ATMOSPHERIC DISCHARGES FROM NUCLEAR FACILITIES DURING DECOMMISSIONING: GERMAN EXPERIENCES AND CONCEPTS

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Abstract

In Germany, a substantial amount of experience is available with planning, licensing and realization of decommissioning projects. In total, a number of 18 nuclear power plants including prototype facilities as well as 6 research reactors and 3 fuel cycle facilities have been shut down finally and are at different stages of decommissioning. Only recently the final „green field" stage of the Niederaichbach Nuclear Power Plant total dismantlement project has been achieved.

From the regulatory point of view, a survey of the decommissioning experience in Germany is presented highlighting the aspects of production and retention of airborne radioactivity. Nuclear air cleaning technology, discharge limits prescribed in licences and actual discharges are presented. As compared to operation, the composition of the discharged radioactivity is different as well as the off-gas discharge rate. In practically all cases, there is no significant amount of short-lived radionuclides. The discussion further includes lessons learned, for example inadvertant discharges of radionuclides expected not to be in the plants inventory. It is demonstrated that, as for operation of nuclear power plants, the limits prescribed in the Ordinance on Radiological Protection can be met using existing air cleaning technology. Optmization of protection results in public exposures substantially below the limits.

In the frame of the regulatory investigation programme a study has been conducted to assess the airborne radioactivity created during certain decommissioning activities like decontamination, segmentation and handling of contaminated or activated parts. The essential results of this study are presented, which are supposed to support planning for decommissioning. for LWRs, Co-60 and Cs-137 are expected to be the dominant radionuclides in airborne discharges.

I. Introduction

During the operational phase of nuclear installations radioactive substances are discharged to the environment in liquid and airborne form. These discharges are subject to licensing and to surveillance and control.

When operation is terminated the transition to decommissioning takes place. This implies in general that plant states are essentially modified, media no longer required are removed and new systems for decommissioning purposes installed. Along with the technical changes, regulatory conditions change. In many cases, a new license is required. As the dominant mechanisms of discharge are different from operation as well, discharge limits or more general criteria for discharges prescribed in the license for decommissioning are in most cases different from those valid for operation.

In this paper, information is provided on German experiences and insights with the assessment, control and regulation of airborne discharges from nuclear installations in the phase of decommissioning. The discussion comprises an overview on plants being shut down permanently, the mechanisms leading to airborne radioactivity inside the plant, technology of discharge control, discharge limits, actual discharges and further regulatory aspects.

II. Nuclear Power Plants in Germany

II.I Overview

The situation concerning the use of nuclear power in the Federal Republic of Germany (early 1995) is as follows [1]:

19 nuclear power plants with a capacity of 21,824 MWe gross (20,735 MWe net) are in operation,

1 nuclear power plant unit with 1,302 MWe (gross capacity) is shut down for an undefined period, following court order,

1 nuclear power plant unit with 806 MWe gross was out of operation in 1993 and 1994 for hot repair works and adaptations,

15 nuclear power plant units with 3,330 MWe (gross) in total are finally shut down, i.e. decommissioning has been started, applied for or planned,

for

6 nuclear power plant units, the construction and assembly works have been stopped or the application for construction and operation has been revoked.

II.II Plants finally shut-down in Germany

The decommissioning of the first nuclear power plant of the Federal Republic of Germany, **Versuchsatomkraftwerk Kahl (VAK Experimental Reactor)** was decided in 1985. The decommissioning concept provides the total dismantling of the plant. The first two decommissioning licences for decommissioning allow the dismantling of internal and external systems of the controlled area, the handling with contaminated tools and equipment and with low activity secondary radioactive waste. Furthermore, procedures and equipment for the dismounting, disassembling, and packaging of contaminated and activated parts of the facility were tested. On 25th September 1993, the third licence for decommissioning according to section 7 of the Atomic Energy Act (Atomgesetz, AtG) was issued. Action against this third licence was dismissed by the Higher Administrative Court of the State of Bavaria on 17th August 1994, which means that the disassembling of the reactor pressure vessel and the biological shield as well as the clearance for reuse or disposal, of non-hazardous substances which have been authorized as non-radioactive waste has been approved. It is planned to finish decommissioning, including site restoration, by the year 2000.

