
Decommissioning and dismantling of nuclear power plants: Radiation protection experience in Germany

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Abstract: The data presented give an overview on the radiation exposure of occupationally exposed personnel of nuclear power plants under decommissioning and dismantling in Germany. As an evaluation of the data collected the paper in its first part presents a summary of the exposure of utility and contracted personnel. The second part of the paper focuses on a more detailed view concentrating on special phases of decommissioning considering also the decommissioning and dismantling philosophy applied in different plants.

1. INTRODUCTION

Since many years GRS on behalf of the BMU operates a data base on the exposure of occupationally exposed personnel in operating nuclear power plants. As a response to the increasing importance of decommissioning in Germany, GRS in recent years has started to compile similar information and data on decommissioning activities in nuclear power plants and on decommissioning practices. In this way the experience present at GRS in the evaluation of radiological data for operating plants is used to collect and evaluate respective data for plants under decommissioning. With the support of the utilities, data are collected on a yearly bases. Joining the data available from operation and the new data on decommissioning, the new database includes information on collective exposure of the personnel since the commissioning of the plants [1].

To understand radiation protection issues and efforts of different plants, there is a need for detailed information on the exposure of the personnel during the different steps of decommissioning. As the data base formed presently is still a starting activity, the degree of detail still may be improved in the future, and it is expected that participation of the operators of the decommissioned plants in the ISOE project (ISOE: Information System on Occupational Exposures) will also give some benefit to this project and will improve the data collection.

2. OVERVIEW ON THE RADIATION EXPOSURE OF THE PERSONNEL IN NUCLEAR POWER PLANTS UNDER DECOMMISSIONING IN GERMANY

2.1 Nuclear Power Plants under Decommissioning

In Germany 14 reactor units of different types and electricity generation capacities are under different stages of decommissioning on 10 different sites. This concerns 2 High Temperature Reactors (AVR, THTR), one Fast Sodium Cooled Reactor (KNK-II), 7 Pressure Water Reactors (KGR-1 to KGR-5, KKR, MZFR) and 4 Boiling Water Reactors (KRB-A, KWL, KWW, VAK). An overview on the plants with information on the electrical capacity, dates of first criticality, shut down, application for and licensing of decommissioning and with the status of the decommissioning are given as table 1 in the appendix of this paper.

2.2 Summary of radiological data of the plants under decommissioning

The information supplied by the utilities is integrated into the GRS data base. This allows different evaluations and presentations of the data. For the plants under decommissioning listed in table 1 the evolution of the radiation exposure of personnel can be derived, e.g. presenting the

- collective dose per year of the utility, contracted and total personnel,
- the number of the utility and contracted personnel employed and
- mean dose values for the exposure of utility and contracted personnel.

In the presentation the date of utility's decision to decommission was chosen as the reference point for the consideration of data in the graphs and tables. This means that the time span from shutdown to this reference point is still considered as part of the operating phase. Due to this reason the graph showing the yearly trend of the collective dose of the decommissioned plants (fig. 1) starts 1979 with the date of decision to decommission the Lingen NPP (KWL). It should be noted that the plants Niederaichbach (KKN) and Karlstein (HDR) already decommissioned are not included in the GRS data base because it would have been very difficult to get information on operation and dismantling of these plants now.

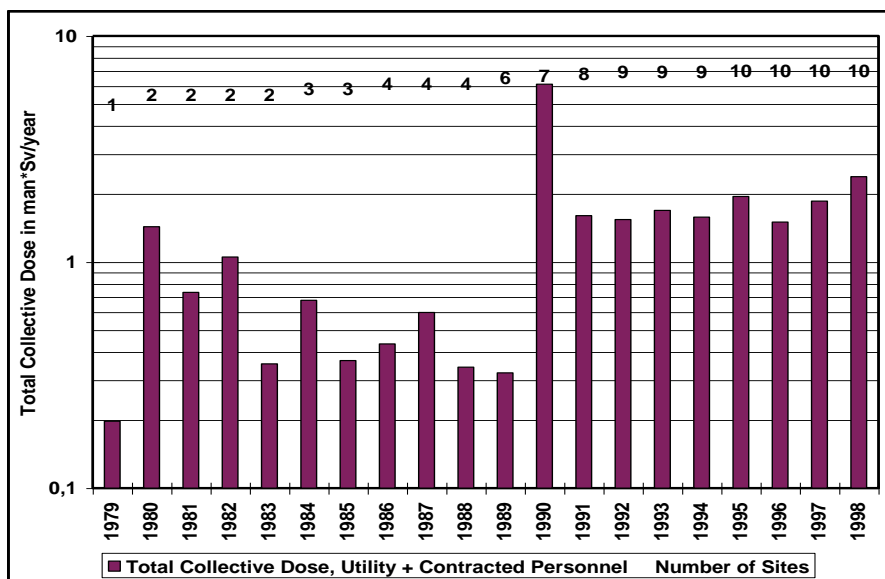


Fig.1: Total collective dose of the German plants under decommissioning (Considering the time span starting with the utility's decision to decommission)

In fig. 1 the trend of the total collective dose per year and the number of plants decided to be decommissioned are shown. Up to 1983 the plants Lingen (KWL) and Gundremmingen Unit A (KRB-A) were the only plants under decommissioning. During this time span the total collective dose per year was dominated by the collective dose of Gundremmingen Unit A.

In 1984 and 1986 the increase of the total collective dose is influenced by the start of decommissioning of the Mehrzweckforschungsreaktor (Multipurpose Research Reactor, MZFR) and of the Versuchsatomkraftwerk Kahl (Experimental Nuclear Power Plant Kahl, VAK). End of 1988 two gas cooled plants with high temperature reactor - the reactor of the Arbeitsgemeinschaft Versuchsreaktor Jülich (Study Group Experimental Reactor Jülich, AVR) and the Thorium-Hochtemperaturreaktor (Thorium High Temperature Reactor, THTR-300) - were decided to be shut down and have to be considered under decommissioning for the dose evaluation starting with 1989. The dose contribution of these two plants is so small that it hardly influences the trend of the total collective dose and as a result in the following years the total collective dose still is influenced by KRB-A in 1988 and 1989.

