Radiation doses to Swedish nuclear workers and cancer incidence in a nuclear power plant

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Introduction, the Swedish nuclear energy program

There are about 2000 nuclear facilities in Sweden licensed by the Swedish radiation safety authority (1). Thirty are nuclear technical plants and three are nuclear power plants with 10 now running reactors. The Swedish nuclear program started in early 50ies with the first nuclear reactor at the Royal Technical Institute of Stockholm reaching criticality in 1954 (table 1). National self-sufficiency was stressed in the beginning of the nuclear program stressing the possibility to both produce energy and create strategic atomic weapons. Sweden has relatively large uranium findings and heavy water could be obtained from the Rjukan facility in Norway. The first commercially energy producing plant started in 1964 in Stockholm, a heavy water reactor for both district heat and electricity. Out of totally 16 Swedish reactors built, presently there are 10 reactors in use (table 1). The two reactors in the Barsebäck nuclear power plant were stopped in 1999 and 2005. Recently the Swedish state enterprise Vattenfall has acquired shares in three German nuclear reactors with 67% shareholding in Brunsbüttel, 50% in Krümmel and 20% in Brokdorf.

Table 1. Table of nuclear reactors located in Sweden or run by a Swedish company abroad.

Site	Type	Electric effect Brutto/Netto (MW)	Thermic effect (MWh)	In operation
Stockholm R1	HWR	n.d.	Up to 1	1954-1970
Studsvik R2 (and R2a*)	Swimming pool LWR	n.d.	30-50	1960-2005
Stockholm R3	PHWR	12/10	80	1964-1974
Norrköping R4	B/PLWR	n.d.	n.d.	Planned 1964*
Barsebäck 1	BLWR	615/600	1800	1975-1999
Barsebäck 2	BLWR	615/600	1800	1977-2005
Oskarshamn 1	BLWR	487/467	1375	1972-
Oskarshamn 2	BLWR	627/602	1800	1975-
Oskarshamn 3	BLWR	1194/1160	3300	1985-
Ringhals 1	BLWR	870/830	2500	1976-
Ringhals 2	PLWR	910/870	2652	1975-
Ringhals 3	PLWR	960/920	2775	1981-
Ringhals 4	PLWR	970/915	2775	1983-

Forsmark 1	BLWR	999/961	2928	1980-
Forsmark 2	BLWR	997/956	2928	1981-
Forsmark 3	BLWR	1227/1185	3300	1985-
Brunsbüttel**	BLWR	806/771	2292	1976-2007
Krümmel**	BLWR	1401/1346	3690	1983-2009
Brokdorf**	PLWR	1480/1410	3900	1986-
Marcoule***	ASTRID	n.d.	n.d.	Planned for 2014?

n.d.= not defined, *Never finished, **Germany, ***France
HWR= Heavy water reactor
LWR= Light water reactor
PHWR= Pressure heavy water reactor
BLWR= Boiling light water reactor
PLWR= Pressure light water reactor
ASTRID= Advanced Sodium Technological Reactor for Industrial Demonstration

Presently only Brokdorf is running, because of the 2011 German governmental decision for a planned termination of nuclear energy production. Instead an agreement between the Swedish and French governments has been signed in 2011 to develop a sodium cooled fast neutron reactor prototype (ASTRID, Advanced Sodium Technological Reactor for Industrial Demonstration) in French Marcoule.

Radiation doses to Swedish nuclear workers

Out of presently ten running reactors four were built in the seventies and have therefore been extensively renovated, to increase both power, safety and life expectancy. Therefore an extensive renovation program was launched to modernize existing reactors. These renovations of existing reactors were performed mainly during the 90ies causing both an increase in the number of exposed workers and their doses (fig 1).

