7. CONCLUSIONS

195. The main objective of this report has been the comparison of radiological impacts caused by two fuel cycle options, of which one is based on the once-through fuel cycle and the other one on the spent fuel reprocessing with the recycle of separated plutonium in the form of mixed oxide fuel bundles. In the preceding chapters the exposures to the workers and the general public brought about by these two spent fuel management options have been presented separately for each of the fuel cycle step. To the extent possible, actual release and exposure data are used to represent the state-of-the-art technology and current practices. Several assumptions are introduced to facilitate comparison of radiological effects of two options and to reduce uncertainties: simplified fuel cycles, long-term stability of mining and mill tailings, no use of depleted uranium from enrichment, no reuse of depleted uranium from reprocessing, no release from waste repository, etc. The comparison is made by using generic models.

196. Another important consideration is that all the public dose contributions are entailed with large uncertainties. Doses to workers are measured individually; but doses to the public are calculated, using scenarios and models. Important uncertainties affect scenarios and models as well as the basic data.

197. Use of models to evaluate public doses are inevitable for many reasons. This situation is not specific to nuclear energy. In particular:

- Doses to public are very small and the various contributions of different origin cannot easily be identified and measured directly.
- The behaviour of radionuclides in the environment is very complex due to many variables and the behaviour of population in question is also complex.
- The larger part of doses resulting from a specific discharge will be received much later in the future, when radionuclides have migrated through the environment.

198. Detailed safety studies are carried out by regulatory authorities before authorising discharges. Uncertainties on scenarios and models are being taken into account, often by taking conservative hypothesis. It is important to note that discharges considered in this study are much below present authorised limits. It is not surprising that resulting doses are also below regulatory limits.

199. The most important results of the radiological effects of the two options are summarised in Table 21. One of the main findings of the study is that radiological impacts brought about by the two fuel cycle options considered are of about the same order of magnitude for both the general public and the fuel cycle facility workers. Only few radionuclides are important: 14c, 1291, Ruthenium are significant both for power production and reprocessing. The exposures in the mining and milling stage are caused by the daughter nuclides of the naturally occurring uranium decay chains. Collective doses are composed of very small doses to a large large number of people over a long period of time. Each contribution is also negligible compared with the level of natural background radiation. Much of the collective dose is produced by 14C.