In 1990 the value of the total collective dose is noticeable and needs some explanation. The total collective dose is dominated by the collective dose contribution of the 5 units of Greifswald Nuclear Power Plant (KGR). The last unit of KGR was shut down in December 1990. There was no information on the break down of the collective dose between those units which were already shut down and the units which were still in operation until end of that year. Thus in 1990 the collective dose of the site

Greifswald includes considerable contributions from the outage dose of the operating units and does not represent the decommissioning dose.

In the further years since 1991 the total collective dose was influenced by the contributions of the utilities

- Greifswald (KGR-1 to KGR-5) with collective doses between 0,24 man*Sv/year and 0,51 man*Sv/year in 1991 up to 1998,
- Rheinsberg (KKR) with collective doses between 0,25 man*Sv/year and 0,15 man*Sv/year,
- Gundremmingen Unit A (KRB-A) with collective doses in the order of 0,4 man*Sv/year between 1992 and 1997 and
- Würgassen (KWW) with collective doses of 0,4 man*Sv/year since 1995 and of 0,9 man*Sv/year in 1998.

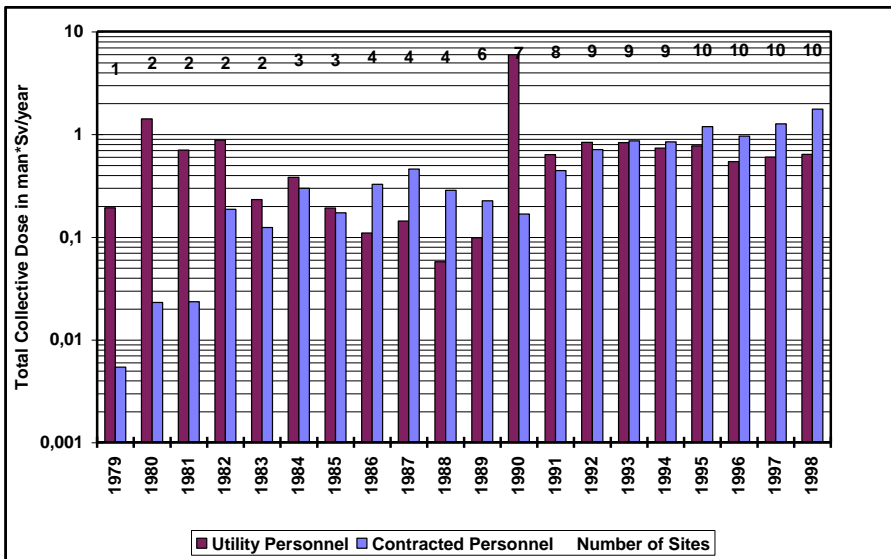


Fig. 2: Collective dose per year of utility and contracted personnel of the decommissioned plants

So in 1998 the total collective dose of the plants under decommissioning is essentially influenced by the contribution of the Würgassen plant, which early 1998 obtained the license to dismantle systems outside of the containment and started with these activities in 1998.

Fig. 2 shows the trend of the collective dose of the utility and contracted personnel of the plants under decommissioning. It is recognisable that up to 1985 the total collective dose was dominated by the dose contribution of the utility personnel. From 1986 to 1990 and since 1993 the dose contribution of the

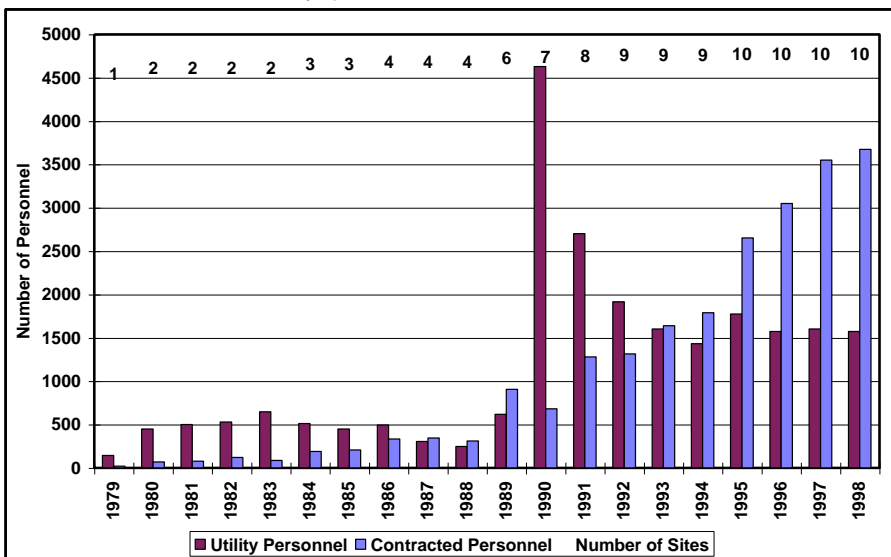


Fig. 3: Number of utility and contracted personnel of the decommissioned plants

contracted personnel dominates the total collective dose. For the time span from 1990 to 1992 the increase of the contribution from the utility personnel results from the personnel of Greifswald and Rheinsberg due to practices in these plants to have only very small numbers of contracted personnel on site.

Fig. 3 shows that the trend of the number of the contracted personnel correlates with the trend of the collective dose per year of the contracted personnel with exception of 1986. In those years when the contribution of the contracted personnel to the collective dose is high, also the number of the contracted personnel employed are higher than the number of the utility personnel.

