# Occupational Exposure in Radioactive Waste Management in Germany

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## 1 INTRODUCTION

On the basis of a relevant data collection in organisations dealing with the disposal of non-heat-generating radioactive waste (nuclear power plants, waste management companies, industry) collective dose values were determined for the essential waste streams, considering the arising of the waste at the waste producer, conditioning up to interim storage of the waste packages. The assessment is based on a study carried out in 1996 by TÜV Nord e.V. for the Federal Office for Radiation Protection (BfS). The results of the study at that time led to a holistic evaluation of the collective dose [1, 2] for this waste management area.

The data collected at that time referred to the period from 1992 to 1995. After more than 10 years, the results were revised through the investigation referring to the period from 2002 to 2006 which is available now. The results are dealt with in chapters 3 and 4.

According to the Directive on Radiation Protection in Maintenance and Repair Work in Nuclear Power Plants (Richtlinie zum Strahlenschutz bei Instandhaltungs- und Wartungsarbeiten in Kernkraftwerken (IWRS II)) [3] it is necessary from the radiation protection point of view to make a detailed planning of activities above a collective dose of 25 mSv. According to IWRS II, waste management campaigns are also considered to be such practices and with respect to the detailed planning they have to be considered by taking into account external activities. The purpose of the following consideration is to assist in deciding whether a detailed planning in accordance with IWRS II can be required for certain waste streams. If they can be recognised, optimisation potentials are identified and pointed out.

## 2 RESULTS OF THE STUDY FROM 1992 TO 1995

The objective of the study from 1992 to 1995 was a waste stream specific holistic evaluation of the collective dose in non-heat-generating radioactive waste management. This evaluation was based on a data collection carried out by TÜV Nord e.V. (now TÜV Nord SysTec) at the waste producers, conditioning companies, research centres and operators of interim storage facilities and repositories [4]. Enquired were the collective dose and the amount of waste for individual campaigns. The investigation was carried out for the following waste streams:

Nuclear field
- Mixed waste (combustible and compactable)
- Concentrates
- Filter materials
- Core components
- Scrap

Non-nuclear field
- Medicine
- Research
- Sources

The aforementioned waste streams show a degree of coverage of more than 90 %. Mean annual amounts of waste were determined for the individual waste streams on the basis of the data provided by the operators and various other sources and the evaluations of the non-official dosimeters. For the disposal of radioactive waste from nuclear power plants the results of the data collection at that time,

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based on a medium-size facility, were presented in Table 8 [2], together with the results of the new study.

Amount-specific collective dose values were determined for the interim storage and disposal of radioactive waste and for disposal in the areas of medicine, research and industry. These values are given in Table 1.

***Table 1: Amount-specific collective doses***

| | |
|---|---|
| Interim storage | approx. 0.025 mSv/container |
| Disposal | 0.003 mSv/Mg |
| Medicine | 0.01 $mSv/m^3$ |
| Research | 0.04 $mSv/m^3$ |
| Sources | 0.006 mSv/source |

On the basis of the data then available, the following conclusions could be drawn:

- The collective dose obtained when sorting mixed waste especially depended on the local conditions. It was clearly lower in facilities equipped with special sorting tables.
- External conditioning (super-compaction of mixed waste, drying of concentrates) did not imply an increase in collective dose, compared with conditioning on site.
- Compared with conditioning, interim storage and disposal of radioactive waste only provided a negligible contribution to the collective dose.
- A comparison of reactor types showed that a boiling water reactor (BWR) produced clearly more waste, the dose having been nearly twice as high as that of a pressurised water reactor (PWR). This was especially caused by the disassembling of the fuel element boxes on site at that time.

## 3 RESULTS OF THE CURRENT INVESTIGATION FOR NUCLEAR POWER PLANTS

As in the study from 1992 to 1995, collective dose values for the waste campaigns carried out and the respective waste arisings were enquired at the operators of nuclear power plants and conditioners within the scope of a data collection. In the following, results for the individual waste streams are shown and compared with the results of the preceding study. The waste arisings in both studies are mean values referring to plants in power operation. The waste arisings resulting from the dismantling of nuclear power plants and the associated doses of the staff were not considered in the scope of this investigation.