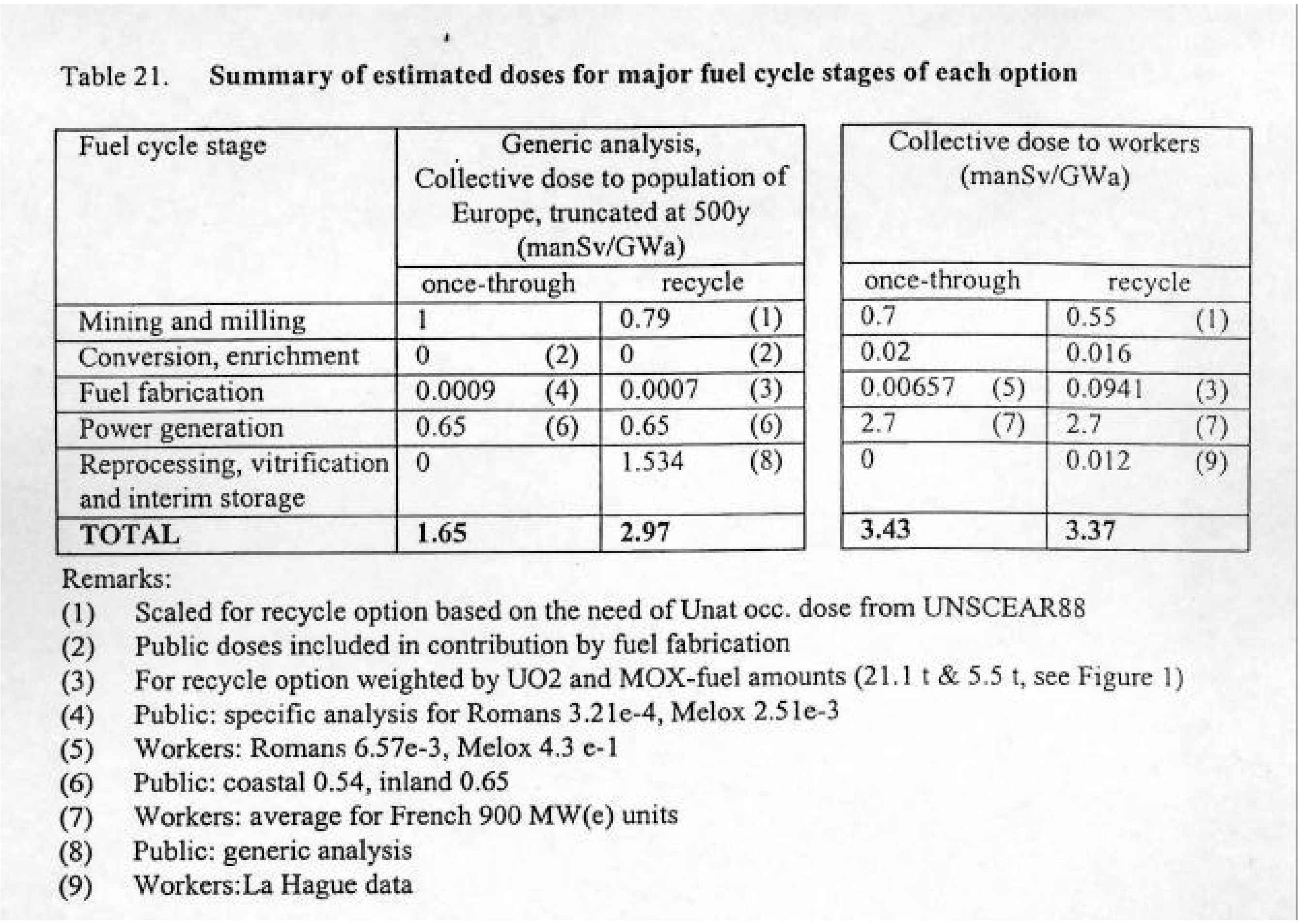

Table 21. **Summary of estimated doses for major fuel cycle stages of each option**

Fuel cycle stage	Generic analysis, Collective dose to population of Europe, truncated at 500y (manSv/GWa)		Collective dose to workers (manSv/GWa)	
	once-through	recycle	once-through	recycle
Mining and milling	1	0.79 (1)	0.7	0.55 (1)
Conversion, enrichment	0 (2)	0 (2)	0.02	0.016
Fuel fabrication	0.0009 (4)	0.0007 (3)	0.00657 (5)	0.0941 (3)
Power generation	0.65 (6)	0.65 (6)	2.7 (7)	2.7 (7)
Reprocessing, vitrification and interim storage	0	1.534 (8)	0	0.012 (9)
TOTAL	**1.65**	**2.97**	**3.43**	**3.37**

Remarks:
(1) Scaled for recycle option based on the need of Unat occ. dose from UNSCEAR88
(2) Public doses included in contribution by fuel fabrication
(3) For recycle option weighted by UO2 and MOX-fuel amounts (21.1 t & 5.5 t, see Figure 1)
(4) Public: specific analysis for Romans 3.21e-4, Melox 2.51e-3
(5) Workers: Romans 6.57e-3, Melox 4.3 e-1
(6) Public: coastal 0.54, inland 0.65
(7) Workers: average for French 900 MW(e) units
(8) Public: generic analysis
(9) Workers:La Hague data

200. The normalised collective radiation doses (manSv/GWa) to the public are dominated by the "Mining and Milling", the "Power Production" and the "Reprocessing" stages. While the power production causes the same radiological impacts for both the fuel cycle options, the other two main stages are different for the options to be compared in this study. By the use of MOX-fuel the need of natural uranium is reduced (by 21 %) and consequently the radiation exposures caused by the mining and milling stage are reduced directly proportional to the amount of natural uranium feeded into the the fuel cycle. On the other hand the use of MOX-fuel necessarily involves the reprocessing of spent fuel and hence causes the radiological impact only in the case of the recycle option. The differences between the compared fuel cycle options in mining and milling and reprocessing are thus opposite and tend to compensate each other. Due to the uncertainties involved as concerns e.g. the demographic conditions around the reference facilities as well the assumptions concerning the calculation of collective doses, the total radiological impacts (collective dose per unit amount of electrical energy produced) caused to the general public by the two fuel cycle options are very similar.

201. It is interesting to demonstrate the complexity of dose evaluation. In the Table 21, the results from the generic analysis of doses to the public are presented and they are significantly different from those of more detailed site specific analysis. In case the results from site-specific analysis for the La Hague reprocessing plant were employed instead of the generic results, the sum of public doses over all fuel cycle stages in the recycling option would reduced to about 2.2 manSv/GWa; i.e. only about 30 % higher than the sum for the once-through option. Uranium mining is very site specific and doses caused by mining and milling tailings disposal are strongly influenced by environmental conditions, mining and milling practices, characteristics of the uranium containing rock and procedures for

maintenance and remedial actions as well as long-term stability of disposed tailings. When a different scenario for mining and milling tailings disposal is used, doses caused by this increase very easily.

202. In view of limitations and uncertainties involved in the generic evaluation, it is not justifiable to draw meaningful conclusions from those differences in the collective and individual radiological effects. Consequently, it is not possible to straightforwardly favour either of the main option based on the collective or individual radiological impact considerations only. Overall, the public exposures in both options are low as compared to the pertinent regulatory limits also insignificantly low as compared to the exposures caused by the natural background radiation.