For the **Mehrzweckforschungsreaktor (MZFR Research Reactor)**, which was finally shut down in 1984, it was decided in 1989, after comparison of various decommissioning options, to perform the immediate and complete dismantling of the installation. The dismantling of the MZFR takes place stepwise, each step requiring a licence according to Atomic Energy Act. On the basis of the five issued decommissioning licences for MZFR, the decontamination of the heat removal system and the moderator system, the dismantling of equipment, such as equipment of the turbine building, electric installations, reactor auxiliary and supporting systems, water treatment system as well as the dismantling of the cooling tower was performed or initiated. The dismantling including restoration of the site should be finished by the year 2001 after altogether 6 partial steps. On 15th April 1994, the fourth, on 30th May 1994, the fifth partial licence for the decommissioning of the MZFR were issued, approving further dismantling works.

Rheinsberg Nuclear Power Plant (KKR) with a gross capacity of 70 MWe (reactor WWER) was finally shut down in 1990. Application for decommissing of the plant was made on 30th March 1992. The first licence for decommissioning was granted on 28th April 1995. Demolition work has been started.

Total dismantling is planned for **Gundremmingen Nuclear Power Plant Unit A (KRB-A)** which was shut down in 1977. Dismantling is taking place in several project phases which are based on the corresponding atomic energy law licences. Phase I, in which lowly contaminated components and the steam- and feedwater circuits in the turbine building were dismounted, was finished in 1989. In phase II, the disassembling of highlier contaminated reactor coolant contacted components and systems from the reactor building was performed. In phase III, the last dismantling step, the disassembling of the reactor pressure vessel and its equipment including the reactor shield, will be provided. Based on the licence for phase III issued on 12th August 1992, the disassembly of the reactor equipment was partly achieved in 1994 (e. g. 2 steam dryer units).

The **Jülich Atomversuchskraftwerk (AVR-Reactor, an experimental high temperature gas-cooled reactor with pebble bed)**, shut down in 1988, shall be transferred to safe enclosure after disassembly of equipment parts such as turbine, generator, condenser and condensate treatment system. The competent regulatory authority has approved the decommissioning concept and the safe enclosure in 1991. In the period from April to June 1992, the available 5,704 unused fresh fuel spheres balls were removed from the AVR-facility. The licence for decommissioning, unloading of the reactor core, dismantling and disassembling of equipment and safe enclosure of the AVR was issued on 9th March 1994.

The unloading of the spherical fuel elements out of the reactor into the central interim storage facility in the Jülich Research Centre was started.

The **Lingen Nuclear Power Plant (KWL)** was decommissioned in 1977 after 9 years of operation. Based on the licence of 21st November 1985, the facility was transferred to safe enclosure, which began in 1988. The safe enclosure involves the reactor building and the auxiliary building including the connecting building. All controlled areas situated outside this area were decontaminated, cancelled, and partly dismounted. The safe enclosure is monitored from the adjacent Emsland Nuclear Power Plant. After about 25 years of safe enclosure operation, it is planned to start the complete dismantling of the plant.

The **Heißdampfreaktor Großwelzheim (HDR, a nuclear superheated BWR)** finally shut down in 1971, was used after shut down for non-nuclear investigations and R&D on behavior of nuclear installations in the case of severe accidents. Decommissioning of the reactor was approved on 16th February 1983. The above-mentioned test programme was finished in 1991. Complete dismantling of the facility is planned until 1998. A second licence for decommissioning was granted on 29th December 1994 which also covers the disassembling of the reactor pressure vessel and parts of the primary circuit.