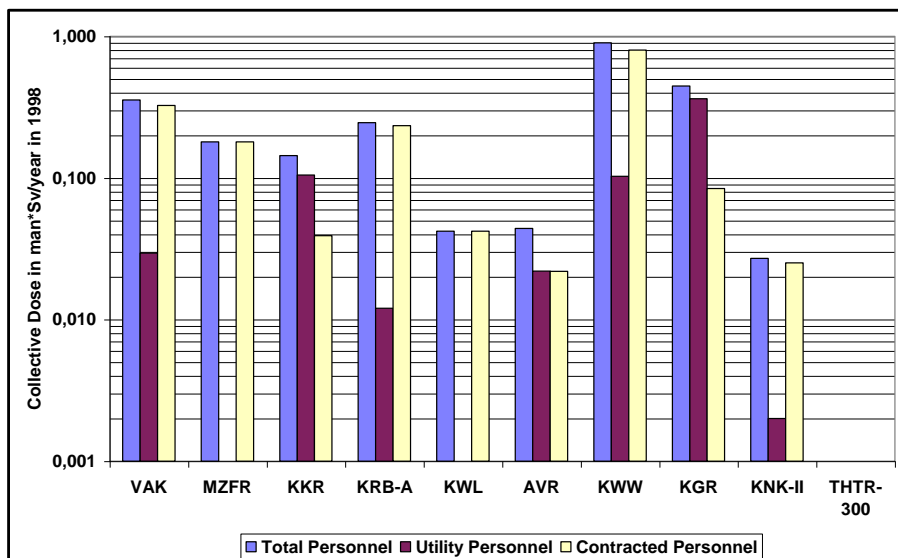


Fig. 4: Collective doses of the decommissioned plants in 1998

As an example fig. 4 presents the collective doses of all plants under decommissioning - divided in utility personnel, contracted personnel and total personnel - for the year 1998. It is obvious that in spite of the dominating dose contribution of the contracted personnel shown for the data of the total collective dose, the collective dose of the utility personnel in some plants still is higher than the collective dose of the contracted personnel. This is the fact for the Greifswald and Rheinsberg NPP in 1998 due to the same personnel politics-reason as mentioned earlier.

This statement is confirmed by the progress of the per utility averaged personal doses shown in fig. 5 and fig. 6 with higher values of the mean utility doses of KGR and KKR.

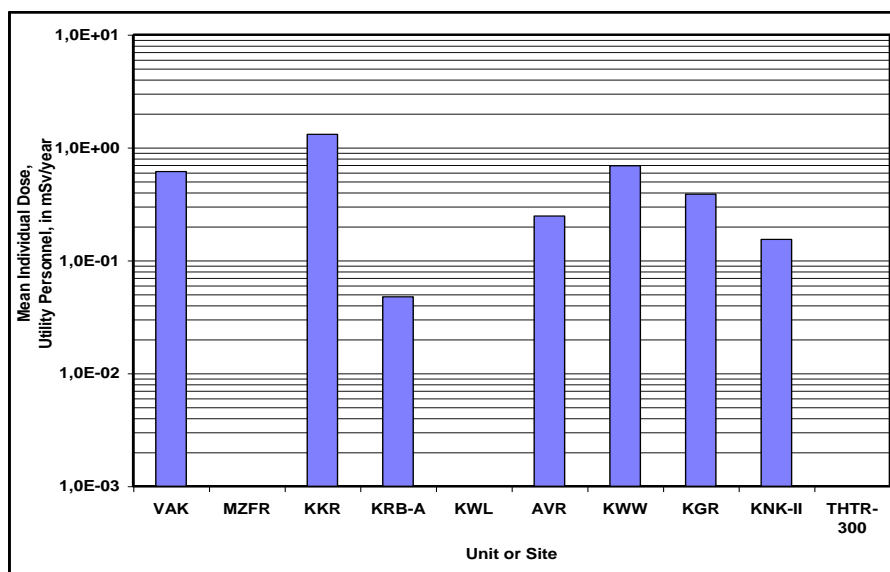


Fig. 5: Mean personal doses of utility personnel of the decommissioned plants in 1998

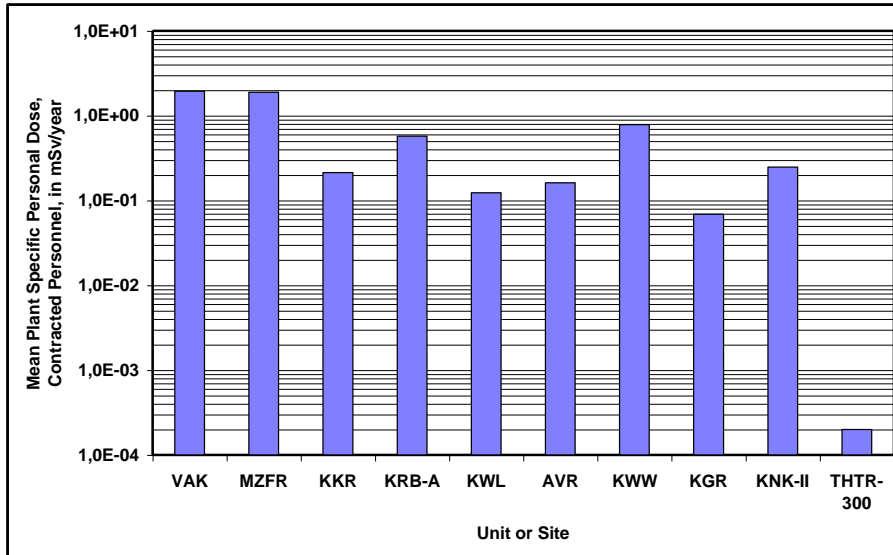


Fig. 6: Mean plant specific personal doses of contracted personnel of decommissioned plants in 1998

3. PLANT SPECIFIC INFORMATION

3.1 Overview

The GRS data base on radiation exposure of personnel in plants under decommissioning contains plant specific information for units under decommissioning such as

- collective doses of the occupationally exposed personnel as well for the operational as for the decommissioning phase of the units,
- the information on the personnel dosimetric systems which are used to determine the exposure data,
- the distribution of the external personal doses of the personnel (individual doses or plant specific doses respectively of the utility and contracted personnel) and
- the most important events since the start-up of operation (up to now not complete for all plants).

To understand the separation of the last but one of the bullets above it has to be mentioned that normally, this means for a single unit plant, the personal doses of the utility personnel generally can be understood as individual doses. For the contracted personnel this may be not true: as this personnel may work for some time in different plants and as the doses reported only hold for the unit under consideration, the personal dose results and the mean personal dose must be understood as a plant specific dose only.

