International
Nuclear
Fuel
Cycle
Evaluation

# INFCE

INFCE/DEP./WG.7/14

# OUTLINE OF ENVIRONMENTAL IMPACT OF WASTE MANAGEMENT

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Prepared by the Australian Delegation
on behalf of Working Group 7

September 1979

## ABSTRACT

This document presents background information on the environmental impacts from the management and disposal of radioactive waste for seven reference fuel cycles selected by INFCE Working Group 7, but excluding the health and safety impact on man. The main factors considered were: use of natural resources, land, water, energy, labour and materials; effects of chemical and thermal effluents; effects of meteorology, hydrology and natural hazards; and social effects.

The environmental impacts are generally largest for the once-through fuel cycles and smallest for the FBR and HWR U/Th cycles, due to the impacts being correlated to uranium requirements. The main impact is the use of land which varies from 0.1 - 1.6 ha/GWa with the FBR strategy requiring the smallest use of land and the LWR once-through strategy the largest. The land use for mill tailings is, except for the FBR and U/Th cycles, dominant compared to the land use for the rest of the fuel cycle.

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## 1. SCOPE

Factors to be considered in assessing the total environmental impact of waste management in nuclear fuel cycles are:

(i) use of natural resources (land, water, uranium, other materials, energy, labour) both temporarily and permanently;

(ii) composition and quantities of solids, liquids and gases discharged to the biosphere and stored or disposed of such that they may potentially be discharged. Both normal and accident conditions should be considered;

(iii) effects of meteorology, local hydrology and natural hazards; e.g., earthquakes, on environmental impact;

(iv) effects of chemical and thermal effluents on biota;

(v) social effects of waste management;

(vi) radiological dose commitments and health effects on mankind.

Factor (vi) will be dealt with in the evaluation of "Health and Safety", hence only the first five factors are considered in this part. Emphasis will be placed on a comparison of the impacts of the seven major fuel cycle strategies selected, and of the relative importance of stages within each fuel cycle.

With regard to factor (ii), the need to calculate eventually the radiological dose commitment to mankind requires the assessment of all appropriate source terms and therefore all wastes discharged to the biosphere, including liquid and gaseous wastes. However, it has been agreed in WG.7 (see Introduction to Final Report) that only effluents will be considered which arise from waste conditioning or disposal operations. These will be taken into account in the evaluation in the "Health and Safety" chapter.

The following two definitions (1) are used for the purpose of this assessment:

Storage : means the emplacement of waste materials with the intention of retrieving them later. Storage is a temporary measure which requires continuing surveillance.

Disposal: means the release or emplacement of waste material without the intention of retrieval. Disposal can be totally irreversible, as for example in the case of environmental release of effluents. Retrieval may be possible, as in some geologic disposal schemes for solid waste, but it is the absence of the intention to retrieve which implies disposal. Disposal concepts do not require continued surveillance. However, in particular cases, surveillance over limited time periods may be desirable.

## 2. TECHNICAL DESCRIPTION OF WASTE MANAGEMENT SYSTEMS

### 2.1 Waste Arisings

The waste arisings, expressed per GWe-year of energy produced from the several stages of the seven selected fuel cycle strategies, are given in Tables IV to IX and Table II of Chapter 3 of the Final Report (2). The stages of the selected fuel cycles from which the wastes arise are illustrated in Figures 1 to 7 of the Final Report.

### 2.2 Waste Handling and Storage Methods Used or Proposed

The methods of handling or conditioning wastes are reviewed briefly in Chapter 3 of the Final Report which defines the physical form of the solid wastes; e.g. tailings as discharged from a mill, low level solids embedded in concrete, spent fuel assemblies packaged for salt or hard rock repositories, and packaged vitrified HLW. Means of transport are taken to meet the IAEA Regulations for the Safe Transport of Radioactive Materials.

### 2.3 Facilities Used or Proposed

The reference repositories for geologic waste disposal are described in Chapter 4 and in the Appendices of the Final Report. Reference facilities in the stages of conversion, enrichment, fuel fabrication, reactors and reprocessing, are described in the Reports of the appropriate INFCE Working Group.

## 3. EVALUATION OF ENVIRONMENTAL FACTORS

### 3.1 Degree of Impact of Fuel Cycle Stages

The degree of environmental impact of a particular stage in the fuel cycle for a given strategy depends upon the type of impact being considered, e.g., land use, water use, energy use, mass or volume of waste for ultimate disposal, or sum of radiological source terms. The use of natural resources is considered in Section 3.2 below.