The **Niederaichbach Nuclear Power Plant (KKN, a heavy water moderated, gas cooled pressure tube reactor)**, which was decommissioned in 1974, is the first NPP in the Federal Republic of Germany being completely dismantled. The NPP was permanently shut down and transferred into safe enclosure in 1983, dismantling began in 1987. The dismantling of inactive and contaminated parts of the facility, except from activated areas near the core, was finished in 1990. The dismantling of the activated parts was finished at the end of 1993. Evidence taking measurements performed in the facility for clearance of the buildings were completed. The Ministry of State for Regional Development and Environmental Aspects of the State of Bavaria dismissed the KKN plant from the application of the Atomic Energy Act on 17th August 1994 and reported that the plant is released for conventional dismantling according to building law. Thus, the complete dismantling of a nuclear power plant was performed for the first time in Europe. The site restoration was celebrated on the 17th August 1995. The radioactive waste amounted to about 2% of the overall amount of decommissioning wastes.

The units 1 to 4 of the **Greifswald Nuclear Power Plant (KGR, WWER type, W-230 reactor)**, were shut down in 1990.

The dismantling of all five units will be achieved without preceding safe enclosure. An application for decommissioning and dismantling of plant units was submitted on 17th June 1994. The first licence for decommissioning was granted by 30th June 1995. Demolition of the facility has started.

Adjacent to the Greifswald site, an intermediate storage and waste treatment facility is under construction (Zwischenlager Nord, ZLN).

The **Kompakte Natriumgekühlte Kernreaktoranlage (KNK II, a sodium cooled Fast Breeder Research Reactor)** was finally shut down in 1991, after finishing its test programme. The shut-down was started with the removal of the fuel elements. The decommissioning concept provides for a stepwise disassembly up to the full dismantling of the plant. The first licence for decommissioning of the facility was granted on 26th August 1993, the second one on 30th May 1994. Since 26th May 1994, the nuclear fuel is completely removed . The third licence for decommissioning was granted on 21st February 1995 approving, among other points, the taking out of operation of the secondary coolant circuit as well as construction, operation and dismantling of a drumming station for the disposal of the secondary natrium. An application for granting the fourth licence for decommissioning has already been submitted.

The **Thorium Hochtemperaturreaktor (THTR-300, a gas cooled high temperature reactor)** was shut down for being decommissioned in 1989. For the facility a period of safe enclosure is planned. On 17th March 1992, the Federal Office for Radiation Protection granted the licence for the storage of irradiated fuel elements from THTR-300 in the **Ahaus Fuel Element Interim Storage Facility (BZA)**.

The first licence for decommissioning, unloading of the reactor core and dismantling of equipment components was issued on 22nd October 1993. Since then, the spherical fuel elements have continuously been removed from the core. The core content had fully been removed by the end of 1994. All 305 Castor containers with fuel elements have been stored in the Ahaus Interim Storage Facility until April 1995.

In 1995, it was decided to finally shut down the Würgassen NPP, a BWR with an electrical power of 670 MW, which had been in operation from 1971 to 1994. Planning for decommissioning is underway.

Obviously, there is a substantial amount of decommissioning experience in Germany. It covers all stages of decommissioning like immediate dismantlement, safe enclosure and dismantlement after safe enclosure and combinations of these basic patterns.

III. Decommissioning operations creating airborne radioactivity

III.I General

Before decommissioning commences, it is assumed that the nuclear fuel and other media not required during decommissioning are removed from the plant in the frame of the operating license. In real cases of decommissioning, however, this is not always fulfilled.

In a nuclear power plant, the remaining inventory of radioactivity is then given by activated RPV and RPV-internals, the activated part of the biological shield, contaminated systems and components and, finally, contaminated building structures.

Decommissioning operations can be roughly divided into dismantling, decontamination, handling and waste management. Each of these areas of activities consists of numerous subtasks characterized by technology and application. During practically all of them airborne radioactivity is created. Thermal cutting techniques like plasma arc cutting or oxy-acthylene cutting for example procuce significant amounts of aerosols. Practically relevant examples of decommissioning operations and aspects of airborne radioactivity are discussed in chapter 4.