3.2 Data of radiation exposure of personnel for selected sites considering the decommissioning strategy

In Germany decommissioning of nuclear power plants may follow one of two strategies which apply different post operational phases between the shut down of the plant and the beginning of the 'final' dismantling:

Decommissioning strategy 1: Total dismantling after a longer period of time with safe enclosure, in total covering the phases "Establishment of the safe enclosure", "Safe enclosure for a longer period of time" and "Total dismantling of all systems of the controlled area including buildings" after the enclosure time. In this paper this strategy 1 will be addressed as "Safe enclosure".

Decommissioning strategy 2: Immediate dismantling when the necessary planning has been performed and has been licensed, this means that dismantling starts more or less shortly after the decision to shut down has been taken. This strategy 2 will be addressed "Dismantling".

Basically, the choice of the decommissioning strategy depends on a number of criteria and issues of consideration as

- radiological considerations including e.g. radioactive decay of radionuclides present and detection of contamination during dismantling for release of dismantling products,
- conditions of the site and intended further use of the site,
- possibilities or need of further employment of utility personnel,
- benefits resulting from the experience of plant maintenance personnel,
- last not least cost arguments.

Table 1 (see Appendix) shows that for the majority of the German plants under decommissioning “Dismantling” will be the strategy applied. Following an overview on the radiation exposure of personnel of selected plants under decommissioning will be given.

• **Radiation exposure of Lingen NPP (KWL) in the decommissioning phase: Safe enclosure**

The Lingen Nuclear Power Plant (KWL) - designed as a boiling water reactor combined with a conventional reheater - had an electrical capacity of 264 MW. In January 1968 the reactor had its first criticality and in January 1977 it was shut down because of repeated damages on the steam

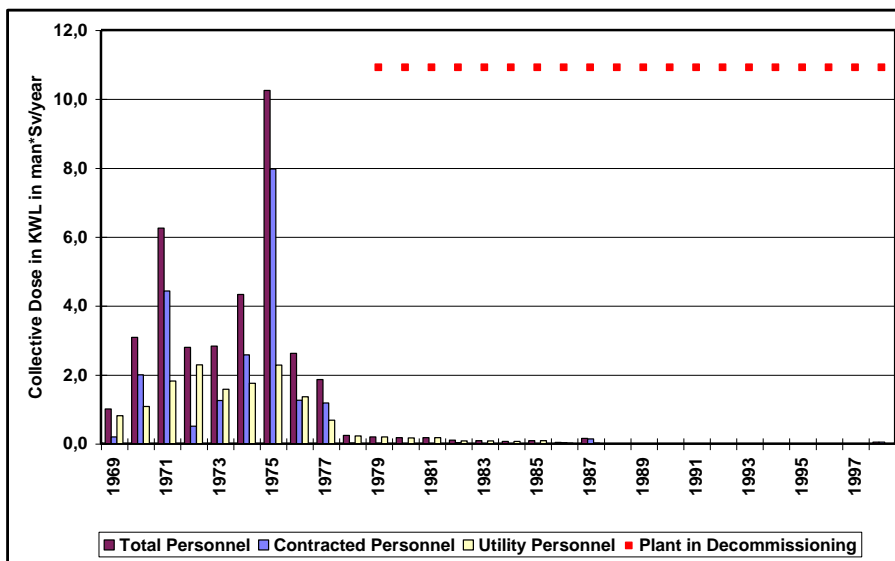


Fig. 7: Collective dose per year of KWL personnel for the lifetime of the plant

converters. In 1977 and 1978 repair activities were carried out on the steam converters and on the core safety system. Improvements of the engineered safety features were implemented to restart operation. Nevertheless in March 1979 the owner decided to decommission the nuclear part of the plant which was planned to be replaced by a gas turbine with waste-heat boiler. In 1981 this project was cancelled and the decision was taken to decommission the whole plant. In August 1985 the owner applied for the licence for decommissioning. The licence to transfer the plant to safe enclosure was granted in November 1985. The status of safe enclosure started in 1988.

Fig. 7 presents an overview on the trend of the collective dose of the plant's whole lifetime since start-up covering as well operation as decommissioning of the unit. In fig. 8 the display of collective doses in KWL concentrates on the decommissioning phase. Together with fig. 9, fig. 8 demonstrates the changes of collective dose and of the number of personnel moving from operational phase of the unit to the preparation of safe enclosure and then to the 'operational state' of safe enclosure: between 1979 and 1988 the safe enclosure is prepared mainly by utility personnel. Only in 1986 and 1987 contracted personnel has a significantly higher collective dose than the utility personnel. Especially the increase in 1987 combined with a quite low number indicates that final more dose intensive tasks have been performed in this year to reach the status of final enclosure.

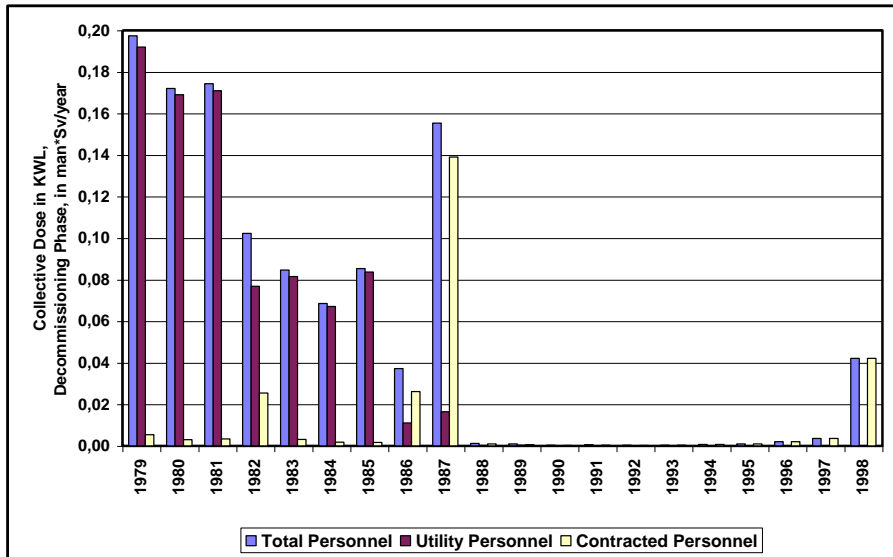


Fig. 8: Collective dose per year of KWL personnel specified for the decommissioning period

