support for the project RADSITE, and suggest that the work performed by the Russian side will be funded by ISTC.

Egorov:

Of course, even now not all the data on the activities of Minatom' combines may be published. The process of declassifying and publishing the data is quite protractive, difficult and labor-consuming. Note, the works on evaluation of radiation situation at the combine Mayak cost approximately $ one million. On principle we agree with objectives and tasks of the project RADSITE and are ready to participate in this one. Minatom and some other institutions of Russia are participating within some years in the analogous international studies, for example such as the ISTC project 245 RADLEG.

I suppose that facilities producing plutonium comprise a group of greatest effects on the environment among all enterprises of the nuclear fuel cycle. The uranium isotope enrichment plants might be related to the same group, although these ones impact to the environment to the lesser extent.

The second group: nuclear submarines of Northern and Pacific navy are subjected to decommissioning.

A civil part is comprised by NPPs and SNF storage facilities (this sector is a prerogative of IAEA). As to enterprises Radon type, one may not consider those as the sources of any serious radiation hazard.

I propose to arrange in the framework of the RADSITE project a comparative study of the nuclear objects in four regions of the world: India (Tarapur), Russia (Krasnoyarsk), USA (Hanford or Savanna-River), and UK (Sellafield).

Of course, a doses reconstruction is an essential problem. But different approach is possible: not to be dug in history, and evaluate the current impact of enterprise or object (say, lake Karachai) on the environment.

Iskra:

Leading institutions (VNIICHT, IGKE, Kurchatov Institute, and IGEM) could issue a compilation of reports (including this Memorandum) which will serve as the initial document for the FSU participation in the SCOPE-RADSITE project.

Nikolai Egorov

Marvin Goldman
Rene Kischmann

SCOPE RADSITE Working Group Meeting

Gembloux (Hotel 3 Clés), 12 June 2002

Agenda :

- Welcome address and objective of the meeting (R. Kirchmann)
- Progress status of the Synthesis volume (C. Vandecasteele)

Chap. 1: Source-term (V. Popov's report)
Chap. 2: Pathways(A. Cigna's report)
Chap. 3: Dose assessment (M. Savkin's report)
Chap. 4: Impact on Population Health (M. Goldman's report)
Chap. 5:. Impact on the Environment (T. Hinton's report)
Chap. 6: Impact Mitigation (R. Kirchmann's contribution)

- Future actions
- Varia

Attendees : Ph. Bourdeau, A. Iskra, R. Kirchmann, U. Mishra, G. Polikarpov, V. Popov, C. Vandecasteele.

- **Welcome address and objective of the meeting**

The objectives of the meeting is to take stock of the report and the progress to-date, reviewing with the

attending contributors the already available information and identifying the remaining gaps. All documents received have been placed on the RADSITE website.

A number of documents are tabled by U. Mishra:

- Environmental surveillance at Trombay, Annual report 1999.
- Environmental radiation measurements around Madras atomic power station (Maps) site 1985-1993.
- Environmental radiation measurements around Tarapur atomic power station (Taps) site 1985-1993.
- Annual report on off-site environmental and micrometeorological studies at Taps site 1998.
- Annual report for 1989 on off-site environmental and micrometeorological studies at Tarapur site.
- **Progress status of the Synthesis volume**

Executive summary (to be produced at the end by M. Goldman)

Introduction (to be produced at the end by the Scientific Committee)

Chap. 1: Source-term (V. Popov's report)

Hanford : a report has been provided by B. Napier.
Krasnoyarsk : new material has been presented at the Krasnoyarsk and Moscow. After they will receive clearance they will be provided to R. Kirchmann to be placed on the website. These reports also contain information relevant for other chapters.
Other not yet published material in the form of a geo-referenced system providing information on the radioactive contamination along the Yenissei river (aero-gamma and terrestrial survey) will be sent later to RADSITE.
Elektrosthal : a report has been produced for INEX. Its has already been sent to A. Cigna and a copy on floppy disk is given to R. Kirchmann.
North-West Russia : the situation in this region is very dynamic, many projects are developed at national and international level (the most urgent is the dismantling of old nuclear sub-marine). A lot of material concerning North-West Russia and the far East is gathered in preparation of the Vladivostok conference in 2002 in the framework of RADINFO (to be launched in July).
A detailed assessment of the situation in the North-West carried out with IIASA (Luxemburg) should be completed by the end of 2002.
There is also material available from various seminars organised in Russia (namely with NATO) on the dismantling of nuclear sub-marines and radwaste management.
The contribution by A. Iskra and V. Popov to the textbook has been included in the programme of the new ISTC project RADINFO. A summary of the situation associated with nuclear sub-marines will be produced.