III.II Study results

In a study, [2] this has been assessed on a generic basis for the case of the total dismantlement of a modern 1300 MWe PWR. Essential results obtained for the atmospheric discharges and the resulting exposure to the public are summarized in table 1. Even if the variability in generically postulated methods and data is taken into account, the central finding that public exposure is substantially below the prescribed limits given in the next chapter remains valid.

Table 1: Dismantlement of a modern 1300 MWe PWR;
estimates of atmospheric discharges and dose calculations as given in a generic study [2]

Radionuclide	Atmospherically discharged radioactivity (Bq)	Calculated effective dose (µSv)
Co-60	$5{,}4 \cdot 10^{6}$	$1{,}4 \cdot 10^{-2}$
CS-137	$1{,}7 \cdot 10^{7}$	$7{,}8 \cdot 10^{-2}$
Cs-134	10^{4}	$6{,}4 \cdot 10^{-5}$
Mn-54	10^{5}	$1{,}5 \cdot 10^{-5}$
Eu-152	10^{4}	$2{,}4 \cdot 10^{-6}$
Ni-59	10^{3}	$7{,}3 \cdot 10^{-9}$
Ni-63	10^{5}	$1{,}4 \cdot 10^{-6}$
Nb-94	10^{3}	$1 \cdot 10^{-5}$
Fe-55	$3 \cdot 10^{5}$	$4 \cdot 10^{-6}$

IV. Regulatory aspects

Accoraing to section 7 para 3 of the Atomic Energy Act the decommissioning of a nuclear installation as well the safe enclosure of a finally decommissioned installation or the dismantling of the installations or of parts thereof require a license.

The level of protection against exposure of the public from discharges in air or water is defined in section 45 of the Ordinance on Radiological Protection (ORP). The dose limits per calendar year are:

1.	Effective dose, partial body dose for gonads, uterus, red bone marrow	0.3 mSv
2.	Partial body dose for all organs and tissues unless specified in 1. or 3.	0.9 mSv
3.	Partial body dose for bone surface, skin	1.8 mSv

In section 28 of the ORP it is furthermore required to keep exposures even below these limits as low as practicable.

In the licensing procedure for decommissioning discharge limits are defined in compliance with these requirements.

V. Selected information on decommissioning projects

V.I General Remarks

For the retention of the airborne radioactive particulates, which are released in dismantling operations in shut down nuclear power plants, firstly the filter systems installed during power operation and still operated at present are available [(3)]. These are filter trains of the vent air filter system, the system exhaust air filter system and the subatmospheric pressure maintenance system which, for particulate removal, are provided with a prefilter, two category C particulate air filters, and one high-efficiency particulate air (HEPA) filter. The effective removal efficiencies of these filter trains with respect to the spectrum of particulates reaching them are well above the decontamination factor of 3×10^3 which is guaranteed solely for the new HEPA filter for the particles of the most penetrating size. On account of the series connection with the prefilter, the two category C particulate air filters, growing dust loading as well as the actual spectrum of particulates taken into account, total decontamination factors $> 10^6$ can be anticipated. So, these filter systems alone offer an effective protection against inadmissible emissions of radioactive particulates arising in decommissioning operations.

In the course of dismounting work additional measures are taken with the goal to support the air filter systems mentioned above and to further reduce discharges to the environment. These measures consist in

- keeping as low as possible the source term,
- retaining the released particulates by exhausting them where they are produced, and
- removing most of them in filter units installed in addition.

the goal pursued is not only to minimize the emission of radioactivity, but, at the same time, to avoid the spread of contaminations from dismounting work and, besides, to reduce internal exposure of the dismounting staff resulting from inhalation. Attaining these goals justifies additional expenditure which, in some cases, might be quite considerable.