Fig. 9 presents the number of the utility personnel. After a reduction since 1977 the number increases between 1981 and 1986 and decreases clearly in 1987. The reason should be the hiring and practical training of new personnel to be employed later in Emsland Nuclear Power Plant (KKE), which was under construction at that time. This personnel was dedicated to KKE in 1987. The numbers of the personnel show that the preparation work for the 'Safe enclosure' was performed by utility personnel. Since 1987 the number of utility personnel is changing due to the transfer to KKE. Due to this reason more contracted personnel has worked in KWL. Some part of this contracted personnel comes from KKE (and may have been utility personnel of KWL before) but some other part also may be employed by other external companies.

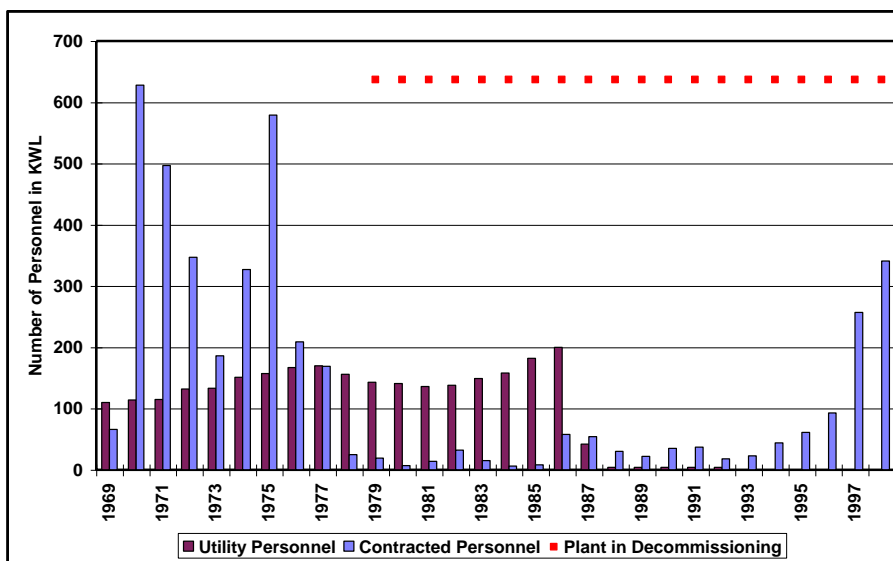


Fig. 9: Number of utility and contracted personnel of KWL

Since the start-up of KWL the averaged total collective dose amounts to 3,53 man*Sv/year for the operational phase till 1978. During the phase of preparation of the safe enclosure (up to 1988) the averaged collective dose amounts to 0,06 man*Sv/year. Since 1988 the collective doses per year are below 1 man*mSv/year. The reason is that there are no important dose relevant activities during this time except the supervision of the safe enclosure. As an exception, in 1998 the collective dose increases for the reason of special works on the ventilation system, on the waste water treatment system, on the access-area of the controlled area and on the control room.

In the decommissioning phase from 1979 to 1992 the mean individual dose of the utility personnel decreased from 1,34 mSv/year to 0,04 mSv/year. The mean plant specific dose of contracted personnel

was in the range of 0,01 mSv/year and about 1 mSv/year with a high single value of 2,6 mSv/year in 1987 (see fig. 10).

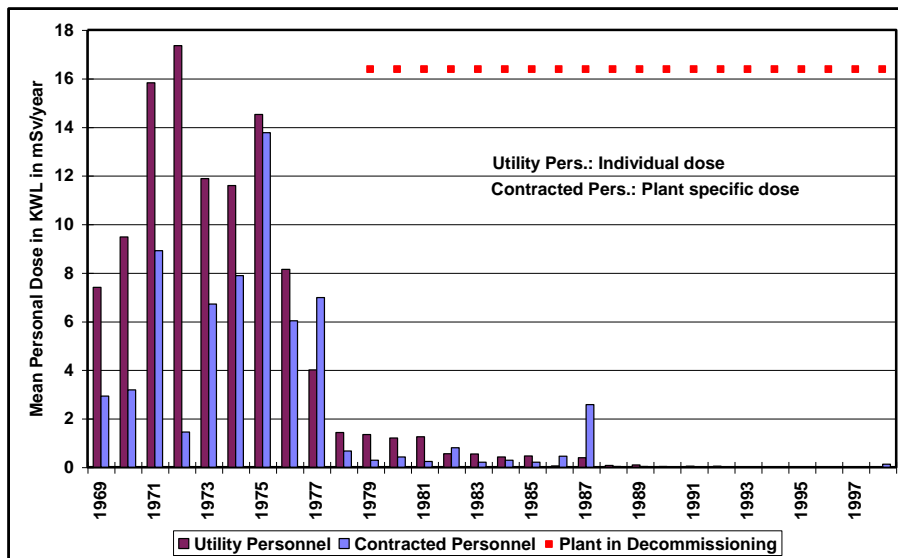


Fig. 10: Mean individual dose of utility personnel and mean plant specific dose of contracted personnel of KWL

The data present the low exposure level of the personnel engaged which is typical for this part of the safe enclosure. Similar observation results from the data of the gas cooled reactor under decommissioning (THTR) which are displayed in fig. 11. This display additionally gives an impression of the low doses during operation and decommissioning of a gas cooled reactor with a short operation period.