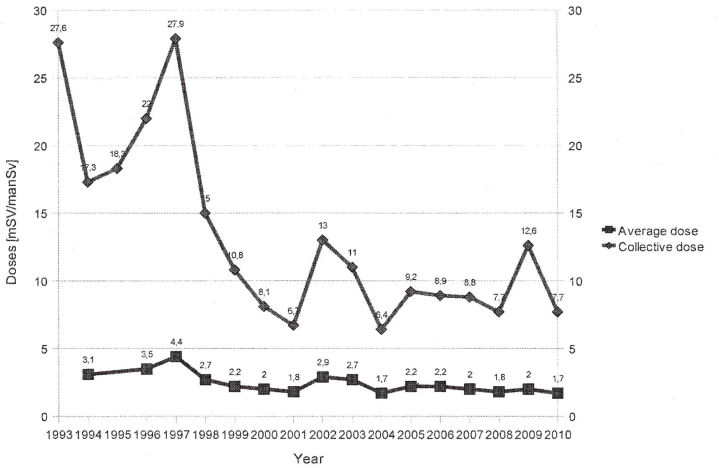

Figure 1. Average effective doses [mSv] and collective doses [manSv] for Swedish nuclear workers reported to the National dose registry from 1993 to 2010.

The average dose among the nuclear workers reached a maximum level in 1997 with an average received external dose of 4,5 mSv to 6500 nuclear workers (table 2) (1). Received average doses for the workers have been roughly constant during the last ten years with annual average received external doses ranging between 1,7 and 2,7 mSv (table 2). Among totally 4 400 nuclear workers, with registered doses, the collective dose during 2010 was 7.7 manSv. The average dose was 1.7 mSv during 2010 compared to 2.0 mSv to 6400 workers during 2009. The Swedish radiation safety authority is also focusing on special sources of radiation doses. Increasing doses have been observed for the turbine hall workers, probably due to higher levels of dampness from boiling water reactors (1). The average received doses are approximately 50% higher in Swedish boiling water reactor plants than for pressure water plants. Also chronic inhalation of uranium dust is an occupational problem with internal radiation doses close to present safety limits. Therefore all nuclear power stations participate in a project measuring whole body radiation of the nuclear workers in order to screen for possible internal contamination. Another major source of received radiation dose is radiographic work when the reactor construction is checked with mobile X-ray equipment (1).

Table 2. Reported external and internal doses for Swedish nuclear workers (only power stations) to the Swedish national dose register from 1993 to 2010

Year→	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
Number of nuclear workers	n.d.	n.d.	n.d.	n.d.	6341	5433	4801	3988	3639	n.d.	4074	3664	4195	4238	4348	4290	6403	4462
Average dose (mSv)	n.d	3,1	n.d.	3,5	4,4	2,7	2,2	2,0	1,8	2,9	2,7	1,7	2,2	2,2	2,0	1,8	2,0	1,7
Collective dose (manSv)	27,6	17,3	18,3	22,0	27,9	15,0	10,8	8,1	6,7	13,0	11,0	6,4	9,2	8,9	8,8	7,7	12,6	7,7
Maximal dose (mSv)	n.d.	31,7	n.d.	n.d.	45,4	33,0	25,0	20,7	19,6	n.d.	26,7	19,5	23,6	19,7	18,2	18,6	22,8	16,9
External dose >20 mSv	216	47	26	n.d.	258	15	6	1	0	n.d.	8	0	n.d.	0	0	0	n.d.	0
Internal dose**	0	0	0	0	0	0	0	0	0	n.d.	1	2	2	0	2	0	0	0

n.d.=not defined/no data
** Number of nuclear workers receiving an external dose exceeding 20 mSv.*
*** Number of nuclear workers receiving an internal dose exceeding the current safety limit (5 mSv to 1999, 1 mSv 2000-2002, 0,25 mSv from 2003)*

Cancer incidence at the Forsmark nuclear power plant, background

There has been concern among the personnel at the Forsmark nuclear power plant about a supposedly increased number of cases of cancer among the nuclear workers, and the department of Occupational medicine at Uppsala university hospital was asked to investigate this.

