Occupational Radiation Protection at Swedish Nuclear Power Plants: Views on Present Status and Future Challenges

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Abstract

The occupational radiation doses at Swedish NPPs have decreased with roughly a factor of two from the beginning of the 1990's until today. The average collective dose during the last five years is 10 manSv for eleven operating reactors. During the same period, the average annual individual dose to the personnel has decreased from 3 – 4 mSv/year to about 2 mSv/year. In this presentation, the measures taken to improve the radiological conditions at the NPPs are briefly reviewed and the present status is described. The expectations for the future are outlined. The SSI summarises past experiences and the prerequisites for preserving good radiation protection conditions by the following catch words: *Competence, Experience Feedback, Preventive Measures,* and *Long-Term Planning*.

The Swedish Nuclear Programme

Sweden has eleven operating nuclear power reactors while two reactors have closed operations. Three of the reactors are Pressurised Water Reactors, PWRs, delivered by Westinghouse Monitor AB and put into commercial power production in the period 1975 – 1983. Eight reactors are boiling water reactors, BWRs. They were delivered by ASEA Atom AB and started their commercial power production during the period 1972 (Oskarshamn 1) to 1985 (Oskarshamn 3 and Forsmark 3).

The two closed reactors, the Ågesta reactor and Barsebäck 1, were shut down in 1974 and 1999, respectively. In Table 1, the main data for the Swedish nuclear power programme is summarized.

	Power (th) MW	Type	Operator	Commercial Operation
Ågesta	105	PHWR	AB Atomenergi /Vattenfall	1964 – 1974
Barsebäck 1	1800	BWR	Barsebäck Kraft AB	1975 –1999
Barsebäck 2	1800	BWR	Barsebäck Kraft AB	1977 -
Forsmark 1	2928	BWR	Forsmarks Kraftgrupp AB	1980 -
Forsmark 2	2928	BWR	Forsmarks Kraftgrupp AB	1981 -
Forsmark 3	3300	BWR	Forsmarks Kraftgrupp AB	1985 -
Oskarshamn 1	1375	BWR	OKG Aktiebolag	1972 -
Oskarshamn 2	1800	BWR	OKG Aktiebolag	1975 -
Oskarshamn 3	3300	BWR	OKG Aktiebolag	1985 -
Ringhals 1	2500	BWR	Ringhals AB	1976 -
Ringhals 2	2660	PWR	Ringhals AB	1975 -
Ringhals 3	2783	PWR	Ringhals AB	1981 -
Ringhals 4	2783	PWR	Ringhals AB	1983 -

Table 1. Main data for the Swedish Nuclear Power Programme

The electric power in Sweden is almost entirely produced in hydro and nuclear power stations. In the period 1990 – 2001, on average, nuclear power accounted for 46 % of the total electric power production in Sweden.

External factors

Good radiation protection conditions are principally the result of good awareness of, and commitment to, radiation protection at the nuclear facility. External factors, however, influence the radiation protection issues.

International Organisations

The work practices and the radiation protection philosophy applied, as well as rules and regulations, in Sweden, are framed and formulated in interplay with views, recommendations and rulings from international organisations.

The International Commission on Radiological Protection, the ICRP, has a leading role in defining and recommending norms and principles within the radiation protection area. The three fundamental principles of the ICRP's protection philosophy: *Justification, Optimisation* and *Dose Limitation* are widely accepted and used. Sweden became a Member of the European Union in 1995 and has implemented the fundamental Directive 96/29/EURATOM *Council Directive of 13 May 1996 laying down basic safety standards for the health and protection of the general public and workers against the dangers of ionising radiation* into Swedish legislation.

The International Atomic Energy Agency, IAEA, develops and sets standards, which are worldwide recognised and accepted – both in the area of safety and radiation protection. Apart from "*Expert missions"* and "*bench-marking activities*", personnel from Swedish authorities and Swedish nuclear industry are involved in the work related to the Convention On Nuclear Safety (Sweden's second national report under the Convention of Nuclear Safety, Ds 2001:41 *Ministry of the Environment*).