The extent of additional measures required is quite different in the three most important dismantling phases, namely dismounting of the contaminated primary system, of the activated reactor pressure vessel with internals, and of the reinforced concrete of building structures, especially the biological shield. A great volume of coarse dust with low specific activities and easily to manage arises in dismantling concrete structures, whereas the most stringent requirements have to be met in dismantling the reactor pressure vessel and ist internals. In the latter case specific activities on the order of 10^8 Bq/g might have to be expected [(4)]. The requirements to be fulfilled in dismantling contaminated systems are on a level between the two cases mentioned above. It should be taken into account also that dismounting of the primary loops is often preceded by chemical decontamination as practiced for instance under the MZFR decommissioning project [(5)]. The primary objective pursued is to allow for manual dismounting with acceptable low radiation exposure of the staff. At the same time, smaller source terms will arise from dismounting work and hence a positive effect on the emissions to the atmosphere is achieved as well.

V.II Engineering Measures for Minimizing Radioactive Particulate Emissions

Emission control starts already with the minimization of the source term resulting from cutting operations. This means that to the extent feasible by the respective dismounting work cutting techniques will be applied which will produce no or only very few aerosols. Thus, preference will for instance be given to techniques such as mechanical cutting, shearing, and abrasive cutting. In cases where the application of thermal cutting techniques cannot be avoided, the relevant parameters will be optimized such that the least possible amount of aerosols is produced [(6)].

In order to remove the radioactive particulates released, the atmosphere has to be exhausted and filtered. In standard cases it will be sufficient to install a hood above the workstation. However, in this way only about 90% of the particulates are normally safely retained which is equivalent to a decontamintion factor of as little as 10. It is known that subsequent filtration produces much higher efficiencies. Consequently, in order to improve primary dust removal, the completest possible exhaust has to be aimed at. This is feasible by setting up a tent or housing around the workstation which is frequently practiced. This concept was implemented in a very sophisticated manner in the course of the meanwhile completed dismounting of the Niederaichbach Nuclear Power Plant (KKN). For remotely cutting up the pressurized tube reactor with its highly complex core structure an additional containment within the reactor containment was installed around the reactor tank [(7, 8)]. Existing structures of the building were used for construction. In this additional containment kept at a negative pressure with respect to the containment atmosphere directed air flow was maintained. The vent air was cleaned in a purpose-built filter bench, 30,000 m^3/h through-put, and then carried into the vent air system of the containment for secondary cleaning. This solution to the problem is represented schematically in Fig. 1. It allowed to avoid the very expensive dismounting under water and thus helped saving a considerable amount of costs. In this context, operations were facilitated by the fact that the maximum specific activations were on the order of 10^5 Bq/g only due to the short operation period of the plant.

By contrast, the highly activated reactor pressure vessel with internals will normally be dismounted under water using remotely handled tools [(9)]. This necessitates, as a rule, installation of a suitable water tank around the reactor pressure vessel. Water in that case does not only serve to remove the aerosols generated in the cutting operations but it acts also as a shield protecting the operating staff. Typical experiments have made evident that 10^{-3} to 10^{-4} of the kerf material removed in the cutting operations is released as aerosols above the water surface [(10, 11)]. As a rule, these aerosols will be exhausted above the water surface and removed in particulate air filters as for instance practiced in the course of decommissioning of the Gundremmingen Nuclear Power Plant, Unit A [(12)].

A great variety of commercial filter techniques are suited for removal of the dusts and aerosols, respectively, released in cutting up operations. Experience accumulated in the recenlty completed demolition of the Niederaichbach Nuclear Power Plant proved that cleanable particulate air filters should be best suited for this purpose. They comprise two series-connected particulate air filters operated at reduced volume flow rate of approx. 1000 m^3/h per standard sized filter element. The first filter is cleaned by cyclic backflushing whereas the second serves as a safety device. Since the late seventies the successful application of particulate air filters provided with cleanup device has been reported in Germany [(13, 14)]. Cleanable particulate air filter systems are available on the market. Work on their improvement is under way [(15, 16)].

It is generally known that the outstanding feature of such a filter combination are extremely high decontamination factors. Besides, very great amounts of dust can be removed. Consequently, the operating costs are justified which are caused mainly by filter changeout and disposal of the loaded filters [(17)]. Finally, cleanable particulate air filter systems are suited to remove all particles of the spectrum encountered in decommissioning work.

