DISCUSSION OF THE ENVIRONMENTAL EFFECTS OF THE URANIUM FUEL CYCLE

Related to Operation of

SEQUOYAH NUCLEAR PALNT, UNITS 1 AND 2

TENNESSEE VALLEY AUTHORITY

DOCKET NOS. 50-327 AND 50-328

SEPTEMBER 1980

U. S. NUCLEAR REGULATORY COMMISSION

OFFICE OF NUCLEAR REACTOR REGULATION

Enclosure (3)

DISCUSSION OF ENVIRONMENTAL EFFECTS OF THE URANIUM FUEL CYCLE
RELATED TO THE OPERATION OF SEQUOYAH NUCLEAR PLANT UNITS 1 AND 2
(DOCKET NOS. 50-327 AND 50-328)

In October 1971, the Tennessee Valley Authority (TVA) published its Draft Environmental Statement on the construction and operation of the Sequoyah Nuclear Plant, Units 1 and 2, for review by Federal, State and other agencies, including the AEC (predecessor agency of the NRC) as a participating agency under the "lead agency" agreement with TVA dated June 30, 1971.

The detailed review of the draft statement by the AEC regulatory staff revealed that it was essentially equivalent in content and depth of study to comparable statements prepared by the AEC for other plants of similar design. The AEC regulatory staff reviewed and commented in particular on those sections of the Sequoyah Draft Statement which dealt with matters involving its unique expertise (radiological effects) and participated with the TVA staff in discussions of these comments during June and July of 1972. The TVA staff's indicated responses were satisfactory to the AEC regulatory staff (letter of July 3, 1972), and TVA proceeded to prepare the Final Environmental Statement including comments and responses of all agencies.

In September 1973, TVA provided a "preliminary" Final Environmental Statement for review by the AEC regulatory staff.

On the basis of these reviews, and the TVA responses to AEC regulatory staff comments, the AEC regulatory staff concluded that the proposed Final Environmental Statement by TVA met existing AEC and CEQ Guidelines, and with the addition of appropriate conditions to ensure the protection of the environment, was adequate.

TVA published the Final Environmental Statement in February 1974. Subsequent discussions between TVA and the AEC regulatory staff satisfactorily resolved the wording of the conditions deemed necessary to protect the environment. The AEC regulatory staff, therefore, adopted the Final Environmental Statement as modified by these agreements.

In accordance with CEQ guidelines regarding "lead-agency" concepts, the AEC regulatory staff prepared an independent weighing of the benefits and costs related to environmental, economic and other matters pertaining to the construction and operation of the Sequoyah Nuclear Plant by the TVA. Supplemental testimony was presented by the AEC regulatory staff to detail this independent consideration during hearings before an Atomic Licensing and Safety Board (ASLB) held in Chattanooga, Tennessee on July 30 and 31, 1974.

During the course of those ASLB hearings, testimony was presented regarding Table S-3 on the environmental effects of the uranium fuel cycle (39FR14118).[1/]

The AEC regulatory staff in its testimony concluded that consideration of these environmental effects will not alter the AEC regulatory staff's conclusion regarding its cost-benefit analysis. The ASLB also made this conclusion in its initial Decision dated December 2, 1974.[2/]

On August 12, 1979, the Nuclear Regulatory Commission published a notice announcing the outcome of a final rulemaking regarding the environmental effects of spent fuel reprocessing and radioactive waste management in the light water power reactor uranium fuel cycle. In that notice, the Commission noted the need for further discussion of the environmental impact of the values given in Table S-3. Pending further treatment by rulemaking, the Commission directed the NRC staff to address these matters in the environmental analysis accompanying a proposal to issue a

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1/ Hearing transcript for July 31, 1974 in the matter of Tennessee Valley Authority, Sequoyah Nuclear Plant Units 1 and 2 at p281

2/ Initial Decision of the ASLB in the matter of TVA Sequoyah Nuclear Plant, Docket Nos. 50-327 and 328 dated December 2, 1974 at pp 13 and 14.

limited work authorization, construction permit, or operating license for a power reactor. These issues are to include but not be limited to environmental dose commitments and health effects from fuel cycle releases, fuel cycle socioeconomic impacts and possible cumulative impacts (44 FR 45362 dated 8/12/79).

