5. RADIOLOGICAL EFFECTS ON WORKERS

5.1 Mining and Milling

139. In Table 16 a summary of occupational gamma and radon progeny exposures for 1997 is shown for two Canadian facilities, Key Lake and Cluff Lake. The collective effective dose for 1997 amounted to 1,8 manSv.

Table 16: Occupational exposures for Canadian facilities

Facility	Year	n	Mean γ-dose (mSv)	Max γ-dose (mSv)	Mean Rn progeny exposure (mSv)	Max Rn progeny exposure (mSv)
Key Lake	1997	369	0,40	4,0	0,65	2,1
Cluff Lake	1997	308	2,52	17	2,0	2,6

140. In Table 17 the exposures for designated workers at the Australian mines, Ranger and Olympic Dam are shown for 96/97. The collective effective dose amounted to 1,7 manSv.

Table 17: Occupational exposures for Australian mines

Facility	Year	n	Mean dose (mSv)	Max dose (mSv)
Olympic Dam	1997	421	3,0	9,6
Ranger mine	1997	87[4]	5,2	9,4

5.2 Conversion and Enrichment

Uranium ore concentrate to Uranium hexafluoride conversion

141. Few data are available on occupational exposure at conversion facilities. In the ExternE-Study, Chapter 5.4.2, collective doses for the Malvesi and Pierrelatte facilities in France are given, in total 0.93 manSv per year. Normalised to the plant throughput an occupational dose of 2.29 E-03 manSv/TWh or 0.02 manSv/GWa is been reported. This value can be taken as reference value for the once-through fuel strategy, the corresponding value for the recycling mode is 0.016 manSv/GWa.

142. The range of radiation doses to workers involved in the process operated at BNFL Springfields can be illustrated by information taken from annual dose statistics presented to the site's Nuclear

---

[4] Calculated from collective doses.

Safety Committee. For the main employee groups involved, in a typical recent year (1996), the mean individual dose was 1.5mSv. No individual worker received a dose greater than 10mSv. Collective dose was approximately 300mSv.

Uranium enrichment

Gaseous diffusion process

143. Occupational doses in gaseous diffusion plants are very small due to the hermetic containment for UF_6 during all process steps and the low radioactivity of uranium during enrichment from natural U-235 content to low enrichment levels as mainly used for thermal LWR. Data from EURODIF show that no annual individual dose above 1.5 mSv occurred in 1997 for more than 1600 workers.

Table 18: Occupational doses at EURODIF in 1997

	Number of workers	Number of workers with doses above zero	Collective dose manSv	Individual dose (mSv) distribution			
				0 - 0.35	0.35 - 0.75	0.75 - 1.5	> 1.5
EURODIF workers	1006	40	0.018	22	13	5	0
Outside workers	614	3	0.001	1	2	0	0
All workers	1620	43	0.019	23	15	5	0

144. Similar collective doses are given in chapter 6.4.2 of the ExternE-Study (0.005 manSv/y or 7E-05 manSv/GWa). Taking the EURODIF experience in 1997 as reference case occupational doses of 4E-04 manSv/GWa and 3E-04 manSv/GWa can be derived for the once-through and the recycling option.

Centrifuge enrichment facilities

145. Occupational radiation doses in centrifuge enrichment facilities are also very small. Data from Capenhurst and Gronau show that on average the individual doses to workers under radiation monitoring are 0.2 to less than 0.1 mSv/a. The collective dose at Gronau (nominal capacity 1000 t SWU/a) in 1994 was less than 0.001 manSv for a real throughput of 760 t SWU [HOE 96]. On this basis the following collective doses normalised to one GWa can be determined: For the once-through fuel cycle strategy 2.3E-04 manSv/GWa, for the recycling strategy l.9E-04 manSv/GWa.