203. Comparison between occupational and public doses is not straightforward. Therefore it is hardly relevant to sum up these together. Based on the summary presented in Table 21, the occupational doses over the whole fuel cycle are dominated (about 75 % of the total) by the doses to the workers at the nuclear power plant. The occupational doses to NPP workers are not affected by the type of fuel used (IJO2 or MOX). In the fuel fabrication stage there is a considerable relative difference between the occupational exposures in the fuel cycle options However, the absolute values are only a small fraction of the sum over the whole fuel cycle for both the fuel cycle options.

204. Occupational doses can be measured. Workers are administratively and medically controlled. Therefore the estimates derived are involved with less uncertainties than the public doses which are estimated by employing mathematical models and data representative for reference facilities and sites.

205. Another aspect of radiological impacts remaining approximately the same in both fuel cycle options is the transportation of radioactive materials. Although the types of material transported and distances involved are somewhat different in the main options, it is not possible to make any clear difference between the options as regards the public or occupational exposures caused by transportation. Furthermore, the share of the radiological impact caused by transportation is small compared to the total impact and to the dominant stages of the fuel cycle.

206. The power production stage at the PWR reactor is the same for both options. Based on extensive measurements one can conclude that the introduction of MOX fuel has not had any noticeable effect on either liquid and gaseous releases during normal operation or occupational exposures of the workers at the power plants.

207. Discharges, hence also public doses, and worker doses have had a strongly diminishing trend in the recent years. This is in particular true for releases from reprocessing plants and for occupational doses in nuclear power plants.

208. It is probably possible to reduce further releases from a reprocessing facility, but difficult to reduce the radon release during operating phase of mining. For long-term radiological impacts caused by radon exhalation from the mining and milling tailings piles there are quite large differences between alternative remedial actions applied to the tailings piles. With very sophisticated remedial actions [*give examples]* the long-term releases could be reduced to insignificant levels. On the other hand with only modest remedial actions the radiological impacts

209. In case of no-reprocessing option, all radioactive nuclides are confined in the geological media. Certain long-lived radioactive nuclides such as I-129 will be leached in the groundwater when the

integrity of spent fuel canister degrade and contact with ground water. Such nuclides will eventually enter in the food chain and be a potential of exposure to the future generation in regional scale. In case of reprocessing option, some long-lived nuclides such as Tc-99 and I-129 are released in the marine environment in accordance with a radiation protection strategy and diluted in the environment. They are measurable with modern technology. They will eventually enter in the food chain. Their radiological significance to future population and environment is estimated nil but they will be a potential of exposure in global scale.

LIST OF PARTICIPANTS

Mr. T. ZEEVAERT

SCK/CEN

Mme. Michele VIALA

Mr. Jean-Francois LECOMTE

Mr. Jean Brenot

Mr. Gabor BUDAY
Public Agency for Radioactive Waste Management
Paks, Hungary

Mr. Tomohiro ASANO
Japan Nuclear Cycle Development Institute
Tokyo, Japan

Mr. Armando URIARTE
ENRESA
Madrid, Spain

Mr. John COOPER
National Radiological Protection Board
Chilton, Didcot, United Kingdom

Mr. Makoto TAKAHASHI
OECD Nuclear Energy Agency
Issy-les-Moulineaux, France

Mr. Seppo WORI (Chairman)
VTT Energy
Finland

Mr. Wolfgang THOMAS
Gesellschaft fur Anlagen- und Reaktorsicherheit (GRS)
Garching, Germany

Mr. David Pollard
Radiological Protection Institute of Ireland
Dublin, Ireland

Mr. David H. DODD
NRG
Petten, The Netherlands

Ms. Synnove Sundell-Bergman
Swedish Radiation Protection Institute (SSI)
Stockholm, Sweden

Mr. Clive WILLIAMS
Environment Agency
Bristol, United Kingdom

Mr. Bertrand RUEGGER (NEA Secretariat)
OECD Nuclear Energy Agency
Issy-les-Moulineaux, France

Occasional participants

Mr. Mark Loos
SCK/CEN
Mol. Belgique

Mr. Hiromitsu KANEKO
Japan Nuclear Cycle Development Institute

Mr. Christian DEVILLERS
IPSN, Commissariat a l'Energie Atomique
Fontenay-aux-Roses, France

Mr. Chong Mook PARK
KEPCO

Paris, France

Mr. Hermann PUCHTA
Mr. Ian HALL
CEC DO XI/C/I
Luxembourg

Mr. E. HORMANN (Consultant)
Gesellschaft fur Anlagen und Reaktorsicherheit (GRS)
Cologne, Germany

Taejon, Korea

Mr. A. CIGNA (Consultant)
Cocconato, Italy

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