The final rulemaking concluded a proceeding which began on May 26, 1977 with a notice that a rulemaking hearing would be held to consider whether the interim rule should be made permanent or, if it should be altered, in what respects (42 FR 26987). The Hearing Board took extensive written and oral testimony from more than 20 participants. On August 31, 1978, the Hearing Board submitted to the Commission a detailed summary of the evidentiary record, followed on October 26, 1978 by its Conclusions and Recommendations.

After studying the Hearing Board's Conclusions and Recommendations and receiving written and oral presentations by rulemaking participants, the Commission adopted as a final rule the modified Table S-3 recommended by the Hearing Board. The impact values in this table differ only slightly from the values in the interim rule. With two exceptions, these values will be taken as the basis for evaluating in individual light water power reactor licensing proceedings, pursuant to requirements of the National Environmental Policy Act (NEPA), the contribution of uranium

fuel cycle activities to the environmental costs of licensing the reactor in question. The exceptions are radon releases, presently omitted from the interim rule (43 FR 15613, April 14, 1978),[3/] and technetium-99 releases from reprocessing and waste management activities.[4/]

The rulemaking record makes clear that effluent release values, standing alone, do not meaningfully convey the environmental significance of uranium fuel cycle activities. The focus of interest and the ultimate measure of impact for radioactive releases are the resulting radiological dose commitments and associated

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3/ With regard to radon releases, the matter of appropriate values is under consideration before the Atomic Safety and Licensing Appeal Board in the proceeding derived from ALAB-480 which involved a consolidation of numerous proceedings. The NRC staff's testimony in this proceeding presents the staff's assessment that impacts from radon releases are not significant.

4/ With regard to technetium-99 releases from reprocessing and waste management activities, in 44 FR 45362 the Commission found:

> "In view of the Hearing Board's conclusion that the conservative assumption of complete release of iodine-129 tends to compensate for the omission of technetium from Table S-3, the Commission finds it unnecessary to reopen closed proceedings or to disturb consideration of environmental issues in presently pending proceedings to provide for consideration of technetium-99 releases."

Thus consideration of technetium-99 releases at Sequoyah Nuclear Plant are unnecessary.

health effects. To convey in understandable terms the signficance of releases in the Table, the Hearing Board recommended that the modified Table be accompanied by an explanatory narrative promulated as part of the rule. The recommended narrative would also address important fuel cycle impacts now outside the scope of Table S-3, including socioeconomic and cumulative impacts, where these are appropriate for generic treatment. The Commission directed the NRC staff to prepare such a narrative. The staff has prepared a narrative which will be submitted for public comment in a further rulemaking.

In accordance with the Commission directive of August 12, 1979 regarding an explanatory narrative to accompany Table S-3, the enclosed narrative has been drafted by the Office of Nuclear Material Safety and Safeguards staff. The narrative is of an explanatory nature, amplifying information contained in Table S-3. Giving due consideration to the values in Table S-3 and the information set forth in the attached narrative, the NRC staff concludes that this information does not affect the cost-benefit conclusion already made in the record of this proceeding on the Sequoyah Nuclear Plant.

August 1980

Explanatory Narrative for Table S-3, Table of Uranium Fuel Cycle Environmental Data