Chap. 2: Pathways (A. Cigna's report)

Recently, A. Cigna send a request by e-mail to V. Popov (Elektrosthal), A. Iskra (North-West Russia), M. Goldman (Oak Ridge), T. Hinton (Savannah River) and M. Chartier (Marcoule) to obtain their contribution to this chapter.
V. Popov has sent to A. Cigna its contribution over Elektrosthal but not yet that over North-West Russia . Data concerning radwaste site in the Kara sea region (paper version) will be sent in a next future.

Chap. 3: Dose assessment (M. Savkin's report)

A paper on methodology from L. Anspaugh can be used as a general introduction to this chapter.
Data are available concerning the Hanford environmental dose reconstruction project.
Some data on Krasnoyarsk and other regions have been provided by M. Savkin.
For Sellafield , a NRPB report has been provided by S. Haywood and another report (from BNFL) is available on marine pathways.
Marcoule should be documented by A. Cigna and M. Chartier.
Dose modelling for Elektrosthal can be found on the report provided in the floppy disk given to R. Kirchmann.
Dose modelling and assessment for North-West Russia will be available by September 2002.

Chap. 4: Impact on Population Health (M. Goldman's report)

The general items should be provided by M. Goldman.
Data about Wismut have been provided by K. Wichterey.
Data on epidemiology and environmental impact at Savannah River have been provided by T. Hinton.
A report on thyroid disease around Hanford is available on the website.

Chap. 5: Impact on the Environment (T. Hinton's report)

T. Hinton has sent to all contributors to this chapter a request to get site specific data for the respective sites.

Chap. 6: Impact Mitigation (R. Kirchmann's contribution)

Some material is available concerning Krasnoyarsk and Elektrosthal , not yet over North-West Russia . V. Popov will prepare a short summary.

- **Future actions**

It seems reasonable to collect the available information and to produce a first draft version on a CD-Rom by the end of 2002. This will also allow to identify the hopeless items and contributors. The American contributors have provided some good material for the various chapters, but the contribution about 'health impact' (M. Goldman) is still almost inexistent. A solution could be to combine chapters III (Dose assessment) and IV (Health impact) in a single one; another possibility could be to identify a new chapter co-ordinator for chapter IV.

Each chapter leader should sent the to-date available material

to R. Kirchmann.

THE MANHATTAN PROJECT

January 1999 edition

The Department of Energy Organization Act of 1977 brought together for the first time in one department most of the Federal Government's energy programs. With these programs came a score of organizational entities, each with its own history and traditions, from a dozen departments and independent agencies. The History Division has prepared a series of monographs on The Origins of the Department of Energy. Each explains the history, goals, and achievements of a predecessor agency or a major program of the Department of Energy.

"The Manhattan Project: Making the Atomic Bomb" is a short history of the origins and develop-ment of the American atomic bomb program during World War II. Beginning with the scientific develop-ments of the pre-war years, the monograph details the role of United States government in conducting a secret, nationwide enterprise that took science from the laboratory and into combat with an entirely new type of weapon.

The monograph concludes with a discussion of the immediate postwar period, the debate over the Atomic Energy Act of 1946, and the founding of the Atomic Energy Commission.

Introduction: The Einstein Letter
(see copy of original letter in Selected bibliography)

On October II, 1939, Alexander Sachs, Wall

Street economist and longtime friend and unofficial advisor to President Franklin Delano Roosevelt, met with the President to discuss a letter written by Albert Einstein the previous August. Einstein had written to inform Roosevelt that recent research on chain reactions utilizing uranium made it probable that large amounts of power could be produced by a chain reaction and that, by harnessing this power, the construction of "extremely powerful bombs..."l was conceivable. Einstein believed the German government was actively supporting research in this area and urged the United States government to do likewise. Sachs read from a cover letter he had prepared and briefed Roosevelt on the main points contained in Einstein's letter. Initially the President was noncommittal and expressed concern over locating the necessary funds, but at a second meeting over breakfast the next morning Roosevelt became convinced of the value of exploring atomic

energy.

Einstein drafted his famous letter with the help of the Hungarian emigre physicist Leo Szilard, one of a number of European scientists who had fled to the United States in the 1930's to escape Nazi and Fascist repression. Szilard was among the most vocal of those advocating a program to develop bombs

based on recent findings in nuclear physics and chemistry. Those like Szilard and fellow Hungarian refugee physicists Edward Teller and Eugene Wigner regarded it as their responsibility to alert Americans to the possibiliity that German scientists might win the race to build an atomic bomb and to warn that Hitler would be more than willing to resort to such a weapon. But Roosevelt, preoccupied with events in Europe, took over two months to meet with Sachs after receiving Einstein's letter. Szilard and his col-leagues interpreted Roosevelt's inaction as unwelcome evidence that the President did not take the threat of nuclear warfare seriously.