5.3 Fuel Fabrication

UO_2 fabrication

146. Based on the measured individual doses in 1997 and the number of workers, the average annual occupational individual dose is 0.15 mSv/y and the normalised collective dose is $6.6.10^{-3}$ man.Sv/GWa. *[Ref.]*

MOX fabrication

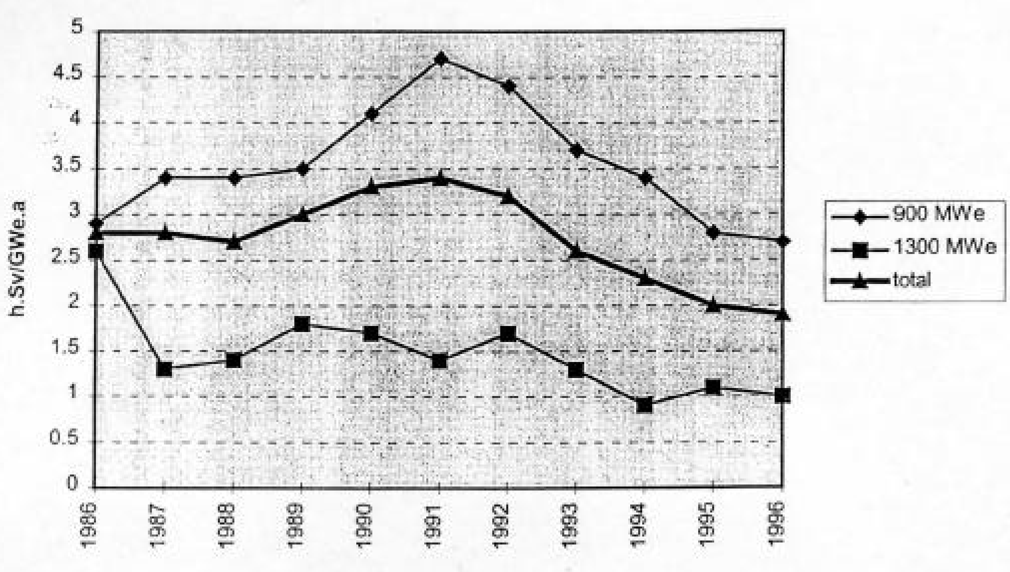
147. Based on the measured collective dose for the workers (MELOX and subcontractors) in 1997 (1.17 man.Sv) and the number of workers, the average annual occupational individual dose is 0.53 mSv/y and the normalised collective dose is 0.43 man.Sv/GWa.

5.4 Power Generation

148. The exposure of workers is essentially related to the type of reactor, the kind of maintenance, the frequency of fuel reloading operations and the radiation protection practices (see reference [4] for the whole section). The NEA [5] evaluated on the basis of the ISOE data base [6] the average collective doses for the period 1994-1996: 1.46 manSv per reactor, 1.43 manSv per GWe installed, and 0.31 manSv per TW.h [*2.7 manSv/GWa*] produced, for reactors whose installed power is between 800 and 1400 MWe. The detailed results appear in Table A9, see Annex A.

149. The record of accumulated doses from French reactors expressed in manSv per GWe.a is given in Figure 2. In 1996, this normalised dose was 2.7 manSv per GWe.year for the 900 MWe reactors, 1.0 manSv per GWe.year for the 1300 MWe reactors and 1.9 manSv per GWe.year for all the reactors combined [4].

Figure 2. **Change in the normalised dose in French reactors**



5.5 Interim Storage and Conditioning of Spent Fuel

Pool storage facilities

150. Because wet and dry AFR storage facilities in most cases are closely related to other nuclear facilities in the vicinity as NPP or waste storage facilities occupational radiation doses normally can only be given including service functions of the personnel at these related installations. As an example most of the occupational dose totalling about 1 manSv/reactor and year at the Olkiluoto NPP is caused by maintenance at the reactor itself during annual outages. Only a very small fraction of the total may be contributed to interim storage operations. For CLAB occupational doses between 1986 and 1996 varied from 0.05 to 0.135 manSv/year depending on the amount of maintenance work performed. Assessing an average of 250 tonnes per year of spent nuclear fuel handled and loaded at CLAB and 25 tonnes /GWa the occupational doses per GWa are approximately 0.05 to 0.0135 manSv/GWa.

Dry storage facilities

151. Present experience with dry storage of spent fuel assemblies is not yet sufficient to derive reliable data on occupational doses. Only very few casks have been transferred to the German AFR facilities at Ahaus and Gorleben. Individual annual doses for the personnel in these facilities are very low. For Ahaus an annual collective dose of 0.0013 manSv has been determined. On the basis of recent studies [HOE 96] an occupational dose of 0.011 manSv/GWa has been assessed for dry cask storage of industrial scale on the basis of annual handling 34 CASTOR-V-19-storage casks holding about 10 t HM each.

Conditioning of spent fuel

152. Based on the German concept of a pilot conditioning plant with the possibility to perform rod consolidation and rod cutting into about 1 m long pieces in a hot shielded cell a collective dose of 0.026 manSv/GWa has been assessed for a facility of industrial scale.