During decommissioning of KKN several small mobile particulate air filter systems were used as well as the already mentioned stationary system with a throughput of 30,000 m^3/h. It was possible by these additional filter devices to keep extremely low the monthly emissions of particulate ß-radioactivity during the whole period of decommissioning from July 1988 until June 1994. Figure 2 shows the respective values of releases [(18)]. As a rule, they range from 10^3 to 5×10^4 Bq, with the maximum values measured during the phase of dismounting of the activated pressurized tube reactor. The radiation burdens resulting from these emissions at the point of maximum deposition are negligible compared with exposure to natural radiation, a finding that is consistent with the general estimate provided in chapter 3.2. This experience shows that particulate removal during dismounting of nuclear power plants can be very effectively controlled with the engineering tools presently available.

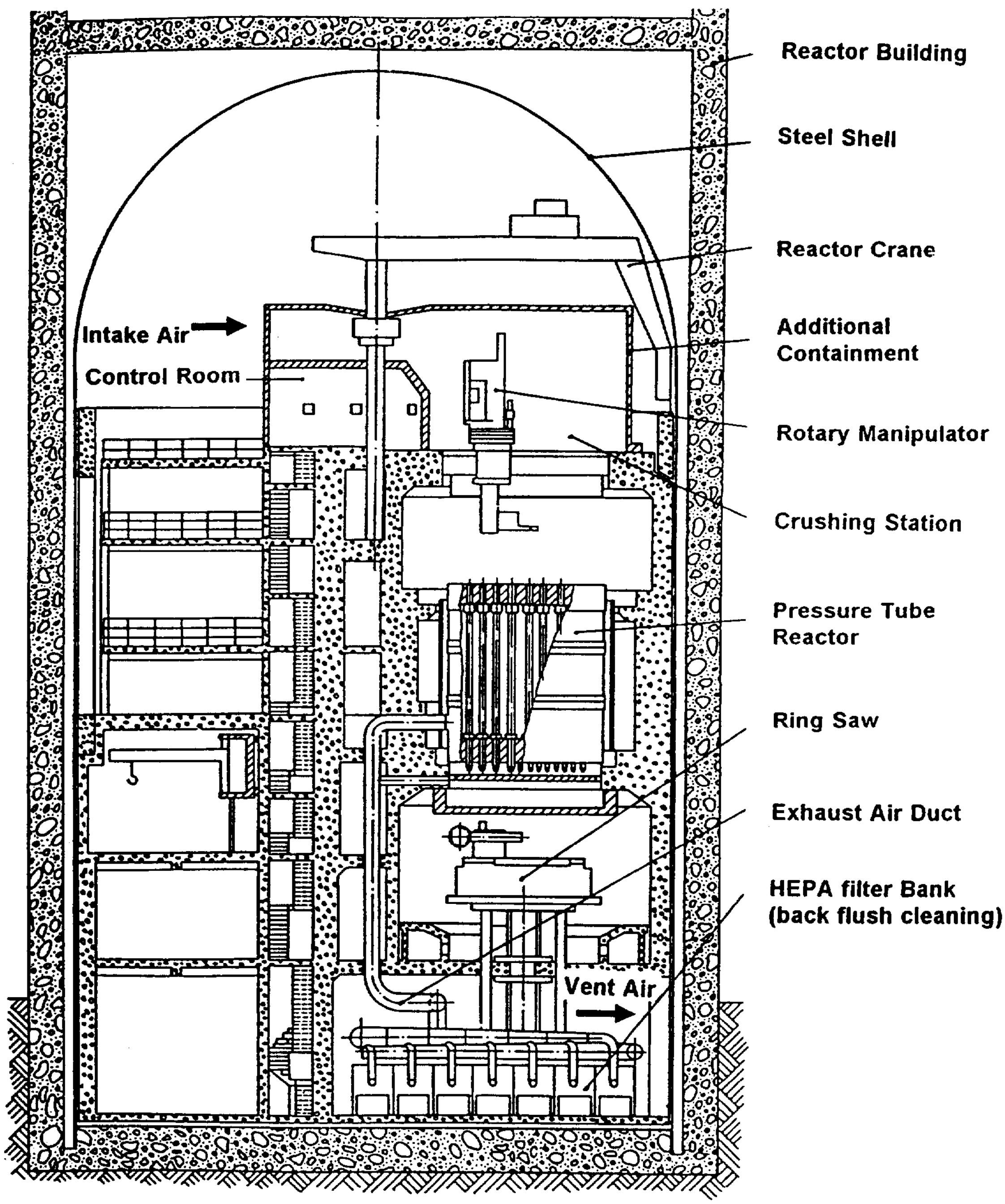

Fig. 1: Additional containment for the dismantling of the activated pressure tube reactor of KKN.

