RADIOLOGICAL IMPACT OF NUCLEAR POWER IN SWEDEN - PRINCIPLES AND TRENDS

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Nuclear power is today a major source of electricity in Sweden. In 1986 the consumption of electric energy in the country - with its 8.3 million inhabitants - was about 130 TWh which is among the highest per capita in the world. Since 1971 twelve light water reactors (LWRs) have been put into operation, the last two in the autumn of 1985. Altogether the reactors have been in operation slightly more than 100 reactor years. Today nuclear power accounts for about 50 per cent of the total production of electricity in Sweden while the remaining half is supplied almost entirely by hydro-electric power.

The occupational radiation exposure has during these years been comparatively low put in an international perspective with only a few exposures over the dose limits. The radiation exposure outside the four nuclear sites caused by the released radioactive substances has generally been only a few per cent of the reference value given by the national regulations. This applies to a situation in which the long term exposure effects from carbon-14 are not included.

1 OCCUPATIONAL EXPOSURE

The occupational exposure is influenced by a number of technical as well as administrative factors. The radiation sources inside a plant are design-related and depend on such factors as material selection and water chemistry. Other important factors are work-planning, education, training, dose surveillance and feed-back of experience. It is also essential that the radiation protection staff has such a position within the plant organization that it can have an overview and influence of all these factors.

The same type of thermoluminescent dosimeters are used by all Swedish plants and the recorded doses are transferred to a joint register for dose data. The intakes of radioactive substances are checked at the plants by whole-body measurements. Internal exposure has, however, been insignificant compared with external exposure.

1.1 COLLECTIVE DOSES

About 70 to 80 per cent of all the collective doses are received during the routine outage periods. The distribution of the annual collective doses has been such that the contractors' personnel received about 75 per cent of the total annual collective doses. To establish a tentative guideline for a restriction of the occupational exposure at the Swedish LWRs, the Swedish National Institute of Radiation Protection (NIRP) has suggested 2 mmanSv per installed MW electrical capacity and year as a level of ambition to which the collective dose equivalent on average should be limited. Table 1 gives the values for the past ten years.

Table 1 NORMALIZED ANNUAL COLLECTIVE DOSES AT SWEDISH LWRs - 1977 - 1986

Year	Number of reactors	Average manSv per unit	a) mmanSv per MW(e)·a	b) mmanSv per MW(e) per year
1977	6	1.70	4.9	2.9
1978	6	1.37	3.2	2.2
1979	6	1.69	4.2	2.7
1980	7	1.43	3.5	2.2
1981	9	1.46	3.2	2.1
1982	9	1.06	2.3	1.5
1983	10	1.47	3.2	2.0
1984	10	1.16	2.0	1.6
1985	12	0.92	1.7	1.2
1986	12	1.43	2.1	1.8

a) Energy generated
b) Installed capacity and year

1.2 INDIVIDUAL DOSES

The average annual dose both for plant personnel and contractors' personnel has been between 2.5 and 3.5 mSv. The distribution has been such that about 85 per cent of the workers received annual doses less than one tenth of the 50 mSv dose limit. On average only three per cent of the workers exceed 15 mSv. Only a very few overexposures have occurred and none of them has been serious.

1.3 PREDICTION OF LIFETIME DOSES

Some attempts have been made to predict the lifetime dose-equivalents for the workers who receive the highest occupational exposure. About two per cent of the exposed workers, which means 150-200 individuals, were considered. The average predicted dose over a 40-year employment period amounted to 0.5 Sv with maximum values in the order of 1 Sv. It is impossible to point out a special occupational group as all groups have a few individuals with comparatively high lifetime doses. However, the group "material testers" and some specialists among the "mechanical workers" seem to be the most interesting groups in this respect.