The Nuclear Energy Agency of OECD, NEA, assists its Member countries in maintaining and further developing, through international co-operation, the scientific, technological and legal bases required for a safe use of nuclear energy. Sweden has actively been involved in the NEA work, covering areas like radioactive waste management, radiation protection philosophy, decommissioning issues, and environmental radiological protection.

The World Association of Nuclear Operators, WANO, has as its mission "to maximise the safety and reliability of the operation of nuclear power plants by exchanging information and encouraging communication, comparison and emulation amongst its members". Some Swedish NPPs have been subject to benchmarking activities co-ordinated through WANO.

Authority requirements

The regulations of the Swedish Nuclear Power Inspectorate, SKI, and the SSI have changed during the past years. Since the beginning of the 90's the safety requirements have increased and the SKI has formulated new regulations about non-destructive testing, safety barriers and staff competence. The SKI is presently in the process of reviewing and updating its main safety regulations, which were issued in 1998. The SSI has, during the last ten years, implemented the common European radiation protection legislation, formulated in binding EC directives, into the Swedish regulations.

Deregulation of the Electricity Market

The Swedish electricity market was deregulated in 1996 when open competition was introduced in trade and production of electricity. The grid system is still regulated and controlled. The company Svenska Kraftnät owns the national grid and has the role of system operator. The trade is performed at Nord Pool -- The Nordic Power Exchange in Oslo, Norway.

The deregulation has led to changes in the financial situation for the power producers, rationalization and new organizational structures. One way of decreasing costs has been to review the investment plans. All power producers do not, however, compete on the same terms since a special excise duty is imposed on nuclear power.

Environmental Protection Issues

Under the last ten years, the interest in environmental issues has continued to increase. For the operators of nuclear power plants, and in the general debate, releases of radioactive substances has come into focus and received a greater attention than earlier. The discussions and the work performed in relation with the environmental issues has also led to the application of a changed protection philosophy: The releases should be reduced if it is possible with reasonable technical efforts even if the resulting radiation doses to the most exposed persons are small. The concept of *Best Available Technique,* BAT, is applied.

The issue of risk transfer between individuals and groups of individuals is a complex issue. When the protection of the environment (eco system) should be considered, the SSI finds it important that new routines for optimisation are established and applied – enabling appropriate attention to occupational exposure in the optimisation process.

Past radiation protection conditions

In the beginning of the 90's the SSI observed a trend of increasing occupational exposure at the Swedish Boiling Water Reactors. The main reasons for this were extended reconstruction work at the reactors and increase in non-destructive testing leading to more work in the controlled areas of the NPPs. It was also noted that radiation levels in water-filled systems at the power plats were still increasing and had not levelled as expected. The SSI and the nuclear industry then implemented measures in order to change the situation and to reduce incurred and projected radiation doses.

Actions to improve conditions

In revised regulations adopted in 1994 the SSI required each utility to prepare special programmes with the aim to reduce occupational doses and radiation levels (ALARA programmes). The SSI also required extended education and training programmes in radiation protection, addressed particularly to foremen and team leaders working at the NPPs. Another important regulatory measure taken by the SSI was the introduction of the dose limit of 100 mSv in five consecutive years (max. 20 mSv as average over five years) in addition to the annual dose limit of 50 mSv. SSI has actively supported research and development projects for understanding, modelling and reducing radiation doses and radiation levels at NPPs.

The nuclear industry introduced programmes with the aim to avoid further increase of radiation levels at the NPPs. One important step is to reduce the amount of cobalt entering the reactor, by exchange of components or passivating surfaces containing Stellite. During the past ten years, at maintenance and modernization programs performed at the plants, piping and vaults have been exchanged. This has decreased the cobalt inventory but also introduced materials less susceptible to corrosion, which affects the need for maintenance and time intervals for in-service inspections. Other important steps for reducing the build-up of radiation levels have been to control the water chemistry in reactor circuits (e.g. Zn-injection, Ni/Fe-ratio) and optimise water flows. Great care was taken in improving different start and shutdown procedures (pH-values, temperature conditions) and other operations, which can lead to unnecessary spread of contamination in the plant. Special filters to catch debris and unwanted pollutants were sometimes installed. The operators have selected to use chemical decontamination more frequently in connection with complex work in high radiation areas. In a few BWRs, lowering the moisture content of the reactor steam successfully reduced the radiation levels at the turbine side.