153. In the Finnish EIA study *[Ref.]* for site selection of the encapsulation and disposal facility for spent fuel. The total annual occupational dose for the personnel of the encapsulation and disposal facility is estimated to be $1.24.10^{-1}$ manSv. Of the total annual occupational dose about 90 % is due to the handling operations in the connection of the acceptance of the spent fuel transportation casks to the encapsulation facility. During certain handling operation in this stage it is assumed that the workers are for a short period exposed to the level of 2 mSv/h external dose. The assumed annual throughput of the facility in that case is 184 t U of spent BWR fuel corresponding approximately of 5.5 GWa of net electricity production. The normalised occupational dose would then be $2.3.10^{-2}$ manSv/GWa. It is expected that in practice the occupational dose would be clearly smaller. However, even these conservative estimates are clearly below the occupational doses (about 1 to 2 manSv/GWa) caused by the NPP operation.

5.6 Reprocessing, Vitrification and Interim Storage

154. The 1997 collective dose received by the workers in the plant, including COGEMA personnel and subcontractors on the site of La Hague, is 0.56 man.Sv. The average annual individual dose is 0.14 mSv/y and the normalised collective dose is $1.2.10^{-2}$ man. Sv/GWa .

5.7 Disposal of Solid Waste

155. In the connection of the Finnish EIA study for repository siting estimates were derived for the occupational doses to the personnel of the encapsulation facility (cf. Ch. 5.5, conditioning of spent fuel). Based on the estimates it was concluded that the occupational doses are dominated by the encapsulation stage (the acceptance of spent fuel after transportation) and only significantly lower exposure (clearly less than 10^{-4} manSv/GWa would be caused to the workers during the transfers to the repository and the subsequent emplacement of canisters into the disposal holes.

5.8 Transportation

156. Concerning the radiological impact from the normal transport operations of radioactive material within the nuclear fuel cycle, mostly fragmentary data are available in the literature. The most comprehensive source of data is constituted by the findings of an IAEA technical committee ([1]) in 1986. These results are summarised in the Annex A. Although the data were incomplete in so far as they do not represent a global set and are restricted in some cases to only part of the transport field in the countries, it could be concluded from this report that exposures from normal transport operations are very low both for workers and for members of the public. UNSCEAR, in its 1988 report ([2]) derived normalised collective effective dose equivalents of 0.2 manSv $(GWa)^{-1}$ and 0.1 manSv $(GWa)^{-1}$ for respectively the occupational and population exposure brought about by transportation activities within the nuclear fuel cycle from the submissions of the United States and the United Kingdom to the IAEA study. In the UNSCEAR report of 1993 ([3]) the normalised CED (collective effective dose) value of 0.1 manSv $(GWa)^{-1}$ for the population was confirmed.

157. When considering routine transportation of radioactive materials in the three important segments of the nuclear fuel cycle, namely spent fuel, fresh fuel and waste, the differences in normalized collective doses (both occupational and public) between the two considered fuel cycle options are expected to be quite small; of the order of some 10^{-3} man Sv / GWa. The differences may be brought about, on the one hand by the location of the installations, on the other hand by factors that are are inherent to the systems. These factors may include the larger amounts of fresh uranium ore and HLW to be transported in the once-through cycle, and the larger amounts of LLW and ILW and reprocessed fuel in the closed fuel cycle.

158. A recent German study ([8]) indicates larger collective doses for the closed cycle with differences of the order of more than 10^{-2} man Sv / GWa for the occupational dose and of an order of magnitude lower for the dose to the public. A Finnish study summarised in [9] however indicates rather high occupational dose values (up to the order of the values for the whole fuel cycle in Germany) for the transport of spent fuel only in a once-through fuel cyle. As already mentioned the differences in the estimated doses may be explained to a large extent by site-specific conditions (transportation distances, densities of population etc.) and the degree of conservatism in the assumptions of the different studies.

159. As an overall conclusion the differences in normalised occupational or public exposures between the fuel cycle options considered in this study are small. Furthermore, the relative contribution of transportation stages is small relative to the most dominant stages of the fuel cycle options considered (i.e. mining & milling, reactor operation and/or reprocessing of spent fuel).

160. The maximum annual individual doses reported range from trivial ones to the public (less than 0.01 or 0.03 mSv / a) to less than 5 mSv / a for the workers in Europe.