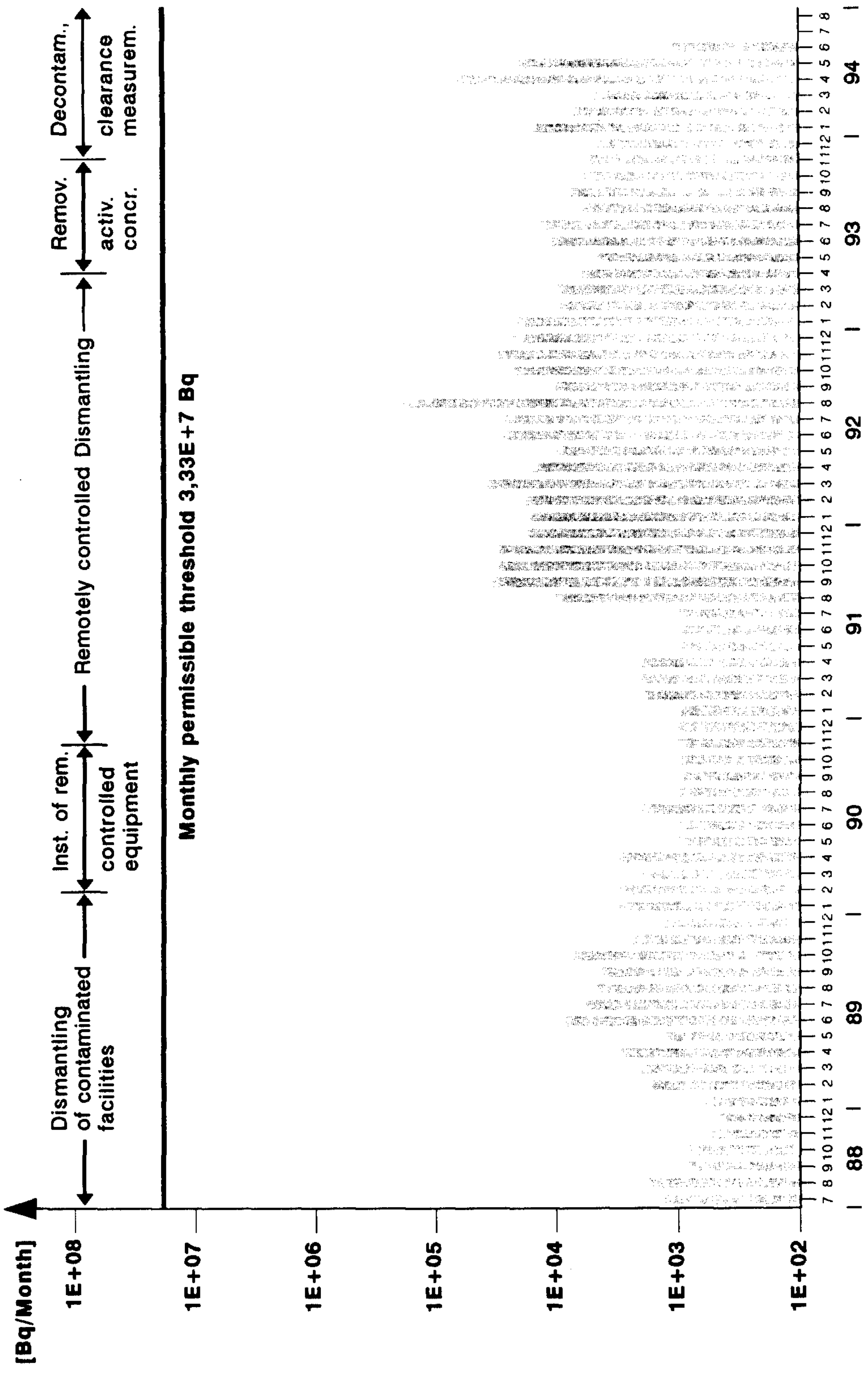

Fig. 2: Monthly emissions of particulate radioactivity during the decommissioning of KKN.

VI. Summary and conclusions

Atmospheric discharges from nuclear facilities finally shut-down are subject to regulation and control as during operation.

The nature of the discharges during decommissioning are in general different. Short-lived radionuclides have decayed and media (nuclear fuel, coolant, operational waste) no longer required are removed from the site and treated or stored elsewhere. In general, long-lived radionuclides in aerosol form are the most relevant group governing the atmospheric discharges during decomissioning.

The processes that lead to the formation of airborne radioactivity during decommissioning operations are quite well known. Generally speaking, they are segmentation, decontamination, handling and conditioning of radioactive parts and components. Thermal cutting of metal components is of special relevance.

As confirmed by the substantial amount of decommissioning experience in Germany, the technology is available for control and retention of airborne radionuclides. It generally consists of a combination of in-situ exhaust with prefiltering and aerosol filters for the overall atmospheric discharges.

Experience shows that in actual decommissioning projects the legal requirements of observing dose limits and keeping exposures below these limits as low as practicable are met. Public exposure due to atmospheric discharges is negligable. Theoretical studies demonstrate that this can be achieved as well in the substantial amount of decommissioning work that will be faced in the decades ahead, when the modern nuclear power plants approach the end of their projected life time and might be taken out of service.

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DISCUSSION

BERGMAN: What is the experience with the cleanable HEPA filter? Has there been any damage to the media? Is the media the reinforced type?