Roosevelt wrote Einstein back on October 19, 1939, informing the physicist that he had set up a committee consisting of Sachs and representatives from the Army and Navy to study uranium? Events proved that the President was a man of considerable action once he had chosen a direction. In fact, Roosevelt's approval of uranium research in October 1939, based on his belief that the United States could not take the risk of allowing Hitler to achieve unilat-eral possession of "extremely powerful bombs," was merely the first decision among many that ultimately led to the establishment of the only atomic bomb effort that succeeded in World War ll-the Manhattan Project.

The British, who made significant theoretical con-tributions early in the war, did not have the resources to pursue a full-fledged atomic bomb research program while fighting for their survival. Consequently, the British acceded, reluctantly, to American leadership and sent scientists to every Manhattan Project facility. The Germans, despite Allied fears that were not dispelled until the ALSOS mission in 1944_ were little nearer to producing atomic weapons at the end of the war than they had been at the beginning of the war. German scientists pursued research on fission, but the government's attempts to forge a coherent strategy met with little succesS.4

The Russians built a program that grew increas-ingly active as the war drew to a conclusion, but the first successful Soviet test was not conducted until 1949. The Japanese mmanaged to build several cyclotrons by war's end, but the atomic bomb research effort could not maintain a high priority in the face of increasing scarcities. Only the Americans, late entrants into World War II and protected by oceans on both sides, managed to take the discovery of fission from the laboratory to the battlefield and gain a short-lived atomic monopoly.

The uranium Committee

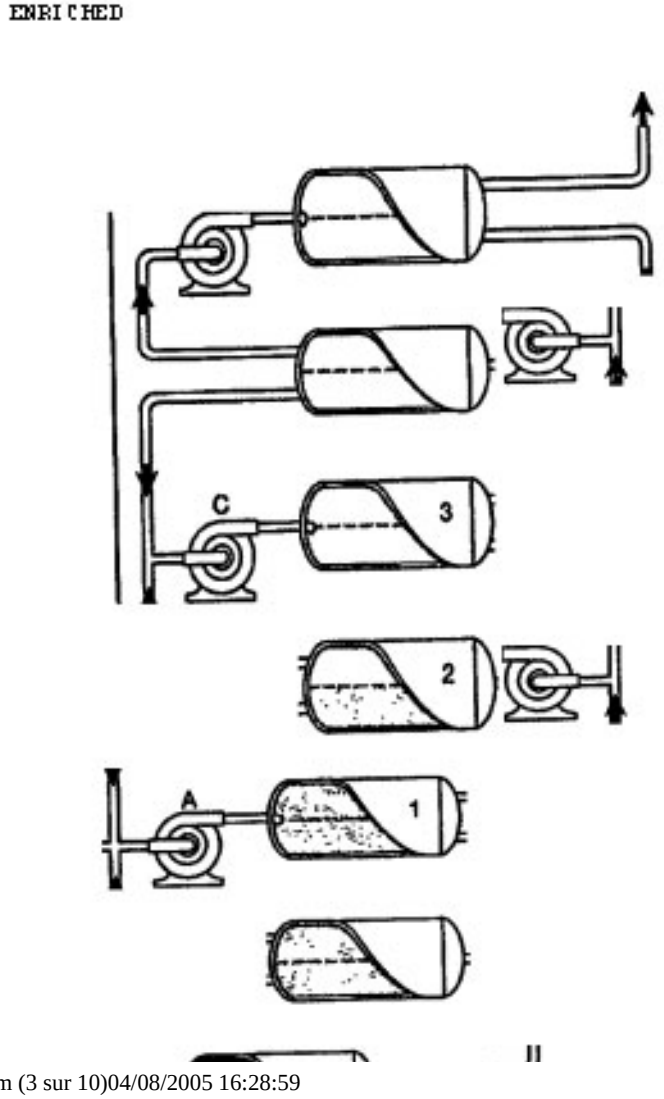
President Roosevelt responded to the call for government support of uranium research quickly but cautiously. He appointed Lyman J. Briggs, director of the National Bureau of Standards, head of the Advisory Committee on Uranium, which met for the first time on October 21, 1939. The committee, including both civilian and military representation, was to coordinate its activities with Sachs and look into the current state of research on uranium to recommend an appropriate role for the federal government. In early 1940 the Uranium Committee recommended that the government fund limited research on isotope separation as well as Fermi's and Szilard's work on chain reactions at Columbia

