Comparison of Performance Indicators of Different Types of Reactors Based on ISOE Database

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Abstract

The optimisation of the operation of a nuclear power plant (NPP) is a challenging issue due to the fact that besides general management issues, a risk associated to nuclear facilities should be included. In order to optimise the radiation protection programmes in around 440 reactors in operation [1] with more than 500 000 monitored workers each year [2], the international exchange of performance indicators (PI) related to radiation protection issues seems to be essential. Those indicators are a function of a type of a reactor as well as the age and the quality of the management of the reactor. In general three main types of radiation protection PI could be recognised. These are: occupational exposure of workers, public exposure and management of PI related to radioactive waste. The occupational exposure could be efficiently studied using ISOE database. The dependence of occupational exposure on different types of reactors, e.g. PWR, BWR… are given, analysed and compared.

Introduction

Regarding [1] altogether 441 nuclear power reactors (NPPs) are in operation world-wide and 32 under construction. Occupational exposure in NPPs is one of the main performance indicators related to safety culture developed in an NPP. It strongly depends on physical characteristics of an NPP as for example:

- type of a nuclear power plant
- life period of an NPP
- maintenance and upgrading as for example steam generator replacement
- refuelling practice of an NPP.

In addition, it also strongly depends on the management of radiation protection issues. As shown in [2] the number of monitored workers all over the world is increasing with time reaching the number around 500 000 of annual monitored workers in the last decade. Worker protection at NPPs is today based on the optimisation principle, so that the doses are as low as reasonably achievable (ALARA).

The Information System on Occupational Exposure (ISOE) which was established in 1992 to provide the forum for radiation protection experts to discuss, promote and co-ordinate the undertakings in the area of worker protection in NPPs [3]. One of the result of ISOE is the ISOE database which includes occupational data from the total 465 reactors in the year 2002, among them 406 operating and 59 in cold shutdown or some stage of decommissioning [4]. The database enables the analysis of exposure regarding different characteristics of the NPPs.

Firstly, the characteristics of the main types of reactors used in commercial purposes are given. Secondly, occupational exposure regarding different types of reactors is compared and analysed.

Types of reactors

From 1950 many types of reactor have been developed, but today, mainly four types of nuclear power plants widely used:

- light water reactors (LWR)
- heavy water reactors (HWR) as for example Canadian Deuterium Uranium Reactors (CANDU)
- gas cooled reactors (GCR)
- light water cooled graphite moderated reactors (RMBK).

Among them around 75% of all reactors are LWR, either pressurised water reactor (PWR) or boiling water reactors (BWR). The detailed characteristics of the above mentioned are described elsewhere [5].

Figure 1 shows the number of different types of operating reactors in the year 2002 [6]. In this year 321 operating reactors were included in the ISOE database with together 6014 of years of experiences and among them 192 PWRs with 3769 years of operating experiences. As shown the majority of operating reactors today use enriched uranium as fuel and light water as a moderator and a coolant.

In Figure 2 the contributions of shutdown reactors of different types participating in the ISOE database in the year 2002 are given. Some of them were not definitively shut down but they did not operate in the year 2002. In the ISOE database, 43 reactors are included with the mean age of 19.4 years of operation at the time of shutdown. The number of GCRs shut down is slightly higher than the numbers of other types of reactors shutdown.

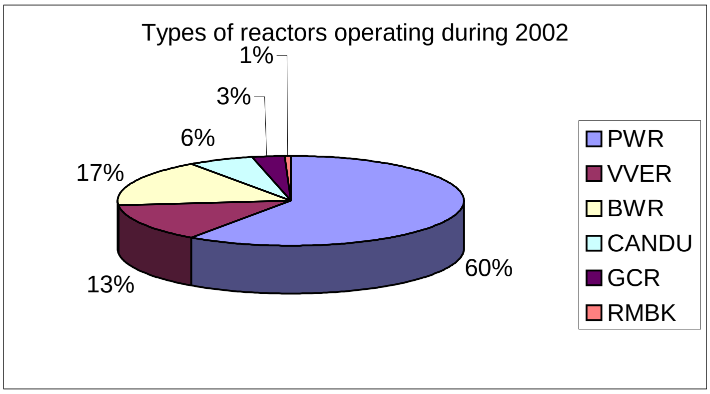

FIG. 1. *Types of reactors operating during 2002 based on data from [6].*

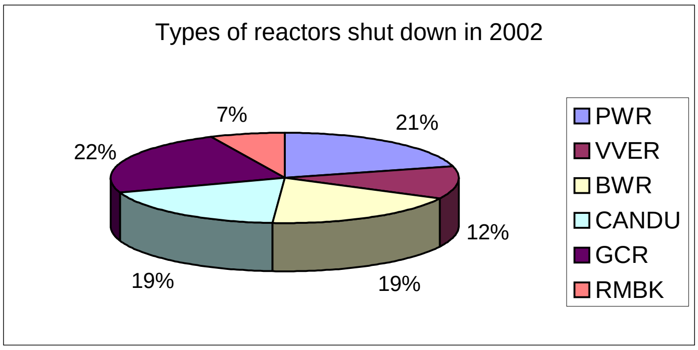

FIG. 2. *Types of reactors definitively shut down as for year 2002 based on data from [6].*

Occupational exposure in reactors

Occupational exposure in NPPs strongly depends on the inventory of radioisotopes in:
- fuel
- reactor coolant
- reactor coolant purification systems and waste–stream processing system
- radioactive waste.

Moreover also the accumulation of radioisotopes in all additional systems related to the reactor coolant should be carefully studied and monitored in the process of planning the work. The inventory of specific types of reactors can be found in literature [7].