2 RELEASES TO THE ENVIRONMENT

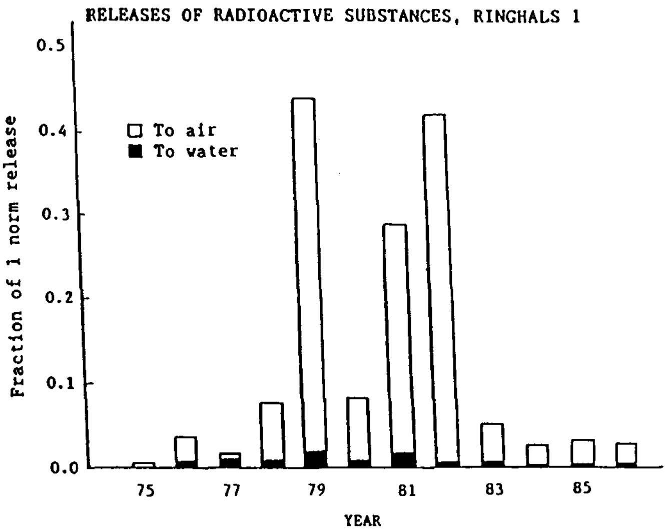
The regulations regarding limitation of releases of radioactive substances from nuclear power plants (NPP) were in their present form issued by the NIRP about ten years ago. The main general provisions state that every NPP shall have such a design for normal operation conditions that the sum of the effective dose equivalents due to expected resulting releases should be less than 0.1 mSv per year. This dose applies to the critical group. An annual evenly distributed release corresponding to this dose value is named a norm release. This value shall be seen as a reference value and it has not the formal character of a limiting value for the permitted dose in a given operating situation.

The limit for the global collective dose equivalent is set to 5 manSv per gigawatt of installed electric power and year. For radioactive nuclides with long half-lives such as carbon-14, the time integral of the collective dose equivalent rate is over 500 years. The purpose of the limitation of the collective dose is to limit the future annual average dose equivalents to 100 µSv at a time when the number of reactors may be much greater than today. This requirement has so far been applied less stringently than was intended but that can be acceptable during the initial period of time of the nuclear power era.

2.1 ATMOSPHERIC RELEASES

The releases of radioactive nuclides have varied in time and between the various units. The dominating amount of releases comes from atmospheric emission of radioactive noble gases. This kind of release depends greatly on the condition of the fuel cladding. For example the releases of noble gases from Ringhals unit 1 have been the highest among the Swedish reactors, see figure 1. In this case the fuel cladding damage is expected to

Figure 1



have been caused during the first years of operation when different power change tests were performed. The original old fuel has been gradually replaced which has resulted in considerably lower releases. In recent years the atmospheric emission from Ringhals 1 has been below 5 per cent of a norm release which corresponds to an annual effective dose equivalent of 5 µSv or less. Furthermore the newer reactors in Forsmark and Oskarshamn have been equipped with offgas treatment systems including charcoal columns and a recombiner system. These systems have limited the emission of radioactive gases from the plant further.

With the exception of a few years, the annual atmospheric emission has been of the order of 1 to 5 per cent of a norm release for Ringhals and Oskarshamn. For Forsmark and Barsebeack the releases have been at least an order of magnitude lower. The contribution from C-14 is not included in this assessment.

2.2 AQUATIC RELEASES

As in the case of the releases to the atmosphere, the releases to water have not varied appreciably between the four nuclear power sites. In this respect Figure 1 can therefore be seen as a representative example. This means that the relative contribution from aquatic releases to the exposure of the critical group is much higher for Forsmark and Barsebaeck than for the other two Swedish sites. The releases to water, which mainly consist of radioactive corrosion products, have been of the order of 1 to 3 per cent of a norm release .

2.3 COLLECTIVE DOSE ASSESSMENT

The major contribution to the collective dose comes from carbon-14 wich is mainly released to the atmosphere. However, no measurements of releases are regularly performed at the Swedish nuclear power plants. To assess the radiological impact of released carbon-14, data are taken from national and international analyses.

The estimated doses are given in Table 2. For Ringhals site this means 3 manSv per GW(e) installed capacity per year and for the other three sites 6 manSv. The latter value is slightly above the ambition level given in the regulations.

Table 2. Annual doses from releases of C-14 from Swedish LWRs

Site	Individual dose b) (µSv)	Collective dose (manSv)
Barsebeack	0.9	7
Forsmark	0.6	18
Oskarshamn	0.5	13
Ringhals	11	10

b) Critical group

2.4 SUMMARY

The highest releases have been at the Ringhals unit 1 and Oskarshamn unit 1, and have in some exeptional years been of the order of 40 to 50 per cent of a norm release. This corresponds to assessed doses of about 50 µSv. For most of the years the assessments of the exposure for the critical group give doses of the order of 5 üSv or less when the contribution from carbon-14 not is included.