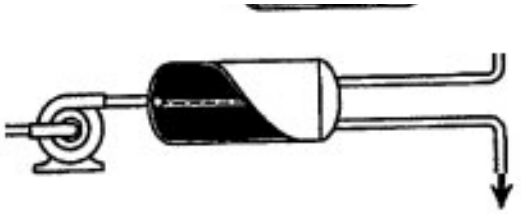
Isotope Separation

Scientists had concluded that enriched samples of uranium-235 were necessary for further research and that the isotope might serve as a fuel source for an explosive device; thus, finding the most effectivemethod of isotope separation was a high priority. Since uranium-235 and uranium-238 were chemically identical, they could not be separated by chemical means. And with their masses differing by less than one percent, separation by physical means would be extremely difficult and expensive. Nonetheless, scien- tists pressed forward on several complicated techni-ques of physical separation, all based on the small difference in atomic weight between the uranium isotopes.

Part H:

Early Government Support





Schematic Diagram of Flow of Process Gas in Gaseous Diffusion Cascade.
Reprinted from Richard G. Hewlett and
Oscar E. Anderson, Jr., *The New World.* 1939-1946. Volume of *A HIStory of the United States Atomic Energy Commtmon*

The Electromagnetic Method

The electromagnetic method, pioneered by Alfred O. Nier of the University of Minnesota, used a mass spectrometer, or spectrograph, to send a stream of charged particles through a magnetic field. Atoms of the lighter isotope would be deflected more by the magnetic field than those of the heavier isotope, resulting in two streams that could then be collected in different receivers. The electromagnetic method as it existed in 1940, however, would have taken far too long to separate quantities sufficient to be useful in the current war. In fact, twenty-seven thousand years would have been required for a single spectrometer to separate one gram of uranium-235.

Gaseous Diffusion

Gaseous diffusion appeared more promising. Based on the well-known principle that molecules of a lighter isotope would pass through a porous bar-rier more readily than molecules of a heavier one,this approach proposed to produce by myriad repetitiond a gas increasingly rich in uranium-235 was separated out in a system of cascades. Theoretically, this process could achieve high concentrations of uramum-235 but, like the electromagnetic method, would be extremely costly. British researchers led the way on gaseous diffusion, with John R. Dunning and his colleagues at Columbia University joining the effort in late 1940.

Cen1rifuge

Many scientists initially thought the best hope for isotope separation was the high-speed centrifuge, a device based on the same principle as the cream separator. Centrifugal force in a cylinder spinning rapidly on its vertical axis would separate a gaseous mixture of two isotopes since the lighter isotope would be less affected by the action and could be drawn off at the center and top of the cylinder. A cascade system composed of hundreds, perhaps thousands, of centrifuges could produce a rich mix-ture. This method, being pursued primarily by Jesse W. Beams at the University of Virginia, receiv-ed much of the early isotope separation funding.lO

Liquid Thermal Diffusion

The Uranium Committee briefly demonstrated an interest in a fourth enrichment process during 1940, only to conclude that it would not be worth pursu-ing. This process, liquid thermal diffusion, was being investigated by Philip Abelson at the Carnegie Institution. Into the space between two concentric vertical

pipes Abelson placed pressurized liquid uranium hexafluoride. With the outer wall cooled by a circulating water jacket and the inner heated by high-pressure steam, the lighter isotope tended to concentrate near the hot wall and the heavier near the cold. Convection would in time carry the lighter isotope to the top of the column. Taller columns would produce more separation. Like other enrich-ment methods, liquid thermal diffusion was at an early stage of development.

Moving Into Action

By the time Roosevelt responded, Bush had set the wheels in motion. He put Eger V. Murphree, a

chemical engineer with the Standard Oil Company, in charge of a group responsible for overseeing engineering studies and supervising pilot plant con-struction and any laboratory-scale investigations. And he appointed Urey, Lawrence, and Compton as program chiefs. Urey headed up work including diffusion and centrifuge methods and heavy-water studies. Lawrence took electromagnetic and plutonium responsibilities, and Compton ran chain reaction and weapon! theory programs. Bush's responsibility was to coordinate engineering and scientific efforts and make final decisions on recom-mendations for construction contracts. In accor-dance with the instructions he received from Roosevelt, Bush removed all uranium work from the National Defense Research Committee. From this point forward, broad policy decisions relating to uranium were primarily the responsibility of the Top Policy Group, composed of Bush, Conant, Vice President Wallace, Secretary of War Henry L. Stim-son, and Army Chief of Staff George C. Marshall. A high-level conference convened by Wallace on

December 16 put the seal of approval on these arrangements. Two days later the S-1 Committee gave

Lawrence $400,000 to continue his electromagnetic work.