In the year 2002, the average annual collective dose per reactor was 1.06 man Sv. The lowest average collective doses per reactor were obtained in GCR and the highest ones in RMBK with the value 4.40 man Sv. Besides the collective dose as a performance indicator of radiation protection also the normalised average annual collective dose, defined as the average collective dose per reactor per generating electrical energy can be used. Figure 3 shows the normalised average annual collective dose for different types of reactors from the year 1998 to 2002.

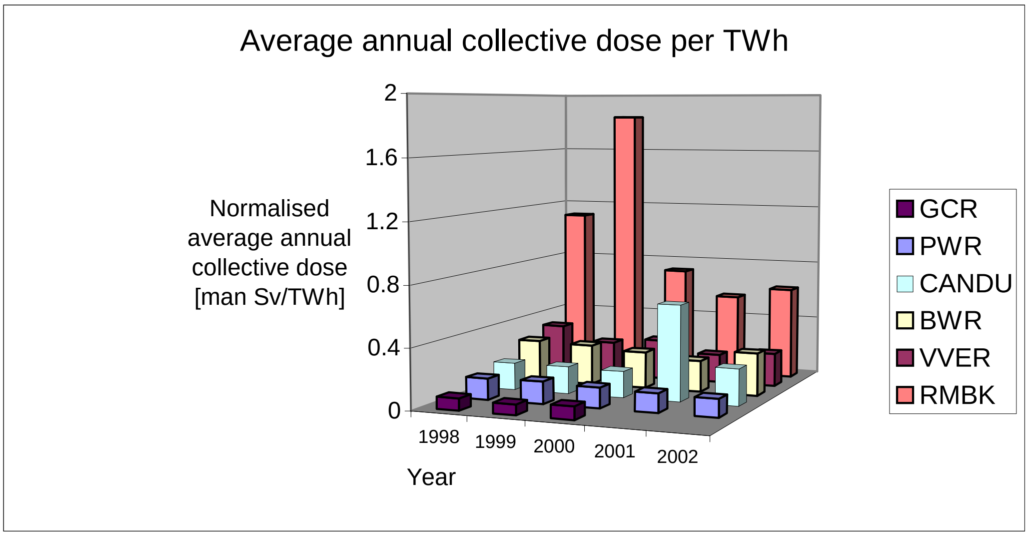

FIG. 3. *Normalised average annual collective dose for different types of reactor from the year 1998 to 2002.*

The highest normalised average annual collective dose is regularly observed in RMBK reactors while the lowest one in GCRs in that period. The operation of PWRs is also related to low levels of normalised collective exposure, which is below 0.15 man Sv/TWh in that period.

Detailed analyses of exposure due to specific maintenance tasks or upgrading of NPPs are rare in literature. The analysis of exposure due to the steam generator replacement can be found [8], as well as exposure related to the reactor head replacement. As stated in [9] around 80% of all exposure is usually due to high dose jobs, which can be estimated to represent only about 20% of all jobs in NPPs. A list of typical jobs which are related to high exposures is given for example in [9].

The ISOE database can be used to perform the analysis of specific tasks performed in NPPs. The doses received during an outage are usually much higher that the doses related to normal operation of an NPP. Figure 4 gives the percentage of the outage contribution to the total collective dose for different types of reactor in the year 2002. Values were obtained averages over contributions in all participating countries. As shown the contribution of outage dose to the total dose do not strongly depend on a type of a reactor.

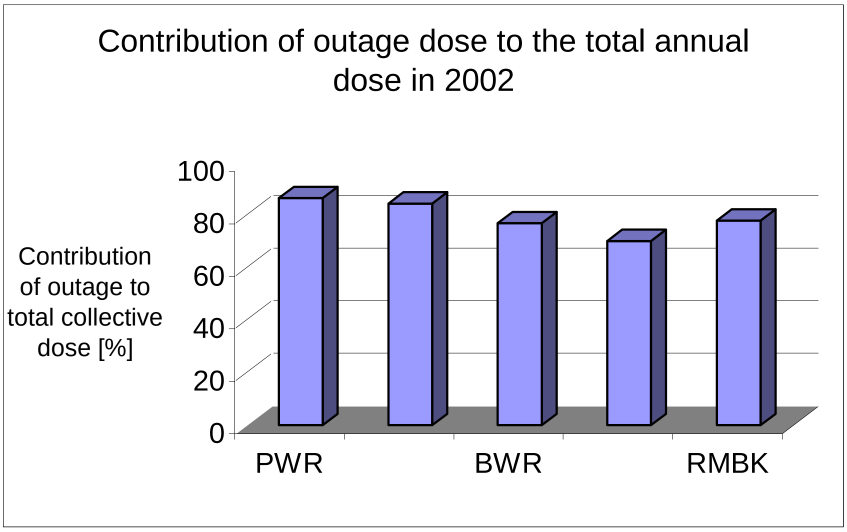

FIG. 4. *Average contribution of the outage dose to the total annual dose in 2002 for different types of reactor from in the year 2002.*

5. Conclusions

The efficient study of workers' exposure regarding six main widely used types of reactors, namely PWR, VVER, BWR, CANDU, GCR and RMBK can be performed using the ISOE database. Occupational exposure performance indicators show that the operation of a GCR leads to the lowest average annual collective dose per energy produced while the highest average annual collective dose per energy exists at RMBK reactors. The outage period is a critical period concerning occupational exposure. The collective dose from that period represents more than 70 % of all annual dose and is not a strong function of a reactor type. In PWRs the contribution is around 87% while in CANDU reactors around 70%.

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