Among the administrative measures, apart from improved education plans and the use of mock-up facilities, changes have been introduced in the planning of outages and projects. Healths physics staff is involved early in the planning and pre-planning phase in order to introduce radiation protection aspects at the design stage (e.g. space, material choice, work procedures). Written procedures for fuel damage management and policy for when to interrupt production in connection with serious damages have been developed by the operators. Efforts to minimise fuel damages have led to internal rules in order to restrain debris and filings to enter the primary reactor systems.

Both international and national systems for feedback and exchange of experiences (e.g. ISOE, WANO, INPO) have been utilised for improving work procedures. An important and still on-going part of the work is to improve the co-operation with external contractors in the field of radiation protection and ALARA planning.

Several research programmes were ordered by the SSI and the nuclear industry in order to improve knowledge and techniques for reducing radiation levels. A few examples are:

- Model development for Activity Build-up adopting theories for Surface Complexes and Diffusion in Oxide Layers,
- Radiological effects of Hydrogen Water Chemistry and Nobel Metal Chemistry addition,
- KEMOX 2000 – Kinetics of Oxide Layers,
- Project DORIS – Dose reduction in Swedish BWRs,
- The fuel failures in Oskarshamn 2 1988 – An Evaluation of the Radiological Effects during Ten Years of Operation.

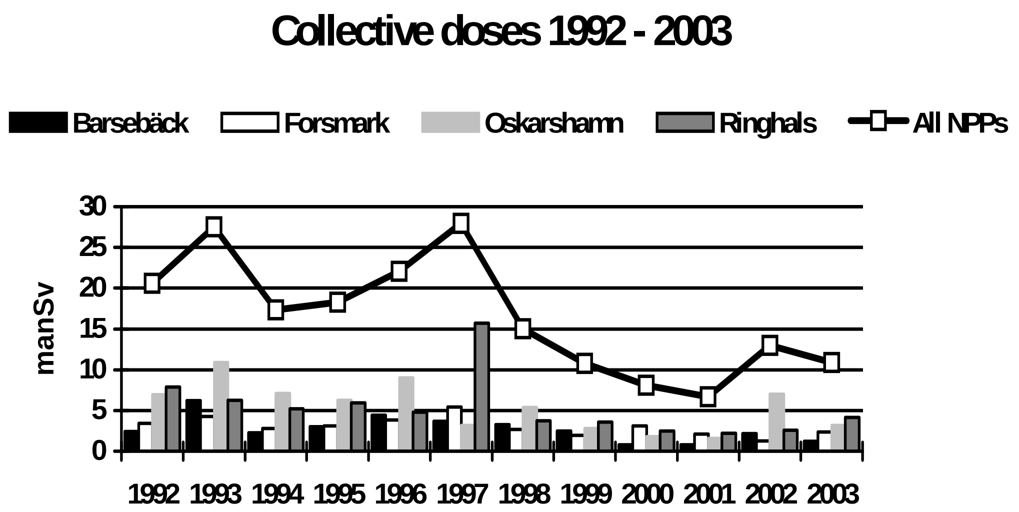

Figure 1. Collective doses at Swedish NPPs during 1992 - 2003

Present status

After a decade, the positive results of the combined actions from the SSI and the Swedish nuclear industry can be observed. Occupational doses have decreased and the radiological environment in the reactors has improved. Figure 1 shows the development of collective radiation doses at Swedish NPPs during 1992 – 2003[1]. As can be seen in the figure the collective dose has decreased from about 2 manSv in the beginning of the 90's to about 1 manSv in the last five years. It is the view of SSI that the occupational doses, today and during the passed years, would have been higher if no counterac-

[1] Since the number of operating reactor units is 12 (11 after 1999) it is possible to scale the y-axis with a factor of ten to get a good estimate of the average collective dose per reactor and year.

tions had been introduced in the beginning of the 90's. The average individual dose has in the same time interval decreased from 3 – 4 mSv/year to about 2,5 mSv.