WILHELM: Often cleanable HEPA filters are used in Germany without prefilters to remove industrial dust in the g/m^3 range. On the downstream side the medium of the cleanable HEPA filters is reinforced with a glass fiber web, such as the medium of the Lydair 3255 LW 1, or with a web from organic fibers, for example of polycarbonate fibers. It is also important that the pleats be round at the edge. We tried cleanable HEPA filters in different factories including the production of cement. They operated well and had long services lives. Using optimized HEPA fillers and cleaning methods, even the loss of removal efficeincy down to around 99% after large numbers of cleaning cycles could be avoided

BERGMAN: A couple of conferences ago we presented a comparison of cleanable steel HEPA filters and standard glass HEPA filters. With a standard very gentle reverse pulse, we had dozens and dozens of holes; all the bottom pleats were blown out. Is the reason your filter survives the reverse air blast because it is a very, very slow and gentle reverse flow?

WILHELM: The method and the flow velocity during loading and cleaning of the HEPA filter are optimized. The flow velocity is not very slow during the reverse air blast. The larger particles should not be removed upstream of the HEPA filters because they produce the removable filter cake on the surface of the medium and thus prevent the very small particles from penetrating deeper into the medium. Small particles, deposited in the depth of the medium, normally will not cause the formation of a removable filter cake. Therefore, also the filtration speed should be limited. With a loading of particles only with diameters around $1 \mu m$ we did not have good results with cleaning cycles.

FUKASAWA: Which nuclides were easy to be discharged to the atmosphere? Did you estimate the discharged ratio i.e., the discharged radionuclides/total amount of the facility?

WILHELM: According to the paper Co-60 and Cs-137 are the most important radionuclides for airborne discharge during decommissioning. The data for the ratio of discharged radionuclides in relation to the inventory are not available.