Section I. The LWR Uranium Fuel Cycle

A. Purpose

The purpose of this narrative explanation of Table S-3 is to assist the reader in identifying the major impacts of each step in the fuel cycle and in determining which fuel cycle steps are the major contributors to each type of environmental impact shown in Table S-3. Table S-3 summarizes the environmental effects of the normal operations of the uranium fuel cycle associated with producing the uranium fuel for a nuclear power plant and in disposing of the spent nuclear fuel and the radioactive wastes. The values in Table S-3 were estimated principally by methods which are described in detail in the reports WASH-1248, "Environmental Survey of the Uranium Fuel Cycle,"[1] NUREG-0116, "Environmental Survey of the Reprocessing and Waste Management Portions of the LWR Fuel Cycle,"[2] and NUREG-0216, "Public Comments and Task Force Responses Regarding the Environmental Survey of the Reprocessing and Waste Management Portions of the LWR Fuel Cycle."[3] In addition, at a public hearing (Docket No. RM 50-3) on the reprocessing and waste management environmental effects, the Commission staff answered questions about the estimates for the back end of the fuel cycle and considered suggestions made by other participants in the hearing. The complete record of this public hearing and the three documents cited above are available in the NRC's Public Document Room at 1717 H Street, N.W., Washington, D.C., and provide further explanation of the factors considered in developing estimates for Table S-3. These reference materials contain the complete technical basis for the estimates in the Table, and give detailed descriptions of the fuel cycle operations and their environmental effects.

The following narrative explanation of the values given in Table S-3 is drawn from the record and cross referenced to source documents for the benefit of readers seeking more information. The Table S-3 values which pertain to the front end of the fuel cycle (up to the loading of the fuel into the reactor) are taken from WASH-1248; values pertaining to the back end of the fuel cycle are taken from NUREG-0116, with changes which are noted in the hearing record.[4] Since the narrative is designed to help the reader in interpreting the environmental effects given on Table S-3, the forementioned documents, together with others that were cited in the documents or discussed during the hearings, are generally the only references cited in the narrative. The exceptions to this statement are found in Section III, where the staff has provided, for purposes of discussion only, information on how long term dose commitments might be calculated, and what incremental releases from waste disposal sites might be. Since these topics were not covered in detail in WASH-1248, NUREG-0116, NUREG-0216 or the hearing record, information not in the record had to be used to develop the material.

Section I of the narrative describes the extant LWR uranium fuel cycle, the broad alternatives and the individual operations of the fuel cycles; Section II contains a description of the environmental effects of the LWR fuel cycles and of the individual fuel cycle operations; Section III contains a discussion of dose commitments and health effects resulting from releases of radioactive materials from the fuel cycle. Section III also includes a discussion of how dose commitment evaluations over extended periods of time might be performed and what their significance might be. In addition, there is a discussion of what, if any, incremental releases from waste disposal sites might occur over

very long periods of time (i.e., an evaluation of repository impacts for the repository considered in NUREG-0116.) Section IV contains a discussion of socioeconomic impacts.

B. Alternative Fuel Cycles

The several alternative fuel cycles which can be used for present generation LWR reactors can be primarily characterized by how the spent fuel is handled, since all presently available alternatives start with uranium fuel. The alternatives are:

Once-Through Fuel Cycle:

- The spent fuel can be disposed of without recovery of residual fissionable isotopes; this is the present operating mode for U.S. nuclear reactors.

Uranium-Only Recycle:

- Uranium can be recovered from spent fuel by reprocessing and can be recycled in nuclear fuel. Plutonium can be stored for later use or combined with residual radioactive materials as wastes. Uranium-only recycle, including plutonium storage, was considered to be the most likely mode of operation at the time of preparation of WASH-1248 (1972-1974), and was the fuel cycle addressed in that document.[5] In NUREG-0116, plutonium was considered to be a waste to be disposed of at a Federal repository.[6]

Uranium and Plutonium Recycle:

- Both uranium and plutonium can be recovered from spent fuel by reprocessing and recycling to the reactor, the plutonium being recycled with

uranium as mixed oxide fuel. The residual radioactive materials are wastes. The wide scale use of this mode of operation was under consideration in the Commission's GESMO[7] proceeding.

The Commission had been in the process of determining whether or not the wide scale use of mixed oxide fuel in light water reactors should be authorized (GESMO proceeding) when President Carter published his "Statement on Nuclear Power Policy" on April 7, 1977. After consideration of the Executive Branch's and the public's comments, the Commission decided (42 FR 65334, December 30, 1977) that, among other things, it would:

- o Terminate the GESMO proceeding.
- o Terminate the proceedings on pending or future plutonium recycle-related licensing applications, except for --
  - (a) proceedings on licenses for the fabrication or use of small quantities of mixed oxide fuel for experimental purposes, and
  - (b) those portions of proceedings which involve only spent fuel storage, disposal of existing waste, or decontamination or decommissioning of existing plants.
- o Reexamine the above matters at a later date.