The total radioactivity in solid wastes (Tables IV-IX is far greater in the spent fuel (13 MCi per GWa), or the HLW (12 MCi per GWa) than in the corresponding uranium mill tailings (944 Ci/GWa) or reactor operation wastes (200 kCi/GWa) for a LWR system, as an example.

However, the corresponding radiological dose commitments to mankind do not necessarily follow this proportionality and are discussed in the evaluation of "Health and Safety".

In terms of volumes of solid waste to be disposed of, the mill tailings constitute the largest volume (together with a large volume of waste rock from the mining stage) compared with solid wastes from other stages, even when the latter wastes are conditioned in concrete or special packages, and decommissioning wastes are considered as well.

### 3.2 Use of Natural Resources

#### 3.2.1 Uranium and thorium use

The quantities (Mg) of fresh uranium (and thorium) per GWa for the seven major fuel cycles at equilibrium are given in Table I from Figures 1 to 7 of the Final Report.

It can be seen from this comparison of steady state systems that significant savings in uranium can be made by using a Pu recycle fuel cycle with both the LWR and the HWR, and a very large saving by use of the FBR or the U-Th cycle HWR. It should be noted that an annual equilibrium FBR fuel cycle also requires the use of 20 Mg depleted U per GWa as well as the 1.2 Mg fresh U per GWa, but this depleted U is recycled around the reactor and reprocessing plant.

#### 3.2.2 Land use

The strategy requiring the largest use of fresh uranium or thorium will also have the largest environmental impact in terms of land use in the mining and milling stages of the fuel cycles. With the exception of FBR cycle 3 these stages make up the largest proportion of land use throughout the fuel cycle. Many factors (open-cut versus underground mining, shape of ore body, amount of overburden, ore-grade, etc.) will affect the amount of land used for mining but the overall land use is correlated to the requirements for uranium and thorium. Due to the less extensive experiences from thorium mining most of the considerations are based on uranium mines. Thorium mining is not, in general, expected to exhibit a greater environmental effect than uranium mining.

In the uranium mining and milling stages of the LWR once-through fuel cycle, about 16 ha of land would be temporarily disturbed and 1.5 ha permanently committed per GWa, and other fuel cycles would use less in proportion to the use of uranium and/or thorium shown above.

For open pit uranium mines, about one-third of the total land involved is disturbed temporarily by the actual mining operation while the remaining two-thirds remain idle. The effect of underground mining on surface land use varies considerably. Most of the land can be reclaimed after mining and piles of overburden can be graded, contoured and revegetated. For an open-pit mine, the final pit area may be converted to a lake and may have social benefits as opposed to disadvantages.

In the milling stage, most of the land area is used for a pond for the disposal of mill tailings. Although tailings piles will almost certainly be covered with suitable materials (e.g. 2 m of earth is assumed), or disposed of in pits, and revegetated in future operations in most parts of the world, it is assumed in this assessment that the land is not available for unrestricted use in the short term.

In the conversion, enrichment, fuel fabrication and reprocessing stages of the LWR fuel cycle (with and without recycle), the total amount of land disturbed and committed is small relative to that in the mining and milling stages; e.g. a total of 0.1 - 0.3 ha/GWa for all five stages combined (3). These stages will not be considered further since only a small part of the area is used for waste management operations. For comparison, the land area temporarily disturbed by the reactor is estimated to be 4.2 ha/GWa. The entombment mode of decommissioning would not release the immediate reactor site area for other uses. The land area committed for one reactor would be typically 0.5 ha, equivalent to 0.024 or 0.021 ha/GWa for load factors of 70 and 80 percent respectively.

The waste disposal stage for the selected fuel cycles is estimated to require a surface land use of about 80 ha to support a 100 GWa/year nuclear program, and an underground land area of 17 to 122 ha per year depending on the fuel cycle and whether a salt or hard rock site is chosen (4). The surface area disturbed is therefore only 0.027 ha/GWa assuming a 30-year life before the repository access is closed. The corresponding total underground area used under these conditions would vary between about 500 and 3600 ha or 0.17 to 1.2 ha/GWa, depending on the fuel cycle and type of site chosen. It is possible that after decommissioning of surface facilities and surveillance for a period of years, the surface land could be available for certain uses, but in this assessment it is considered to be permanently committed.