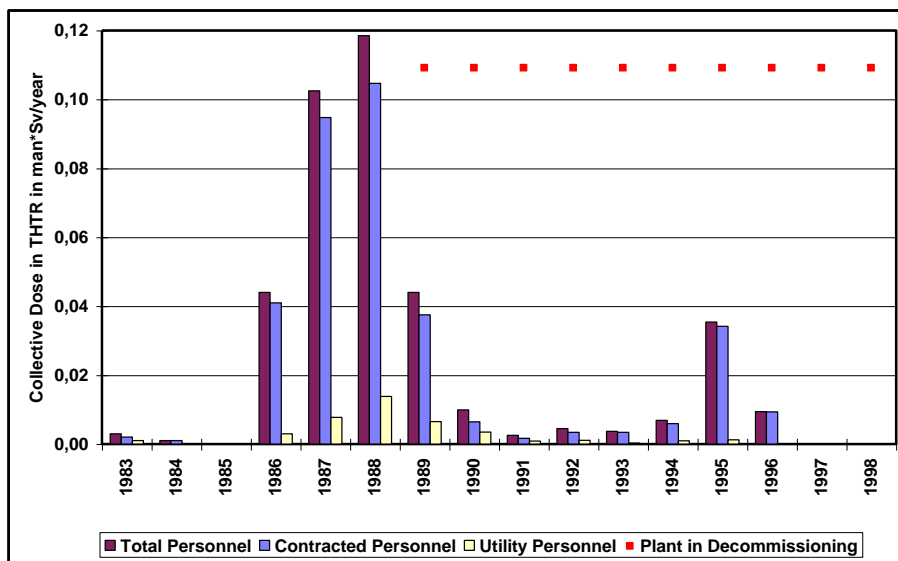


Fig. 11: Collective dose per year of THTR personnel during operation and decommissioning

- **Radiation exposure of Gundremmingen Unit A (KRB-A) in the decommissioning phase: Dismantling**

The Gundremmingen Unit A (KRB-A) was a boiling water reactor plant with an electrical power of 252 MW. In August 1966 the plant became critical the first time. It was shut down due to an incident in January 1977. After the incident extensive repair activities for remedy of the damages were carried out until 1979 with the intention to finally restart the plant. These activities caused high collective doses especially in 1977 and 1978. When it became obvious, that in spite of high economic investment the safety of the plant could not be established in January 1980 the owner decided to decommission the plant. In June 1980 the owner applied for decommissioning. The licence to dismantle the plant was granted in May 1983.

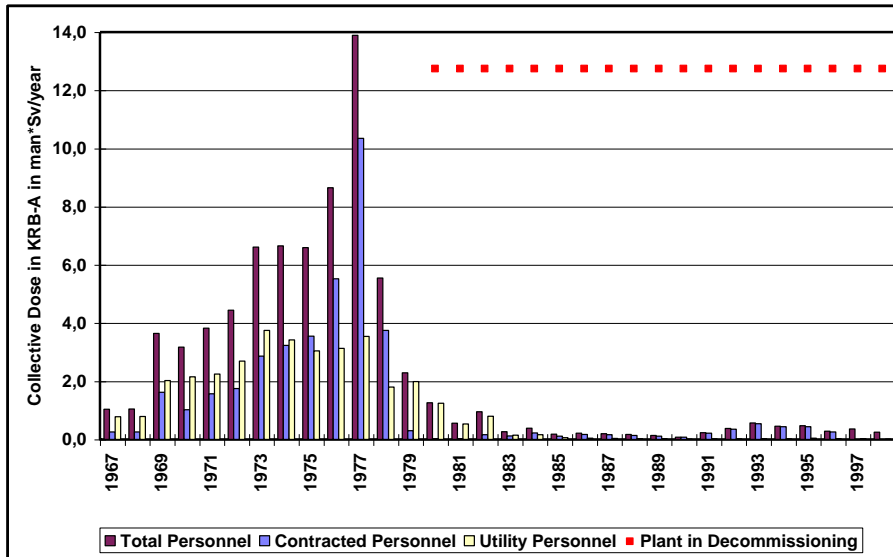


Fig. 12: Collective dose per year of KRB-A personnel for the lifetime of the plant

The collective dose of the utility and the contracted personnel for the lifetime of the plant since start-up is shown in fig. 12 and specified for the decommissioning period in fig. 13. Considering the time span from start-up to 1979, the average of the total collective dose is 5,18 man*Sv/year. For the decommissioning period the averaged collective dose is about 0,4 man*Sv/year with higher dose values in the beginning of the decommissioning period and between 1993 and 1995.

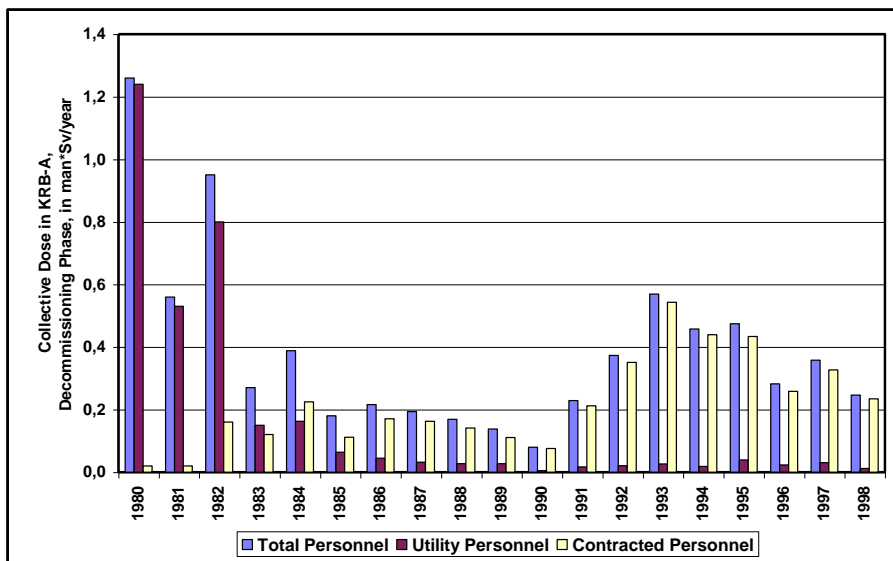


Fig. 13: Collective dose per year of KRB-A personnel specified for the decommissioning period

The trend of the collective doses of the utility and contracted personnel with time shows that mainly utility personnel realised the preparation of dose relevant dismantling activities between 1980 and 1983. Since the licence for decommissioning is with utility, contracted personnel received the main share of the collective dose. Between 1980 and 1987 the collective dose of the utility personnel decreased to 0,03 man*Sv/year and fluctuates around this value in the following time period up to 1998.