The result of the Commission's decision is that there are only two LWR fuel cycles potentially licensable for wide scale use in the United States at this time: the once-through cycle, and the uranium-only recycle fuel cycle. The back end steps of these two fuel cycles are considered in NUREGs-0116 and -0216, and the larger effect of the two fuel cycles is included in the

Table S-3. Since the fuel cycle rule is to cover LWRs during their operating lifetimes, even though there are no reprocessing plants operating in the United States at this time, the proceedings of January 1978 through April 1978 considered both the once-through and uranium-only recycle fuel cycles to cover the reactor lifetime with some flexibility.

C. Fuel Cycle Operations

Many different operations are required for either the once-through fuel cycle or the uranium-only recycle fuel cycle. Operations involved in preparing fresh fuel for use in a reactor are collectively known as the "front end" of the fuel cycle. The operations following irradiation of the fuel in the reactor are known as the "back end" of the fuel cycle. Figure 1 shows a block flow diagram for the front end of the fuel cycle; Figures 2a and 2b show the back end of the once-through and uranium-only recycle fuel cycles respectively.

Five operations comprise the front end of the fuel cycle (Figure 1): ore is mined; the uranium content of the ore is recovered as an impure compound (yellowcake) by milling; a purified uranium compound (UF_6) is produced; the uranium-235 content of natural uranium is increased at enrichment plants; and uranium fuel is fabricated.[3]

Two different sets of operations comprise the back end of the fuel cycle. In the once-through fuel cycle (Figure 2a), spent fuel from the LWR is stored, either at the reactor or at special facilities away from the reactor, for periods of time in excess of 5 years. The spent fuel is packaged and disposed of in Federal repositories. In the uranium-only recycle mode (Figure 2b),