Since in the period under consideration from 2002 to 2006 no repository was available no collective dose is given for disposal. This was different in the preceding study when radioactive waste was disposed of in the Morsleben repository (ERAM). This situation will only change when the Konrad repository will be taken into operation (from approx. 2013). Compared with the values determined for the ERAM, a dose reduction can be expected here for the same waste volume. This is because larger waste packages with a higher activity but the same permissible surface dose rate will be disposed of in the Konrad repository.

### 3.1 Mixed waste, combustible

For the waste stream „mixed waste, combustible“, the mean annual amount has been considered individually for both reactor types. Due to the larger controlled area the amount of waste in boiling water reactors is usually higher than in pressurised water reactors. While in the earlier study no differentiation was made between reactor types with respect to waste arising, the amount of waste produced was now determined to be 21 Mg/a for boiling water reactors and 13 Mg/a for pressurised water reactors. It is thus clearly lower than it was ten years ago with 25 Mg/a. This is in correspondence with the waste producers´ efforts to further reduce the waste arisings.

Sorting in nuclear power plants still provides the major contribution to occupational radiation exposure. In this area there are clear options for optimising especially the use of sorting tables designed for this purpose which are equipped with lead glass windows and a shielded area for the storage of waste in the sorting area. The peak dose value was reached by a plant which has meanwhile taken new sorting facilities into operation. There, a clear reduction of the collective dose is expected for the future.

In the area of external conditioning, too, the collective dose could be reduced through further process optimisation. In contrast, according to our recent investigations, the collective dose in interim storage has increased, since meanwhile work on follow-up qualification and repair of containers has increased because of long lasting interim storage.

Altogether, the collective dose determined for the waste stream „mixed waste, combustible“ has decreased compared with the earlier study, which is especially due to the reduced amount of waste. The corresponding figures are given in Table 2.

***Table 2: Waste stream specific collective dose for ”mixed waste, combustible“ referring to a mean annual amount***

| **Period** | **2002-2006** | **1992-1995** |
|---|---:|---:|
| **PWR** | | |
| Annual amount | 13 Mg | 25 Mg |
| Sorting in NPP<br>(depending on sorting conditions) | 0.4 – 3.5 mSv/a | 0.4 - 8 mSv/a |
| Incineration (Studsvik) | 0.5 mSv/a | 1.2 mSv/a |
| Super-compaction | 0.1 mSv/a | 0.5 mSv/a |
| Interim storage / follow-up qualification | 0.05 mSv/a | 0.02 mSv/a |
| Disposal | – | 0.01 mSv/a |
| **Total** | **1.0 – 4.1 mSv/a** | **2 - 10 mSv/a** |
| **BWR** | | |
| Annual amount | 21 Mg | 25 Mg |
| Sorting in NPP<br>(depending on sorting conditions) | 0.4 – 5.7 mSv/a | 0.4 - 8 mSv/a |
| Incineration (Studsvik) | 0.8 mSv/a | 1.2 mSv/a |
| Super-compaction | 0.2 mSv/a | 0.5 mSv/a |
| Interim storage / follow-up qualification | 0.05 mSv/a | 0.02 mSv/a |
| Disposal | – | 0.01 mSv/a |
| **Total** | **1.4 – 6.7 mSv/a** | **2 - 10 mSv/a** |

### 3.2 Mixed waste, compactable

The same statements as for combustible mixed waste apply to the waste stream „mixed waste, compressible". The collective dose for compaction and interim storage is higher referring to the same amount of waste. This can be attributed to the fact that more waste packages are produced and must be handled, compared with incineration which is associated with a clear loss of mass. Figures are given in Table 3.

***Table 3: Waste stream specific collective dose for "mixed waste, compressible" referring to a mean annual amount***

| Period | 2002-2006 | 1992-1995 |
|---|---|---|
| **PWR and BWR** | | |
| Annual amount | 25 Mg | 25 Mg |
| Sorting in NPP<br>(depending on sorting conditions) | 0.4 - 7 mSv/a | 0.4 - 8 mSv/a |
| Compaction (external conditioning) | 3.1 mSv/a | 5 mSv/a |
| Interim storage / follow-up qualification | 0.1 mSv/a | 0.05 mSv/a |
| Disposal | – | 0.07 mSv/a |
| **Total** | **3.6 - 10 mSv/a** | **5.5 - 13 mSv/a** |

### 3.3 Filter materials (resins)

Resins from PWR plants are meanwhile partially conditioned together with evaporator concentrates. In the following, this subset is only taken into account in the concentrates. The annual volume of 1 m3 given in Table 4 exclusively refers to resins without evaporator concentrates having been added. Compared with the earlier period it can clearly be stated that the dose has increased. However, this increase can currently not be clearly attributed to any cause. This would require further considerations.