The surplus mine spoil from the excavation of the repository space would cause an environmental concern unless the excavated salt and hard rock are shipped away from the site and used for commercial purposes. The working group has not studied these impacts in any detail. However, the volumes of rock salt and granite which may have to be stored on the ground surface are given in the technical appendices of Chapter 4 of the Final Report. In the salt case after the backfill volume is excluded the annual disposal requirement of mine spoil is of the order of 1.6 million t per 100 GW reference repository. If this amount of rock salt is piled 25 m deep it would occupy an area of approximately 7 ha, i.e. the land use is 0.07 ha/GWa. Correspondingly, in the hard rock case the amount of surplus mine spoil would be some 2.5 million t per 100 GW reference repository whereas the land use is 0.055 ha/GWa.

A summary of the land use (ha/GWa), disturbed and committed, for waste management operations (mining and milling stages, reactor entombment and waste disposal, but excluding fuel cycle facilities from conversion through to reprocessing) for the seven major fuel cycles at equilibrium is given in Table II.

The total surface area committed for strategies 3 and 6 is significantly less than that for the other strategies mainly because of the much smaller uranium use and consequently smaller land use in the mining and milling stages.

### 3.2.3 Water use

Water used and discharged is considered as a waste in the assessment even though it is recycled in nature. The water use ($10^6$ $m^3$/GWa) for the seven major fuel cycles at equilibrium, including operation of the reactor, is given in Table III based on estimates provided in the Generic Environmental Study of Mixed Oxide Fuel (GESMO) (3) for the LWR fuel cycles and pro-rating from the outline fuel cycles in Figures 1 to 7 for other fuel cycles.

From this comparison, it can be seen that the water use in the LWR fuel cycles with and without recycle is about the same, while the other fuel cycles only require about 60 to 80 per cent of the water use of LWR fuel cycles. In the LWR fuel cycles the stage of enrichment (assuming a fifty-fifty mix of gaseous diffusion and centrifuge enrichment and 0.2% tails) accounts for about 36 per cent of the water use, and the operation of the reactor about 60 per cent, leaving about 4 per cent for all of the other stages combined. In the other fuel cycles the main use of water is in the operation of the reactor, and the amount used will depend mainly on the thermal efficiency of the plant.

### 3.2.4 Energy use

Energy is also considered as a waste in this assessment because it ends up as a thermal effluent. The total energy use ($10^{15}$ J/GWa) for the seven major fuel cycles at equilibrium, including operation of the reactor, is given in Table IV based on estimates provided in GESMO (3) for the LWR fuel cycles, and pro-rating from the outline fuel cycles in

Figures 1 to 7 with adjustment for heavy water use in HWR cycles.

The total energy used includes energy in the form of coal, fuel oil, gas and electricity. About 24 per cent of the total energy used in the LWR fuel cycles is accounted for in the enrichment stage (assuming a technology mix as above), 73 per cent in the operation of the reactor, and 6 per cent in all of the other stages combined. About 8 - 11 per cent of the gross reactor output is consumed in operating the plants and fuel cycle facilities. Less than 0.1 per cent of the total energy used in all of the fuel cycles is for waste management operations.

### 3.2.5 Labour use

The total operational labour use per GWa for the seven major fuel cycles at equilibrium, including operation of the reactor, is given in Table V based on estimates by Hardy (5). Of these totals, the proportion due to waste management operations is small (less than 6 per cent).

Although the total labour use is about the same for the LWR fuel cycle with and without recycle, the distribution through the stages is different. As an example, in the once-through LWR fuel cycle (percentages for LWR Pu recycle given in brackets), 51 per cent (57) is accounted for by the reactor, 27 per cent (17) in mining, 6 per cent (4) in milling, 4 per cent (3) in enrichment and 6 per cent in $UO_2$ fuel fabrication (17 per cent in MOX fabrication and 3 per cent in reprocessing). The labour use in the FBR, and Uranium/Thorium fuel cycles is less largely because of the lower use of uranium. It is estimated that the total labour force occupied in running the waste management and disposal operations for each of the fuel cycles would be some 1500-2000 persons for a nuclear program producing effectively 100 GW per year.