The increase in radiation levels (apart from re-oxidation of contaminated surface layers) was generally stopped and in some plants lower levels were achieved due to the efforts to reduce the production and distribution of Cobalt 60. Low contamination levels and improved work procedures are also reflected in the low number of reported intakes of radionuclides. The number of reported intakes (leading to a committed effective dose larger than 0,25 mSv) is presently 1 – 2 per year.

The Future – Catchwords and Outlook

Competence

A basic condition for good performance in the radiation protection area is that the staffs is familiar with the risk of ionising radiation, actions to prevail unnecessary exposures and the meaning of good practice. The changed education programmes, earlier introduced at the nuclear power plants, had a significant influence on the workforce competence as well as the general commitment to radiation protection items. SSI continues to underline the importance of the plant management commitment to radiation safety issues and the use of preventive measures to decrease dose rates and doses.

SSI recently inspected the radiation protection education programmes at the NPPs. SSI has the view that in the next few years it is possible to maintain the level of competence and secure necessary educations and training. In order to secure good long-term radiation protection conditions at the Swedish nuclear power plants it is, however, important that national support of natural sciences and nuclear technology can be sustained. The SSI is today using a large fraction of its research budget to support critical competence areas at the universities (professorial chairs, postgraduate appointments) such as radiobiology, radiation medicine, radio physics and radioecology.

Experience feedback

An important task in developing radiation protection is the use of channels for exchange of information and feedback of good/bad practices. The operators use both national and international information systems. The ISOE (Information System of Occupational Exposure), organised by OECD/NEA and IAEA, is used for exchange on dose statistics, information and technical issues. Another important system is INES (International Nuclear Event Scale) through which occurring accidents/incidents are classified and communicated to the media and the public.

The SSI stresses the need for openness and transparency within the nuclear industry. This will lead to early reporting on poor situations, the use of good practices, and improvements. In the present Swedish nuclear industry safety culture, feedback from both incidents and good practice are reported, collected and analysed. Communication, both internal and external, should be encouraged as a natural part of the daily work. It is important to retain this openness also in the future and it must therefore be a central issue in the organisational work. A key resource is every individual worker who must feel responsibility and commitment to report and inform within and outside of the organisation without the risk of punishments or repressive actions.

Preventive Measures

Good radiation protection conditions are achieved by proactive actions and preventive measures. The necessary work starts with the source-term, i.e. to prevent distribution and build-up of radioactive nuclides on the reactor system surfaces. The Swedish nuclear power industry has improved the radiation levels at the stations by improving the reactor water chemistry and by selecting new, more appropriate materials in valves and piping. Development of new methods and new equipment for non-destructive testing are other examples of preventive measures. It should also be recognised that radiation protection issues are now considered in the early planning stage of projects and maintenance work.

The SSI is led to believe, based on the development of new safety requirements and on the expressed wish to increase power production in existing power plants, that more refurbishment work will take place at the Swedish reactors. The SSI therefore identifies as one of its principle future tasks to, in the dialogue with the plant operators, ensure that radiation protection issues are adequately addressed in these processes. Sufficient resources should be allocated and radiation protection issues have a reasonable priority, in order to maintain and possibly improve radiological protection conditions.

Long-Term Planning

For the industry to invest, technically as well as in human resources, in increased safety and bettered radiation protection, there is a need for long-term perspectives and long-term planning. It is important to see beyond the short-term perspective and try to foresee and meet the future needs. This is true when competence, research, technical development as well as economical investments are addressed.

On the political agenda, discussions are presently held between the Swedish government and the nuclear power industry on the future use of nuclear industry and how the politically decided phase-out of nuclear energy should be performed. If such an agreement is reached, it could perhaps improve on the existing situation in the sense that uncertainties are removed and improved planning of maintenance, repair and modernisation of the nuclear power plants can be performed. It is the experience of the SSI that long-term views and planning in advance improve radiation protection conditions.

Final conclusion

It is the view of the SSI that essential efforts to improve the radiation protection conditions at the Swedish nuclear power plants have been made. The radiation protection conditions are good, which is a result of long-term efforts on reducing radiation levels, improving work procedures as well as increasing the knowledge of, and the commitment to, radiation protection issues at the staff level. Some of the most important aspects that led to the present good radiological situation can be summarised by the following catchwords: *Competence*, *Experience Feedback*, *Preventive Measures* and *Long-Term Planning*.