As shown in fig. 14, the number of utility personnel increases by a factor of 2 between 1980 and 1983, when preparation activities for the dismantling phase were performed. The reason for this increase is the remedy of damages and contamination and even more the education and training of new hired personnel to be deployed in the utility KRB II; B and KRB-II; C later, as these units were in a late stage of construction at that time.

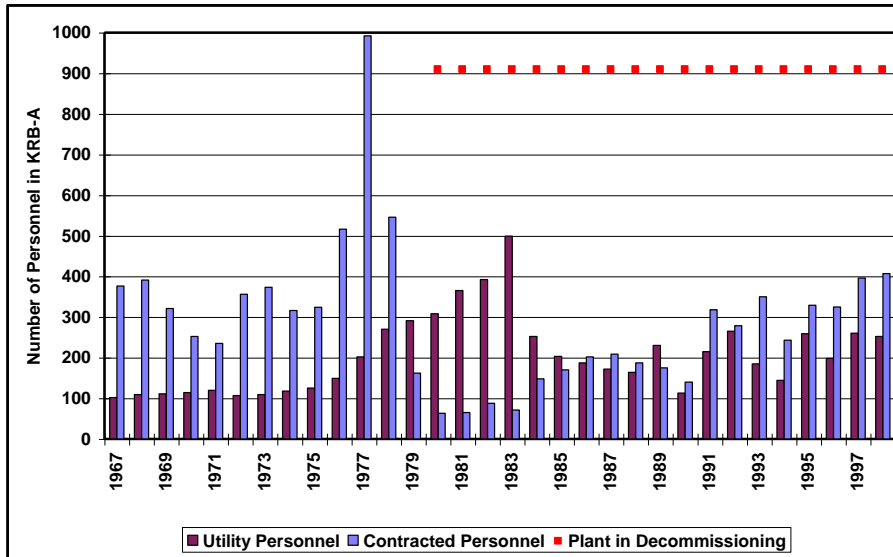


Fig. 14: Number of utility and contracted personnel of KRB-A

The preferred deployment of utility personnel during the preparation phase of dismantling compared to the exposure of the contracted personnel resulted in a higher mean individual dose of the utility personnel which, however, compared to the operational phase of KRB-A is smaller by one to two orders of magnitude. Since 1983 the mean plant specific personal dose of the contracted personnel is higher, as it can be seen in fig. 15.

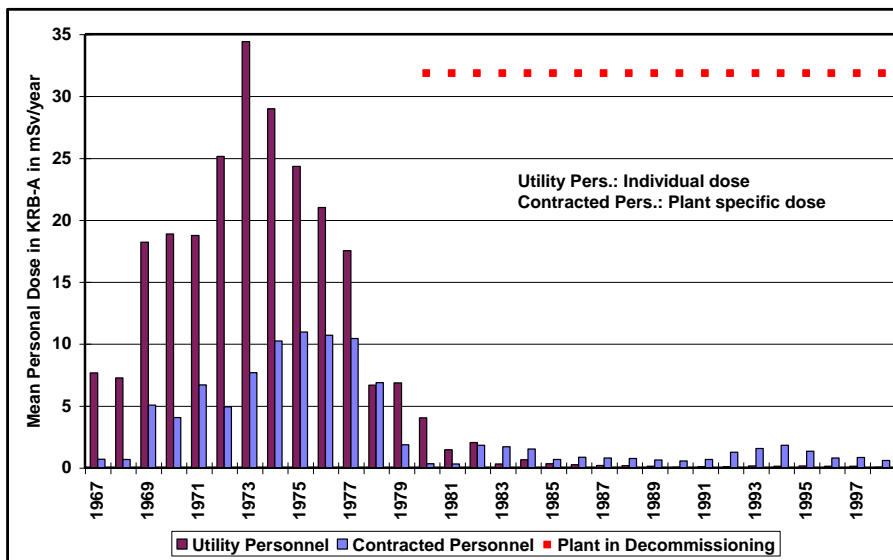


Fig. 15: Mean individual dose of utility personnel and mean plant specific dose of contracted personnel of KRB-A

The data prove the decrease of the collective dose during the preparation and planning phase of dismantling, when especially less dose intensive activities were performed, and the later (slight) increase of the collective dose as a result of the dismantling activities started in plant areas with higher radiation fields.

As an additional example for the trend of the collective dose during operation and dismantling fig. 16 shows the data of the Würgassen Nuclear Power Plant (KWW). The similar trend of decay and increase of the collective dose shows up after a short time period.

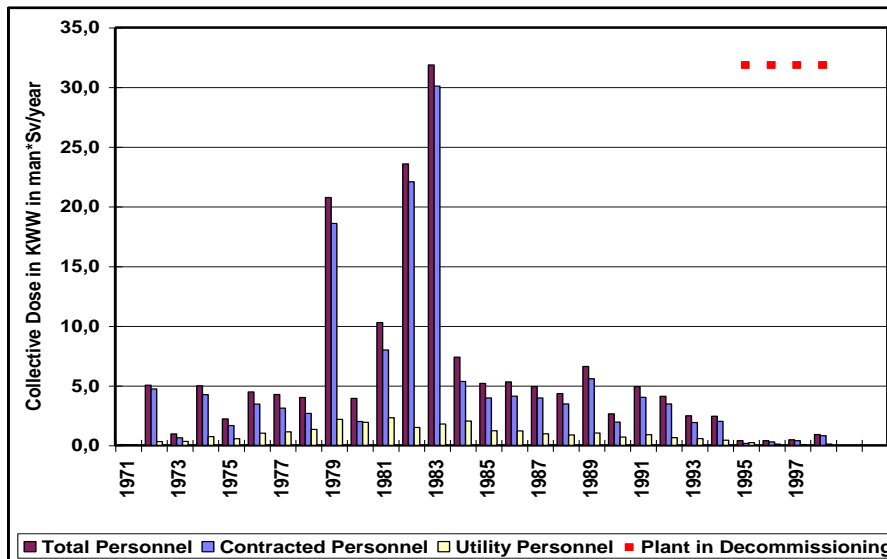


Fig. 16: Collective dose per year of KWW personnel during operation and decommissioning

4. SUMMARY

In Germany 14 nuclear power plants of different types and power levels are in different stages of decommissioning on 10 sites. The practices of decommissioning could be categorised into the two strategies outlined by the headwords "Safe enclosure" and "Dismantling". The actual status of the plants shows that the preferred decommissioning strategy today is to start dismantling after a longer or shorter post-operational phase.