### 3.2.6 Other materials

It is not considered appropriate to carry out a complete materials balance across each of the fuel cycles because to a first approximation the use of raw materials for the construction and operation of the reactors and fuel cycle facilities is expected to be about equal. Each fuel cycle involves mines, mills, fuel fabrication plants, reactors, and waste disposal plants, and recycle strategies involve conversion and enrichment plants or reprocessing plants. Differences will only be seen in the size of the plants, e.g. mines/mills, to service a particular fuel cycle depending upon the uranium use, and in the substitution of one plant, e.g. enrichment, for another, e.g. reprocessing. The use of materials such as lead in large quantities for containers in a waste repository could have a considerable environmental impact from their mining, purification and fabrication stages compared with the impact from other stages of the nuclear fuel cycle. The adverse effect of this potential toxicity inserted into the repository is not evaluated here.

### 3.3 Meteorology, Hydrology, Natural Hazards

Environmental impact on the local climate can arise from some stages of the fuel cycles, e.g. thermal releases from large nuclear reactor sites, or from enrichment plant sites using the gaseous diffusion process. These can produce local mists, fogs and clouds, but do not constitute a major impact outside the immediate locality.

Conversely, meteorological, hydrological and seismic conditions can markedly affect waste disposal operations. Disposal of tailings in a tailings dam in a wet climate may require different standards and costs than in a semi-arid climate. Seismic problems will affect the standards for facilities in all stages of the fuel cycle. Location of facilities in areas subject to tornadoes or major tidal waves will require higher standards of construction and could therefore involve larger masses and volumes of decommissioning wastes.

## 4. CONSTRUCTION AND DECOMMISSIONING OF FACILITIES

The construction of fuel cycle facilities, including reactors, will require significant amounts of natural resources (materials, labour, energy) and produce waste (usually non-radioactive) compared with the normal operations of these facilities. Similarly, the decommissioning of facilities will require significant amounts of labour and energy and produce wastes (both radioactive and non-radioactive); examples of the relative amounts of wastes are given below.

Preliminary estimates in Table VI (taken from Table VI of Final Report) indicate that the number of low level waste packages arising from the decommissioning of a LWR (strategies 1 and 2) by entombment is very much less than the number of low level waste packages produced during reactor operation.

A similar relationship is seen for the other reactor strategies in Table VI.

The number of low-level and medium-level waste packages arising from the decommissioning of reprocessing facilities, for example, 335 drums/GWa for the HWR-Pu recycle strategy 5, is somewhat less than the number of similar waste packages produced during normal operations (566 drums/GWa). A similar relationship is seen for the LWR-Pu recycle strategy 2, FBR strategy 3 and HWR U-Th strategy 6; however, the HTR strategy 7 is estimated to have a large amount of reprocessing maintenance waste and a small amount of decommissioning waste relative to these strategies.

In comparing volumes and activities of decommissioning wastes for different strategies, it is important to estimate these for equivalent levels of decommissioning, i.e. mothballing, entombing or complete dismantling; decommissioning by entombing has been used for the estimates in WG.7.

## 5. EFFECTS OF CHEMICAL AND THERMAL EFFLUENTS

The principal concern with effluents from nuclear fuel cycle operations has been with radioactivity and its effect on human health and this is considered under "Health and Safety". Other effluents; e.g. oxides of sulphur, from the nuclear fuel cycles may affect not only human health but also animals, plants and materials. The major non-radiological impact due to effluents arises from the direct use of coal and the use of electricity produced from coal.

This review is not an appropriate place to describe in detail the environmental impact of coal-fired power stations. However, the energy used in the fuel cycles that is derived from coal will contribute a significant quantity of oxides of sulphur and nitrogen, and also sludges and particulates, compared with the chemical effluents arising from these fuel cycles. This aspect was discussed in detail in the GESMO report for LWR strategies 1 and 2.

The major thermal effluents from the various fuel cycles arise from the reactors themselves and the enrichment plants associated with strategies 1, 2, 6 and 7. However, the waste heat per GWa released from an enrichment plant amounts to less than 2 per cent of that from a power reactor, hence to a first approximation the seven selected fuel cycles will release amounts of heat per GWa inversely in proportion to their thermal efficiencies in Table I that is, heat released in the order: 4 and 5 and 6 > 1 and 2 > 3 > 7.

Regions containing commercial grade uranium ore often contain other toxic heavy metals which can leach and produce environmental degradation to biota. This effect is common to most metal mines. The strategy which uses the smallest amount of uranium (or thorium) will contribute least to chemical effluents of this type, and hence the FBR strategy 3 will show the least effect, followed by strategies 6, 7, 5, 2, 4 and 1.