With the United States now at war and with the fear that the American bomb effort was behind Nazi Germany's, a sense of urgency permeated the federal government's science enterprise. Even as Bush tried to fine-tune the organizational apparatus, new scientific information poured in from laboratories to be analyzed and incorporated into planning for the upcoming design and construction stage. By spring 1942, as American naval forces slowed the Japanese advance in the Pacific with an April victory in the battle of the Coral Sea, the situation had changed from one of too little money and no deadlines to one of a clear goal, plenty of money, but too little time. The race for the bomb was on.

Continuing Efforts on Isotope Separation

During the first half of 1942 several routes to a

bomb were explored. At Columbia, Urey worked on the gaseous diffusion and centrifuge systems for isotope separation in the codenamed SAM (Substitute or Special Alloy Metals) Laboratory. At Berkeley, Lawrence continued his investigations on electromagnetic separation using the mass spec-trograph he had converted from his thirty-seven-inch cyclotron. Compton patched together facilities at the University of Chicago's Metallurgical Laboratory for pile experiments aimed at producing plutonium.

Meanwhile Murphree's group hurriedly studied ways to move from laboratory experiments to production facilities.

Research on uranium required uranium ore, and obtaining sufficient supplies was the responsibility of Murphree and his group. Fortunately, enough ore was on hand to meet the projected need of 150 tons through mid-I944. Twelve hundred tons of high -grade ore were stored on Staten Island, and Murphree made arrangements to obtain additional supplies from Canada and the Colorado Plateau, the only American source. Uranium in the form of hexafluoride was also needed as feed material for the centrifuge and the gaseous and thermal diffusion processes. Abelson, who had moved from the Carnegie Institution to the Naval Research Laboratory, was producing small quantities, and Murphree made arrangements with E. I. du Pont de Nemours and Company and the Harshaw Chemical Company of Cleveland to produce hexafluoride on a scale sufficient to keep the vital isotope separation research going.

Lawrence was so successful in producing enriched samples of uranium-235 electromagnetically with his converted cyclotron that Bush sent a special progress report to Roosevelt on March 9, 1942. Bush told the

President that Lawrence's work might lead to a short cut to the bomb, especially in light of new calculations indicating that the critical mass required might well be smaller than previously predicted.

Bush also emphasized that the efficiency of the weapon would probably be greater than earlier estimated and expressed more confidence that it could be detonated successfully. Bush thought that if matters were expedited a bomb was possible in 1944. Two days later the President responded: "I think the whole thing should be pushed not only in regard to development, but also with due regard to time. This is very much of the essence.”

In the meantime, however. isotope separation studies at Columbia quickly confronted serious engineering difficulties. Not only were the specifica-tions for the centrifuge demanding. but, depending upon rotor size. it was estimated that it would re-quire tens of thousands of centrifuges to produce enough uranium-235 to be of value. Gaseous diffu-sion immediately ran into trouble as well. Fabrica-tion of an effective barrier to separate the uranium isotopes seemed so difficult as to relegate gaseous diffusion to a lower priority (the barrier had to be a corrosion-resistant membrane containing millions of submicroscopic holes per square inch). Both separa-tion methods demanded the design and construction of new technologies and required that parts, many of them never before produced. be finished to tolerances not previously imposed on American industry.

In Chicago, Compton decided to combine all pile research by stages. Initially he funded Fermi's pile at Columbia and the theoretical work of Eugene Wigner at Princeton and J. Robert Oppenheimer at Berkeley. He appointed Szilard head of materials ac-quisition and arranged for Seaborg to move his plutonium work from Berkeley to Chicago in April 1942. Compton secured space wherever he could find it, including a racket court under the west grandstand at Stagg Field, where Samuel K. Allison began building a graphite and uranium pile.

Although it was recognized that heavy water would provide a moderator superior to graphite, the only available supply was a small amount that the British had smuggled out of France. In a decision typical of the new climate of urgency, Compton decided to forge ahead with graphite. a decision made easier by Fermi's increasingly satisfactory results at Columbia and Allison's even better results in Chicago. In light of recent calculations that cast doubt on the MAUD report's negative assessment of plutonium produc-tion, Compton hoped that Allison's pile would pro-vide plutonium that could be used as material for a weapon.