For the boiling water reactor the annual waste volumes in both periods under investigation are comparable. Measures to reduce the collective dose, e. g. through optimising the loading concept, are effective, however, the increased effort of proving that the waste packages are free of contamination reduces what has been saved in terms of dose.

Altogether no significant changes compared to earlier times result for both reactor types. Figures are given in Table 4.

### 3.4 Concentrates

Compared with the earlier investigations, there have been no changes with regard to the conditioning of concentrates in boiling water reactors. Conditioning is here generally remote-controlled and provokes only a negligible collective dose. The following comments therefore exclusively refer to boiling water reactors.

As a result of the more recent investigation, the collective dose arising in this waste stream in pressurised water reactors has been differentiated with respect to conditioning with the help of mobile devices and stationary devices on site. Since conditioning for PWR is mainly remote-controlled, a considerable portion of the collective dose can be allotted to the setting up and dismantling of mobile devices. From the radiation protection point of view the use of mobile devices is therefore disadvantageous compared with the one-time setting up of a stationary device, in the course of which the control station can be erected too with optimised doses.

The values for interim storage also include collective dose values for follow-up qualification of containers. Figures are given in Table 5.

***Table 4: Waste stream specific collective dose for filter materials (resins) referring to a mean annual amount***

| Period | 2002-2006 | 1992-1995 |
|---|---|---|
| **PWR** | | |
| Annual amount | approx. 1 $m^3$ | approx. 2 $m^3$ |
| Dry pumping and dewatering with mobile devices in NPP | 1.1 - 2 mSv/a | < 1 mSv/a |
| Interim storage<br>1 cast-iron container per year | 0.04 mSv/a | 0.05 mSv/a |
| **Total** | **1.1 - 2 mSv/a** | **Approx. 1 mSv/a** |
| **BWR** | | |
| Annual amount | approx. 22 $m^3$ | approx. 24 $m^3$ |
| Dry pumping and dewatering with mobile devices in NPP | 3.5 – 7.5 mSv/a | 7.2 mSv/a |
| Interim storage<br>8 cast-iron containers per year | 0.3 mSv/a | 0.05 mSv/a |
| **Total** | **3.8 – 7.8 mSv/a** | **7.25 mSv/a** |

***Table 5: Waste stream specific collective dose for concentrates referring to a mean annual amount for PWR***

| Period | 2002-2006 | 1992-1995 |
|---|---|---|
| **PWR** | | |
| Annual amount | 17 $m^3$ | 25 $m^3$ |
| Drying<br>(a) With mobile devices in NPP<br>(b) With stationary devices in NPP | <br>4 mSv/a<br>1.5 mSv/a | <br>2.5 mSv/a |
| Interim storage (cast-iron containers) in NPP | 0.9 mSv/a | 0.1 mSv/a |
| Disposal | | 0.012 mSv/a |
| **Total** | **2.5 - 5 mSv/a** | **2.6 mSv/a** |

### 3.5 Core components

Practically unchanged dose values result from the disposal of core components of a pressurised water reactor. Compared with the earlier study, waste volumes to be disposed of have not changed either. In both plant types approximately 1 to 2 cast-iron containers arise per year.

In boiling water reactors, on the other hand, a very clear reduction of the collective dose has been achieved by changing the disposal of fuel element boxes. In the period under investigation of the earlier study the fuel element boxes were initially conditioned in the fuel pool. A considerable collective dose resulted from dissecting and subsequently packing the fuel element boxes into cast-iron containers [1, 2]. Until 2003, the fuel elements were then delivered abroad for reprocessing, so that it was not necessary to condition the waste in Germany. Meanwhile the fuel element boxes are directly stored in the transport and storage containers (e. g. of the CASTOR® type), together with the spent fuel elements.

Figures are given in Table 6.