Method

Medical records for the nuclear workers during 6 years were retrieved from the local occupational health clinic to verify the occurrence of neoplastic disease. Smoking habits were also recorded. The Forsmark nuclear power plant has 1050 employees. The expected number of neoplastic diseases were calculated according to age- and gender standardized data from the Swedish cancer registry. The standardized incidence rate (SIR) was calculated as the ratio between the number of observed and expected cases. A Chi-square significance testing of the supposedly poisson distributed cases was made. Accumulated individual effective doses were retrieved from the Swedish dose registry.

Results

Retrospectively during a period of 6 years 20 cases with malignant disease could be verified (table 3). For comparison 14.7 cases were expected among the work force according to age- and gender-standardized data from the Swedish cancer registry. SIR, the standardized incidence rate was 1.4 with confidence interval 0.8-2.1. The average cumulative effective dose registered by the national dose registry was 4,5 mSv for the 20 subjects with malignant disease (table 3). This cumulative dose is about twice the average yearly dose for all Swedish nuclear workers (table 1). A clear dose-response pattern could not be found from registered doses. The mean age during the study period increased from 39 to 43 years and the proportion of female employees were constant (18 %). Information about smoking habits in all personnel was not available, but among the cases 63 % had been smokers.

Table 3. Cumulative doses and smoking habits among 20 cases with neoplastic disease.

Type of cancer	Age	Cumulative dose [mSv]	Ever smoker*
Lung	52	2,1	+
Lung	52	-	-
Lung	53	1,4	+
Lung	53	8,9	+
Lung	66	0,9	+
Breast	40	-	-
Breast	47	-	-
Breast	49	44,9	?
Colon	54	2,9	-
Colon	55	-	+
Brain	49	-	?
Brain	39	0,1	?
Germinalcell	41	6,1	+
Thyroid	58	-	+
Hodgkin	52	12,7	+
CLL*	50	2,1	+
Stomach	55	-	+
Prostate	62	6,7	+
Uterus	52	1,5	+
Cervix	54	-	+

*Chronic lymphatic leucemia

Discussion

According to the Swedish dose registry the average mean dose to Swedish nuclear workers has been relatively stable during the last ten years, ranging between 1,7 to 2,7 mSv (table 2). It is about the same level as the mean yearly natural background radiation dose of 2,4 mSv to the Swedish population (2). Due to extensive renovation jobs higher doses were received during the 90ies with mean received yearly doses up to 4,4 mSv. In the Forsmark nuclear plant, where there had been an alarm about increased occurrence of cancer among the nuclear workers the average doses have been lower than the national average doses (1). A significantly increased incidence of malignancies could not be verified by a crude comparison between the number of observed and expected cases.

There has been a debate whether nuclear workers have an increased risk of cancer or not. Rosalie Bertell claimed already in the seventies that they are at risk of having malignant diseases (3). The largest study on cancer incidence among nuclear workers, the 15 countries collaboratory study comprising 407 391 personnel, found an increased risk for total cancer incidence (RR=1,1 at a nominal accumulated dose of 100 mSv) (4). The Swedish sub-cohort of this study showed on the contrary a lower risk for Swedish nuclear workers. This could probably be explained by a "healthy-worker effect" which was observed in most participating countries (5). It is also well-known that smoking is an effect-modifier of cancer induction together with ionizing radiation, for example increasing the risk of lung cancer with concomitant radon exposure (6). Since a majority of the workers in the present study were smokers, as compared to less than 20% in the general Swedish population, the attribution of smoking to the cases of lung cancer, which were 25 % of total cases of cancer, would be significant. Furthermore the individual mean accumulated dose over several years of employment among the cases was less than 5 mSv. Therefore ionizing radiation at work as a causative factor behind the 40% increase in observed cases of cancer in the present study could not be distinguished from the influence of chance or life-style factors.

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