By May 1942 Bush decided that production plan-ning could wait no longer, and he instructed Conant to meet with the 8-1 section leaders and make recommendations on all approaches to the bomb, regardless of cost. Analyzing the status of the four methods of isotope separation then under considera-tion-gaseous diffusion, centrifuge, electromagnetic, and pile-the committee decided on May 23 to recommend that all be pushed as fast as possible. This decision reflected the inability of the committee to distinguish a clear front-runner and its consequent unwillingness to abandon any method. With funds readily available and the outcome of the war con-ceivably hanging in the balance, the 8-1 leadership recommended that all four methods proceed to the pilot plant stage and to full production planning.

During summer and fall 1942 technical and administrative difficulties were still severe. Each of the four isotope separation processes remained under consideration, but a full-scale commitment *to* all four posed serious problems even with the pro-ject's high priority. When Groves took command in mid-September, he made it clear that by late 1942 decisions would be made as to which process or processes promised to produce a bomb in the shortest amount of time. The exigencies of war, Groves held, required scientists *to* move from laboratory research *to* development and production in record time. Though traditional scientific caution might be short-circuited in the process, there was no alternative if a bomb was *to* be built in time *to* be used in the current conflict. As everyone involved in the Manhattan Project soon learned, Groves never lost sight of this goal and made all his decisions accordingly.

While the centrifuge was cancelled and gaseous diffusion received mixed reviews, optimism prevailed

among the pile proponents at the Metallurgical Laboratory in Chicago. Shortages of uranium and graphite delayed construction of the Stagg Field pile-CP-l (Chicago Pile Number One)-but this frustration was tempered by calculations indicating that a completed pile would produce a chain reac-tion. With Fermi's move to Chicago in April, all pile research was now being conducted at the Metallurgical Laboratory as Compton had planned, and Fermi and his team anticipated a successful ex-periment by the end of the year. Further optimism stemmed from Seaborg's inventive work with plutonium, particularly his investigations on plutonium's oxidation states that seemed to provide a way to separate plutonium from the irradiated uranium to be produced in the pile. In August Seaborg's team produced a microscopic sample of pure plutonium, a major chemical achievement and one fully justifying further work on the pile..

No Turning Back: Final Decisions and

Presidential Approval

The 8-1 Executive Committee met to consider the Lewis report on December 9, 1942, just weeks after Allied troops landed in North Africa. Most of the morning session was spent evaluating the controver-sial recommendation that only a small electro-

magnetic plant be built. Lewis and his colleagues

based their recommendation on the belief that Lawrence could not produce enough uranium-235 to be of military significance. But since the calutron could provide enriched samples quickly, the commit-tee supported the construction of a small elec-tromagnetic plant. Conant disagreed with the Lewis committee's assessment, believing that uranium had more weapon potential than plutonium. And since he knew that gaseous diffusion could not provide any enriched uranium until the gaseous diffusion plant was

in full operation, he supported the one method that might, if all went well, produce enough uranium to build a bomb in 1944. During the after-noon, the S-1 Executive Committee went over a draft Groves had prepared for Bush to send to the President. It supported the Lewis committee's report except that it recommended skipping the pilot plant stage for the pile. After Conant and the Lewis com-mittee met on December 10 and reached a com-promise on the electromagnetic method, Groves's draft was amended and forwarded to Bush.

On December 28, 1942, President Roosevelt ap-proved the establishment of what ultimately became a government investment in excess of $2 billion, $.5 billion of which was itemized in Bush's report sub-mitted on December 16. The Manhattan Project was authorized to build full-scale gaseous diffusion and plutonium plants and the compromise electro-magnetic plant, as well as heavy water production facilities. In his report, Bush reaffirmed his belief that bombs possibly could be produced during the first half of 1945 but cautioned that an earlier delivery was unlikely.

No schedule could guarantee that the United States would overtake Germany in the race for the bomb, but by the beginning of 1943 the Manhattan Project had the complete support of President Roosevelt and the military leadership, the services of some of the nation's most distinguished scientists, and a sense of urgency driven by fear. Much had been achieved in the year between Pearl Harbor and the end of 1942.

No single decision created the American atomic bomb project. Roosevelt's December 28 decision was inevitable in light of numerous earner ones that, in incremental fashion, committed the United States to pursuing atomic weapons. In fact, the essential pieces were in place when Roosevelt approved

Bush's November 9, 1941. report on January 19, 1942. At that time, there was a science organization at the highest level of the federal government and a Top policy Group with direct access to the Presi-dent. Funds were authorized, and the participation of the Corps of Engineers had been approved in principle. In addition, the country was at war and its scientific leadership-as well as its President-had the belief, born of the MAUD report, that the pro-ject could result in a significant contribution to the war effort. Roosevelt's approval of $500 million in late December 1942 was a step that followed directly from the commitments made in January of that year and stemmed logically from the President's earnest tentative decisions in late 1939

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The Letter

This letter from Albert Einstein to President Franklin D. Roosevelt led to the Manhattan Engineering District, also known as "the Manhattan Project," a national crash program racing to develop atomic weapons before Nazi Germany. The Manhattan Project was the seed that grew into the modern national laboratory system, which today includes many non-weapons-research laboratories, such as Argonne.