***Table 6: Waste stream specific collective dose for core components referring to a mean annual amount***

| **Period** | **2002-2006** | **1992-1995** |
|---|---|---|
| **PWR and BWR** | | |
| Annual amount | 1 to 2 cast-iron containers | |
| Direct packing into cast-iron containers in the fuel pool | approx. 1.8 mSv/a | 1.5 mSv/a |
| Interim storage | 0.06 mSv/a | 0.05 mSv/a |
| **Total** | **1.9 mSv/a** | **1.6 mSv/a** |
| **For BWR additionally** | | |
| Dissecting of fuel element boxes, followed by packing into cast-iron containers | dropped | 20 mSv/a |
| **Total** | – | **21.6 mSv/a** |

### 3.6 Scrap

As regards the disposal of scrap it has to be pointed out that the annual amount of waste was clearly reduced because of decontamination efforts on site. Thus, a clearly larger amount of waste can be cleared after decontamination than was the case previously. The major reason for this is the standardised regulation relating to clearance set out in the provisions of the Radiation Protection Ordinance after its amendment of 2001.

Figures are given in Table 7.

***Table 7: Waste stream specific collective dose for scrap referring to a mean annual amount***

| **Period** | **2002-2006** | **1992-1995** |
|---|---|---|
| **PWR and BWR** | | |
| Annual amount | 6 Mg | 47 Mg |
| Dissecting, sorting, followed by super-compaction and packing or utilisation | 0.1 mSv/a | 0.5 – 1.9 mSv/a |

# 4 COMPARISON OF RESULTS OF BOTH STUDIES

## 4.1 Annual collective dose in nuclear power plants

The following conclusions can be drawn from the comparison of the two periods under investigation from 1992 to 1995 and from 2002 to 2006:

- In the area of disposal the collective dose has clearly been reduced. This is mainly due to the fact that fuel element boxes were no more disposed of in boiling water reactors.
- The collective dose associated with the disposal of mixed waste has altogether decreased, too. The values associated with the other disposal paths have practically remained unchanged on a low level.
- With respect to the overall radiation exposure associated with disposal there are no more differences between the two reactor types, the boiling water reactor performed clearly worse than the pressurised water reactor did in the earlier study. There are only differences in the disposal of concentrates and filter materials. In the first case a higher collective dose is produced in the PWR and in the second case in the BWR.
- Optimisation potentials are still considered to exist in the area of sorting of mixed waste. However, it should be pointed out that the vast majority of the plants are already equipped with sorting devices and that thus a reduction of radiation exposure could be achieved.
- Since mobile devices have to be set up and dismantled, the conditioning of evaporator concentrates with the help of mobile facilities is disadvantageous from the radiation protection point of view. Lower collective doses are produced when using stationary devices in a power plant.
- In the following it is shown that the collective dose in the field of disposal continues to be low, as compared to the overall occupational radiation exposure arising in Germany.

Table 8 shows a comparison of results of the current study (light fields) with the earlier dose values and waste arisings (dark fields). If one applies the now determined radiation exposures – as was done in the earlier study – to altogether 19 plants, this results in a collective dose of approximately 0.4 Sv/a for the area of nuclear power plant disposal. Although in the period of consideration from 2002 to 2006 the Obrigheim and Stade NPPs already stopped their power operation, the number of 19 plants has been retained, since operational waste was produced there in the following years with a similar amount as under power operation.

In the period under consideration from 2002 to 2006 the mean overall collective dose produced in the operation of German nuclear power plants was approximately 20 Sv and the overall occupational radiation exposure in Germany approximately 44 Sv [5]. On the basis of the data given in the BfS Radiation Protection Register, approximately 0.8 Sv on average arose in the same period in the field of radioactive waste disposal in the Federal Republic of Germany.

However, these figures cannot be directly compared with the data collected here, since in contrast to this study, the official dose is registered in the Radiation Protection Register. Especially for activities with relatively low individual doses, such as interim storage (not including conditioning measures), the official dose can be clearly below the dose determined with non-official (internal) dosimeters, since with official dosimeters only radiation exposures above a threshold of 0.1 mSv in the respective period under consideration are counted. This was also the case in the operation of the Morsleben repository. There, the operational dose determined in the disposal period from 1994 to 1998 was by factor of 2 higher than the official dose.

Yet, the value of 0.4 Sv determined here for disposal provides a consistent picture as compared with the Radiation Protection Register with 0.8 Sv, even if the latter may be a little bit higher due to the effects described above. The difference mainly corresponds with the radiation exposure as a result of activities in the area of disposal in research institutions and the dismantling of nuclear facilities.