The results at hand up to now show that decommissioning can be realised with acceptable radiation exposure of utility and contracted personnel. The paper presents an overview and some more detailed results on the total, utility and contracted collective dose values, on the mean personal doses and the number of utility and contracted personnel for all plants which are under decommissioning since 1979 - with the exception of the plants Niederaichbach (KKN) and Karlstein (HDR).

In the 80ies the trend of the collective dose is mainly influenced by the decommissioning activities of Gundremmingen Unit A (KRB-A), in the early 90ies the collective dose of the Greifswald NPP utility personnel dominates and in the end of the 90ies the beginning of the decommissioning of the Würgassen NPP (KWW) is noticeable. Giving rise to the conclusion, that the other plants under decommissioning actually have minor contributions to the collective dose either to the decommissioning strategy chosen or due to the smaller plant or the lower dose rate level in the plant.

As two examples to show some more detailed data on a plant specific level and to cover the decommissioning strategies "Safe enclosure" and "Dismantling", the decommissioning of the plants Lingen (KWL) and Gundremmingen Unit A (KRB-A) were presented. The results display a very clear decreasing of the total, utility and contracted collective dose values and of the mean personal doses in comparison with the operational time period. Generally the collective dose values of the plants not presented in detail show the same trend.

The main difference between the radiation exposure characteristics during the decommissioning of KWL and KRB-A could be seen in the practically neglectable exposure after establishing the safe enclosure of KWL. The same result was also noticed after establishing the safe enclosure of THTR. Contrary to this fact in case of decommissioning of KRB-A the radiation exposure during dismantling activities is much smaller in comparison with the operational time period of the plant but cannot be neglected. The exposure data of the dismantling of KWW basically show the same trend.

GRS intends to continue and - if possible - to expand this work to cover future activities and to prepare a common, if possible more detailed data base on doses, practices and experiences in dismantling of NPPs on behalf of the Federal Authorities. To succeed with this intention there is a strong need for the further support of the utilities engaged in dismantling of units to be able to retrieve collective dose values and additional information on important decommissioning steps with assistance of the utilities.

GRS hopes that the participation of the utilities in the international OECD/NEA project "Information System on Occupational Exposures" (ISOE) for a mutual benefit of all participating partners will improve the data collection and the availability of data as well as the transfer of experience and information between the utilities engaged.

5. REFERENCES

- [1] Marx, H., Pfeffer, W., Urbahn, H.
Die Strahlenexposition der Arbeitskräfte in stillgelegten Kernkraftwerken in Deutschland
GRS-A-2809
April 2000

APPENDIX

Table 1: Overview on German Nuclear Power Plants under Decommissioning

Plant	Name	Type	el. Power (MW)	First criticality	Shut down	Decomm. applied for	Decomm. licensed	Status
AVR	ARGE VERSUCHS-REAKTOR JUELICH	GCR/HTR	15	26.08.68	31.12.88	18.12.86	09.03.94	Safe enclosure
KGR-1	KERNKRAFTWERK GREIFSWALD, Block 1	PWR (VVER)	440	15.12.73	18.12.90	17.04.94	30.06.95	Dismantling
KGR-2	KERNKRAFTWERK GREIFSWALD, Block 2	PWR (VVER)	440	03.12.74	14.02.90	17.04.94	30.06.95	Dismantling
KGR-3	KERNKRAFTWERK GREIFSWALD, Block 3	PWR (VVER)	440	06.10.78	28.02.90	17.04.94	30.06.95	Dismantling
KGR-4	KERNKRAFTWERK GREIFSWALD, Block 4	PWR (VVER)	440	22.07.79	02.06.90	17.04.94	30.06.95	Dismantling
KGR-5	KERNKRAFTWERK GREIFSWALD, Block 5	PWR (VVER)	440	24.04.89	24.11.89	17.04.94	30.06.95	Dismantling
KKR	KERNKRAFTWERK RHEINSBERG	PWR (VVER)	70	06.05.66	02.06.90	26.03.92	28.04.95	Dismantling
KNK-II	KOMPAKTE NATRIUMGEKÜHLTE REAKTORANLAGE	FSR	21	10.10.77	23.08.91	21.04.92	26.08.98	Dismantling
KRB-A	KERNKRAFTWERK GUNDREMMINGEN, Block A	BWR	252	14.08.66	01.01.77	20.06.80	26.05.83	Dismantling
KWL	KERNKRAFTWERK LINGEN	BWR	268	01.07.68	05.01.77	21.08.85	21.11.88	Safe enclosure
KWW	KERNKRAFTWERK WÜRGASSEN	BWR	640	20.10.71	29.05.95	25.09.95	14.04.97	Dismantling
MZFR	MEHRZWECK-FORSCHUNGS-REAKTOR KARLSRUHE	PWR	57	29.09.65	03.05.84	22.04.86	17.11.87	Dismantling
THTR-300	HOCHTEMPERATUR-REAKTOR HAMM-UENTROP	GCR/HTR	308	30.09.83	20.09.88		22.10.93	Safe enclosure
VAK	VERSUCHSATOMKRAFT-WERK KAHL	BWR	16	13.11.60	25.11.85	01.08.85	05.05.88	Dismantling

Abbreviations:

PWR Pressurised Water Reactor

BWP Boiling Water Reactor

GCR/HTR Gas Cooled/High Temperature Reactor

FSR Fast Sodium Cooled Reactor

VVER Pressurised Water Reactor, Russian
Construction