Albert Einstein
Old Grove Rd.
Nassau Point
Peconic, Long Island

August 2nd, 1939

F.D. Roosevelt,
President of the United States,
White House
Washington, D.C.

Sir:

Some recent work by E.Fermi and L. Szilard, which has been communicated to me in manuscript, leads me to expect that the element uranium may be turned into a new and important source of energy in the immediate future. Certain aspects of the situation which has arisen seem to call for watchfulness and, if necessary, quick action on the part of the Administration. I believe therefore that it is my duty to bring to your attention the following facts and recommendations:

In the course of the last four months it has been made probable - through the work of Joliot in France as well as Fermi and Szilard in America - that it may become possible to set up a nuclear chain reaction in a large mass of uranium,by which vast amounts of power and large quantities of new radium-like elements would be generated. Now it appears almost certain that this could be achieved in the immediate future.

This new phenomenon would also lead to the construction of bombs, and it is conceivable - though much less certain - that extremely powerful bombs of a new type may thus be constructed. A single bomb of this type, carried by boat and exploded in a port, might very well destroy the whole port together with some of the surrounding territory. However, such bombs might very well prove to be too heavy for transportation by

the whole port together with some of the surrounding territory. However, such bombs might very well prove to be too heavy for transportation by air.

The United States has only very poor ores of uranium in moderate quantities. There is some good ore in Canada and the former Czechoslovakia, while the most important source of uranium is Belgian Congo.

In view of this situation you may think it desirable to have some permanent contact maintained between the Administration and the group of physicists working on chain reactions in America. One possible way of achieving this might be for you to entrust with this task a person who has your confidence and who could perhaps serve in an unofficial capacity. His task might comprise the following:

a) to approach Government Departments, keep them informed of the further development, and put forward recommendations for Government action, giving particular attention to the problem of securing a supply of uranium ore for the United States;

b) to speed up the experimental work, which is at present being carried on within the limits of the budgets of University laboratories, by providing funds, if such funds be required, through his contacts with private persons who are willing to make contributions for this cause, and perhaps also by obtaining the co-operation of industrial laboratories which have the necessary equipment.

I understand that Germany has actually stopped the sale of uranium from the Czechoslovakian mines which she has taken over. That she should have taken such early action might perhaps be understood on the ground that the son of the German Under-Secretary of State, von Weizsäcker, is attached to the Kaiser-Wilhelm-Institut in Berlin where some of the American work on uranium is now being repeated.

Yours very truly,

A. Einstein

(Albert Einstein)

Uranium Mining Legacy: Long-Term Stewardship Challenges

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Extended Abstract

Introduction

Former uranium mining and milling sites often cannot be remediated to residual levels of contamination that are below concern and cannot be released for unrestricted use. Hence, they have to remain under some form of institutional control. Residual contamination, mill tailings or low-grade ore, and other hazards may remain for several reasons after clean-up is complete: technical limitations, economic feasibility, worker health and safety issues, or prevention of collateral environmental impacts. An optimisation between social and economic cost on one side and level of protection on the other side has to be found. With long-lived radionuclides present, maintenance of institutional control is likely to be required for nearly unlimited periods of time.

The paper highlights the relevant issues and attempts to outline the conceptual, management, and technical problems of maintaining institutional control over possibly hundreds or even thousands of years.

What is Stewardship ?

A ‘steward' is a person entrusted with the management of another's property. In this sense, stewardship means taking care of legacy sites. More specifically, it refers to those instances or phases of sites, where active remediation has been completed, but some residual contamination is left, not allowing the free release of the site or land. There are a variety of views of what may be considered ‘long-term', but one could distinguish between stewardship strategies for the societal planning horizon, i.e. for one generation (approx. 30 years), and ‘archaeological' (i.e. 1000+ years) and ‘geological' (i.e. 10,000+ years) horizons. Essentially, stewardship is one phase of the life-cycle of a site or facility.

Typically, approaches to long-term stewardship share the following common elements: risk assessment, risk management, and risk communication. Stewardship encompasses activities directed at a particular site, but also has to maintain and develop the scientific understanding and technical know-how supporting the stewardship activities.

Selecting a steward is not an easy task, and the paper will examine some of the properties required by the respective organisation.