*Table 8: Waste stream specific collective doses for mean annual amounts*

| | PWR | | BWR | |
|---|---|---|---|---|
| **Waste stream** | **Annual amount** | **Collective dose** | **Annual amount** | **Collective dose** |
| Mixed waste, combustible | 13 Mg | 1 - 4 mSv | 21 Mg | 1.4 – 6.7 mSv |
| | 25 Mg | 2 - 10 mSv | 25 Mg | 2 - 10 mSv |
| Mixed waste, compactable | 25 Mg | 3.6 - 10 mSv | 25 Mg | 3.6 - 10 mSv |
| | 25 Mg | 5.5 - 13 mSv | 25 Mg | 5.5 - 13 mSv |
| Core components | 1-2 container[1] | 1.9 mSv | 1-2 container[1] | 1.9 mSv |
| | 0.3 Mg | 1.6 mSv | 4 Mg | 20 mSv |
| Scrap | 6 Mg | 0.1 mSv | 6 Mg | 0.1 mSv |
| | 47 Mg | 0.5 – 1.9 mSv | 47 Mg | 0.5 – 1.9 mSv |
| Concentrates | 17 $m^3$ | 2.5 - 5 mSv | 35 $m^3$ | < 0.1 mSv |
| | 25 $m^3$ | 2.6 mSv | 35 $m^3$ | < 0.1 mSv |
| Filter materials (resins) | 1 $m^3$ | 1.1-2 mSv | 22 $m^3$ | 3.8 – 7.8 mSv |
| | 2 $m^3$ | approx. 1 mSv | 24 $m^3$ | 7.25 mSv |
| Total | | 11 - 27 mSv | | 11 - 28 mSv |
| | | 13 - 30 mSv | | 35 - 52 mSv |
| • Mixed waste/metals | 60 Mg | | 60 Mg | |
| | 97 Mg | | 101 Mg | |
| • Concentrates/resins | 18 $m^3$ | | 57 $m^3$ | |
| | 27 $m^3$ | | 59 $m^3$ | |

Light fields: Results of the current study (2002 to 2006)
Dark fields: Results of the earlier study (1992 to 1995)
[1] cast-iron containers

## 4.2 Disposal in the field of medicine, research and industry

For radioactive waste disposal in the fields of medicine, research and industry the results of the earlier study were only confirmed in an exemplary way. It has shown that the application of conditioning methods in this area has changed.

In research institutions, for instance, no more waste from nuclear power plants is conditioned as was the case in the past. Instead, the conditioning of own waste from the decommissioning of research facilities and the follow-up qualification of waste with respect to later disposal in the Konrad repository are increasingly added. Scrapping of MAW has been added, too. With 150 mSv/a, despite of this expansion of conditioning, the collective dose has remained the same in both periods under investigation in the considered facility which plays a central role for the large research institutions in Germany.

With respect to the disposal of sources from the fields of industry and medicine it should be pointed out that, compared with the earlier study, the collective dose in the facility under consideration has clearly been reduced from about 80 mSv/a to approx. 25 mSv/a. On the one hand, the decrease in dose was due to the fact that the conditioning measures were remodelled, or, respectively, that orders were cut back or the order situation had altered.

Even though the data collected by us now do not have the degree of coverage of the earlier study, it can be estimated that a collective dose of approx. 0.3 Sv/a arises in the disposal of waste from medicine, research and industry.

## 5 Summary

Due to the different data sets (official and non-official dosimeters), it is difficult to evaluate the collected data and to compare them with the data from the Radiation Protection Register. Discrepancies might be based on the allocation of the doses to individual activities in the power plants. Nonetheless, at least the aforementioned qualitative conclusions can be drawn.

Thus, occupational radiation exposure has generally declined. In particular it should be pointed out that the discontinuation of conditioning measures for the disposal of fuel element boxes led to a clear reduction. The area of disposal still contributes less than 2 % to the overall occupational radiation exposure in Germany.

Meanwhile the conditioning activities have been included in the IWRS II Directive [3] and have been subjected to a collective dose value of 25 mSv with respect to planning a waste campaign. On the basis of the available data for campaigns to be carried out annually, this criterion is usually not achieved, so that a plan according to the special radiation protection procedure is not necessary.

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