## 6. SOCIAL EFFECTS OF WASTE MANAGEMENT

The potential environmental impact on society of waste management in the various fuel cycle strategies is discussed briefly in this part, and effects of a legal or institutional kind are considered in the section on "Legal and Institutional Impact". Each major stage (or group of stages) of the nuclear fuel cycle is considered separately, and comparisons made between different strategies.

In the mining and milling stages combined, the main social impacts are on the use of the land, the amount of land required, the location of the land (whether remote and uninhabited, or close to population centres), and whether access is restricted during operation and after decommissioning. Even if land is remote from large population centres, it may have major social benefits for dedication as a National Park, or for use by regional and local populations. In terms of differential social impact of the selected strategies, the strategies which require the smallest use of uranium and thorium and therefore land will have the smallest social impact, i.e., in the order 3, 6, 7, 5, 2, 4, 1, with strategy 3 requiring only 0.5 per cent of the land committed for 1. However, it should be noted that large open-cut mines may have some social benefit after decommissioning as large areas of water for recreation, or the support of fauna and flora in an arid climate. The setting up of company towns in remote areas may lead to social difficulties. The importance of this concern is related to the uranium and/or thorium needs as the number of these towns would increase with increasing mining activity.

The conversion and enrichment stages are relatively large industrial developments comparable to many chemical industries and produce relatively little waste (except $^{238}U$ regarded as waste in WG.7) or effluents compared with the stages of mining, milling, reactor operation or reprocessing. They have social disadvantages from the viewpoint of potential effluents and accidents and advantages from employment, local rating and added-value in exports or import substitution costs. These stages are required for strategies 1, 2, 6 and 7, but not for strategies 3, 4 and 5 at equilibrium.

The potential environmental and social impact of a major accident at a mixed oxide fuel fabrication plant handling large amounts of plutonium could be the most significant impact for the fuel fabrication stage. This type of facility would be required for strategies 2, 3 and 5, but not for strategies 1 and 4, which only require $UO_2$ fuel fabrication plants with a relatively low impact from a major accident.

Since a reactor is involved in each of the seven strategies, the major difference in social impact between strategies is seen as the use of large quantities of plutonium or highly-enriched uranium in the fuel versus small quantities. Plutonium is present in the cores of all of the reactors at equilibrium, but the amounts in the cores will increase significantly in the order of strategies 6,7,1,2, 4,5,3. However, the reactors will be designed to very high standards of safety, and it is not appropriate in this evaluation to attempt to assess the relative safety and potential social impact of accidents involving the release of activity. The social benefits to offset the risks include the large quantity of energy produced with minimal environmental degradation compared to energy generation using coal, or the depletion of oil and gas reserves.

The reprocessing stage is also a relatively large industrial development comparable to major chemical industry plants and has social advantages and disadvantages. It is required for strategies 2,3,5,6 and 7, but not for strategies 1 and 4. The potential social impact of a major accident is greater than that of facilities in the front end of the various fuel cycles, but the high standard of its design and construction takes this potential risk into account.

The waste disposal stage is required for all of the seven fuel cycles, and at this stage of the evaluation no major difference in social impact has emerged between disposal of unreprocessed spent fuel or high level waste from reprocessing. It is anticipated that ultimate disposal of high level waste or spent fuel will be carried out in selected areas only after extensive assessment of total environmental impact.

## 7. SUMMARY OF ENVIRONMENTAL IMPACT EVALUATION

In the use of the natural resources of land, uranium, water, energy and labour, only the use of land and uranium show significant differences between different fuel cycle strategies. The use of water, energy and labour in waste management operations in all of the fuel cycle strategies considered is small relative to their use in other parts of the nuclear fuel cycle and reactor operations.

The use of uranium as a natural resource in equilibrium fuel cycles is smallest with the FBR strategy 3. The two HWR fuel cycle strategies 4 and 5 use less uranium than the comparable LWR strategies 1 and 2, and the HWR U-Th recycle strategy 6 uses only one-tenth the amount of uranium used by the HWR U-Pu recycle strategy 5. The U-Th recycle in the HTR (strategy 7) uses significantly less uranium than U-Pu recycle in the LWR (strategy 2) and HWR (strategy 5).

The strategy requiring the largest use of uranium has the largest environmental impact in terms of land use in the mining and milling stages of the fuel cycles. With the exception of FBR cycle strategy 3, these stages make up the largest proportion of surface land use throughout the fuel cycle.