The ethical question

Long-term stewardship is one conclusion from the strife for sustainable development that demands that our current activities do not impair the ability of future generations to live in a way they choose. It is interesting to note that we are the first generation entertaining such ethical notions and that we are holding ourselves responsible for the detriments caused by past generations. Future generations will enjoy the accumulated benefits from all previous generations and one could argue that each generation should also carry some of the burden incurred by their predecessors. Hence, we could ask ourselves, whether we really need to find ‘permanent' solutions, or whether we should not be able to leave some legacy to future generations that are likely to command as much knowledge and capability as ours, and should be quite able to look after themselves.

Objectives and outcomes of remedial actions

Decision makers are faced with three fundamental choice for the intended remedial action. They must decide whether they will (1) leave the site undisturbed, while establishing a scheme for monitoring the evolution of the site; (2) contain or restrict the mobility of the radioactive contaminants; (3) remove the radioactive contaminants from the site, using an appropriate treatment and disposal scheme.

Remediation typically proceeds in an iterative fashion and end states emerge as the *de facto* result of multiple interim actions. The measurement of remediation success is still a developing science.

While, obviously, contaminant removal is a permanent solution for the site in question, any engineered solution to contain residues at some other place or to reduce exposures will only have a limited period of useful life. Natural forces will gradually degrade structures, such as barriers or covers. Stewardship and life-cycle management will have to take this into account.

Technological challenges

Long-term stewardship requirements pose a range of technological challenges. The ultimate goal are engineering solutions that obviate stewardship. There is a high degree of interaction between remediation technology or strategy deployed and the resulting stewardship needs. One has likely to accept that it will be impossible to find a really ‘permanent' solutions. Learning from natural processes, such as diagenesis and erosion behaviour, could be a way forward that could be summarised in the paradigm: Engineering with nature, not against it. Compatibility with the surrounding geology and geomorphology, thus achieving low relief energy (shallow slopes), and compatibility with surrounding eco-systems, including the hydrologic regime and vegetation system may be the answer.

Long-term stewardship strategies

Public interest may call for low stewardship needs, but there may be economic constraints to achieve this. In many Member States the current treasury rules and political domination of budgeting make it difficult to provide for the necessary long-term funding security of stewardship programmes. Alternative instruments, such as trusts and bonds, have been proposed.

Stakeholder participation in the development of stewardship plans is considered a key factor to success, as it has the potential to create ownership in the chosen solution.

Maintaining institutional control is the major issue and land-use planning and associated control instruments will be a major instrument. A variety of control instruments are being discussed, such as zoning regulations, deeds, and easements, but all assume that the system of governance will not change dramatically, that somebody will be there to enforce them. Alternative strategies, such as ‘taboos', ‘stigmas', or certain sustained uses, such as cemeteries are being discussed.

Effective stewardship requires certain skills and knowledge. Retaining these has proven difficult as mining and milling sites undergo the transition from operation to remediation to stewardship. Surprisingly also, the maturing market for environmental services has led to a decrease of skilled personnel.

Record Keeping and Information Management

There is a general notion that future generations will command more knowledge and capability than the present generation. However, as is evident from many archaeological ‘mysteries', such e.g. as the true purpose and design objectives of the Egyptian pyramids, and ‘lost' production technologies, such as e.g. the composition of certain medieval glass stains, some critical knowledge and insight, that is information, might and will get lost.

Records are an essential basis for a successful stewardship programme, but there is no consensus as to which records are really important and how they should and can be preserved. Different stakeholders will have different information needs that also will change over time.

While archiving and maintenance procedures for paper records are fairly well established and time proven, electronic records are a major concern. Many systems that were once considered high technology simply no longer exist and records stored in the respective format become virtually (intended pun) lost. Also most electronic records are physically much more vulnerable than paper records. No final solution to this problem has emerged yet.

Conclusion

The technological and organisational challenges that are posed by long-term stewardship programmes are reasonably well understood, but there are no satisfactory solutions to many of these problems. The present generation may have to be content to provide state-of-the-art technical solutions, accepting that future generations may have different judgements. Our engineered solutions may well become the future contaminated sites.















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Brussels Worhshop-Dec 2000

Brussels Worhshop-Dec 2000

M.Goldman, Brussels Mtg

Nice time at datcha family Stukin

Boat trip on Enisey river (Krasnoyarsk-26)

Boat trip on Enisey river pic nic

Boat used for the radioecological trip

Some participants to the Brussels Mtg (1998)

C.Vandecasteele;V.Popov;A.Iskra

R.Kirchmann-Ph.Bourdeau ,Brussels Mtg (1998)

Gembloux Mtg,June 2002

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