The volumes of waste arisings from decommissioning operations are less than the volumes of low and medium level waste arisings from normal operations per GWa.

The effects of chemical and thermal effluents are small and largely governed by the use of coal to produce electricity, for which the enrichment stage in strategies 1, 2 and 7 requires a large proportion in these fuel cycles.

The social effects of waste management parallel the overall environmental impact in being small relative to the effects of other parts of the nuclear fuel cycle.

## REFERENCES

(1) Objectives, Concepts and Strategies for the Management of Radioactive Waste Arising from Nuclear Power Programs, Nuclear Energy Agency/OECD, September 1977.

(2) INFCE WG.7 Final Report Chapter 3.

(3) Final Generic Environmental Statement on the Use of Recycle Plutonium in Mixed Oxide Fuel in Light Water Cooled Reactors, NUREG-0002, Vol. 3, Health, Safety and Environment, U.S. Nuclear Regulatory Commission, August 1975.

(4) INFCE WG.7 Final Report Chapter 4 and Appendices 1 and 2.

(5) HARDY, C.J., Manpower Requirements for Nuclear Fuel Cycles. Unpublished work, Australian Atomic Energy Commission, 1978.

TABLE 1, URANIUM AND THORIUM USE

| Fuel cycle | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| | LWR | | FBR | HWR | | | HTR |
| | once through | Pu re-cycle | Pu re-cycle | once through | Pu re-cycle | U-Th cycle | U-Th cycle |
| Mg/GWa | 205.4 | 119.5 | 1.2 | 178.8 | 74.6 | 7.0 +2.6 (Th) | 56.4 +0.9 (Th) |

TABLE II. SUMMARY OF LAND USE FOR WASTE MANAGEMENT OPERATIONS

| Fuel cycle | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| | LWR | | FBR | HWR | | | HTR |
| ha/GWa | once through | Pu re-cycle | Pu re-cycle | once through | Pu re-cycle | U-Th cycle | U-Th cycle |
| Mining/milling area disturbed | 16 | 9 | 0.09 | 14 | 6 | 0.7 | 4.5 |
| Mining/milling area committed | 1.46 | 0.85 | 0.0086 | 1.27 | 0.53 | 0.059 | 0.4 |
| Entombed reactors | 0.024 | 0.024 | 0.024 | 0.021 | 0.021 | 0.021 | 0.024 |
| Waste repository area or surface | 0.027 | 0.027 | 0.027 | 0.027 | 0.027 | 0.027 | 0.027 |
| Waste repository area underground | 0.48 - 0.88 | 0.41 - 0.87 | 0.38 - 0.65 | 0.55 - 0.77 | 0.30 - 0.93 | 0.75 - 1.22 | 0.17 - 1.10 |
| Mine spoil area (salt) | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 |
| Total surface area committed | 1.58 | 0.97 | 0.13 | 1.39 | 0.65 | 0.18 | 0.52 |

TABLE III. WATER USE

| Fuel Cycle | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| | LWR | | FBR | HWR | | | HTR |
| | once through | Pu re-cycle | Pu re-cycle | once through | Pu re-cycle | U-Th cycle | U-Th cycle |
| $10^6$ $m^3$/GWa | 103 | 101 | 62 | 65 | 64 | 65 | 80 |

TABLE IV. ENERGY USE

| Fuel cycle | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| | LWR | | FBR | HWR | | | HTR |
| | once through | Pu re-cycle | Pu re-cycle | once through | Pu re-cycle | U-Th cycle | U-Th cycle |
| $10^{15}$ J/GWa | 3.4 | 3.4 | 2.5 | 2.6 | 2.8 | 2.9 | 2.9 |

TABLE V. LABOUR USE

| Fuel Cycle | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| | LWR | | FBR | HWR | | | HTR |
| | once through | Pu re-cycle | Pu re-cycle | once through | Pu re-cycle | U-Th cycle | U-Th cycle |
| persons/GWa | 313 | 282 | 217 | 310 | 317 | 236 | 229 |

TABLE VI. LOW LEVEL WASTE ARISINGS FOR STRATEGIES 1 AND 2

| Total operating and maintenance wastes | Decommissioning wastes | Total |
|---|---|---|
| 2,275 drums/GWa | 125 drums/GWa | 2,400 drums/GWa |