LWR URANIUM FUEL CYCLE FRONT END OPERATIONS

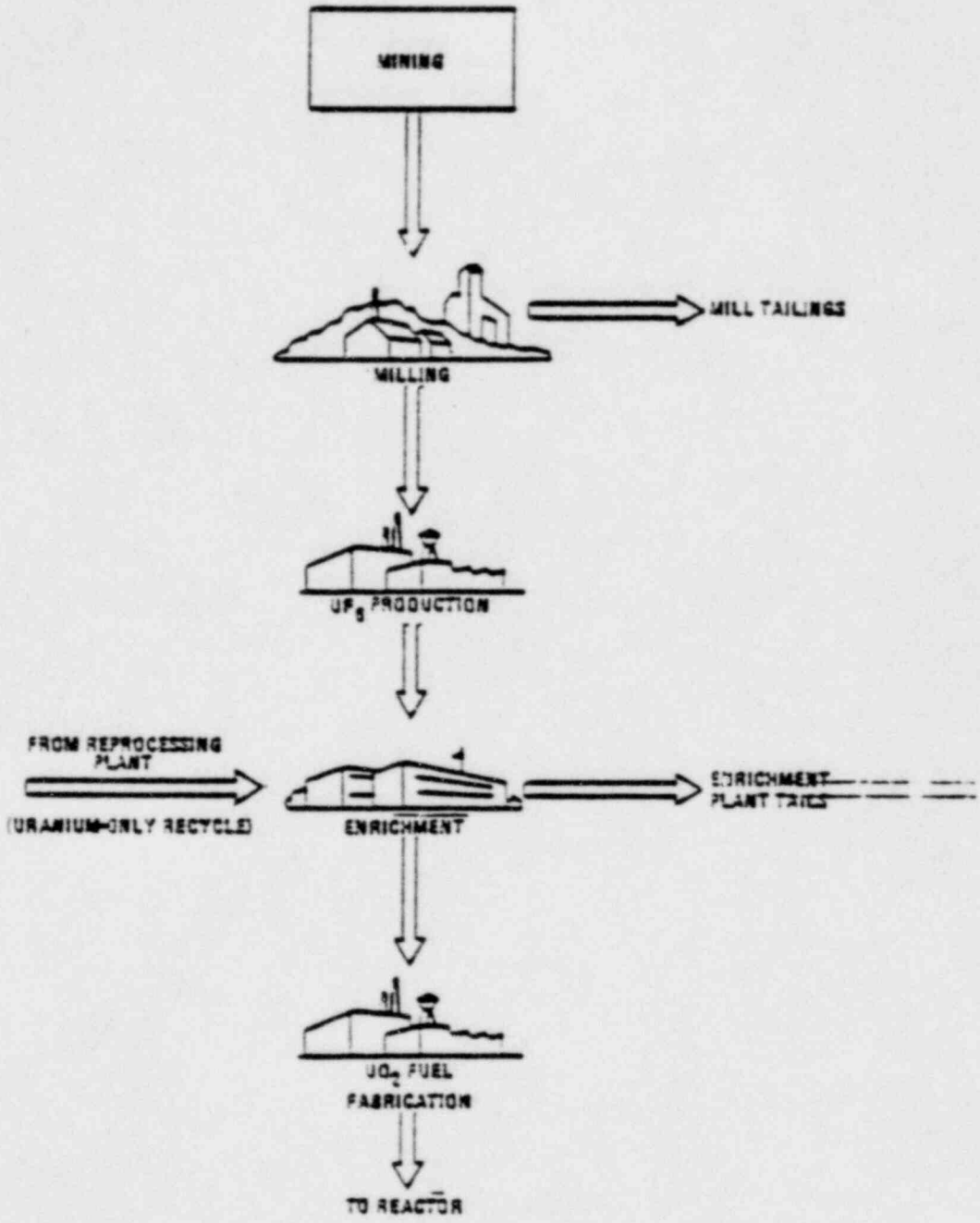

Figure 1 LWR Uranium Fuel Cycle Front End Operations

LWR URANIUM FUEL CYCLE BACK END OPERATIONS

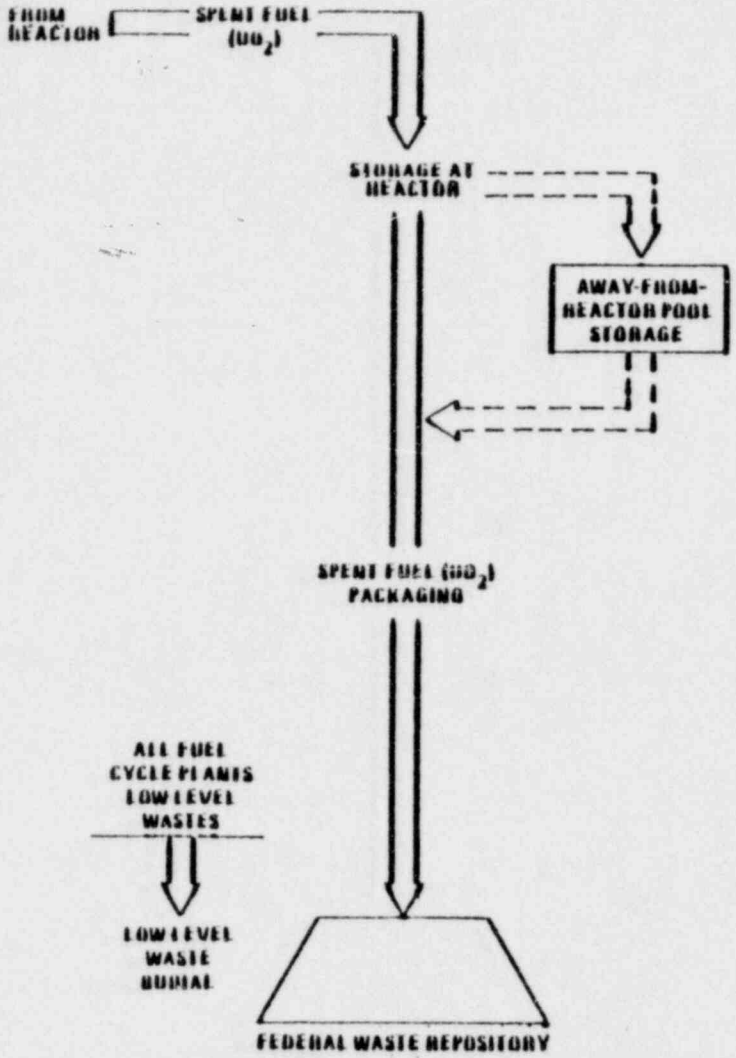

Figure 2a Once Through Fuel Cycle

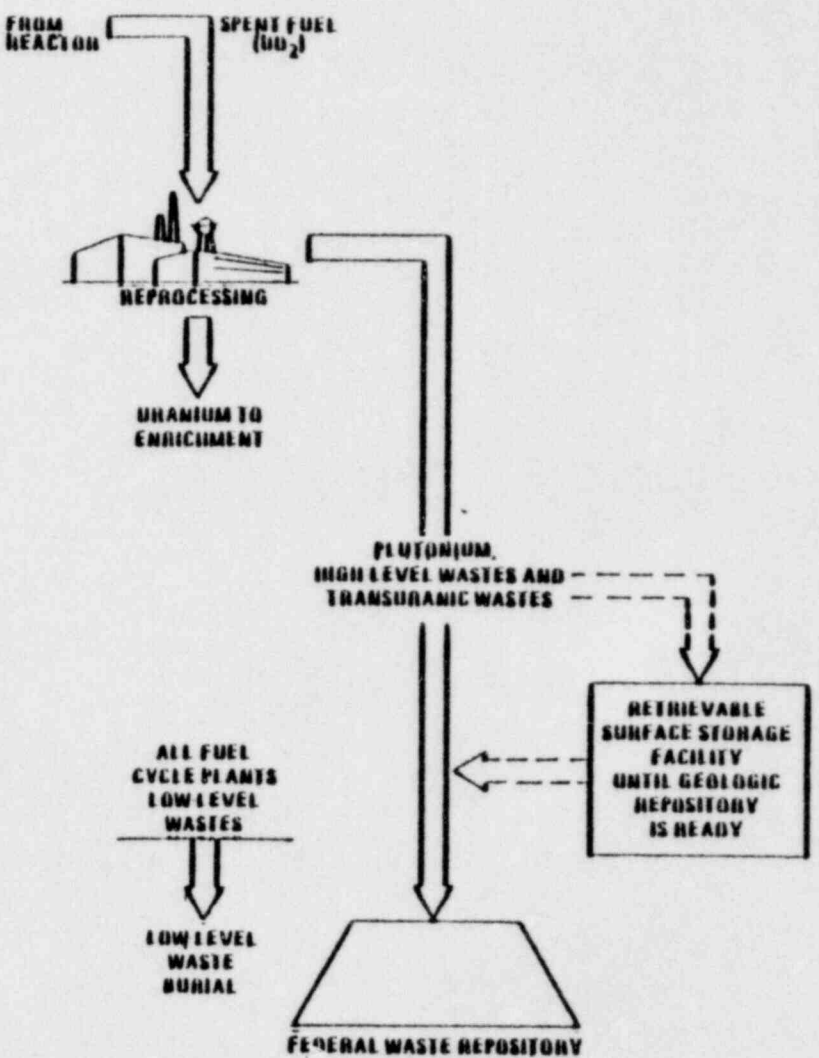

Figure 2b Uranium Only Recycle Fuel Cycle

spent fuel is stored at reactors for short periods of time (greater than 90 days), and then shipped to reprocessing plants, where uranium is recovered in a form suitable for feed to enrichment plants. Plutonium and other residual materials from the spent fuel (cladding, fission products, actinide elements, activation products) are solidified, and packaged in a form suitable for disposal. Current regulations (10 CFR Part 50, Appendix F) require that certain wastes from reprocessing plants be solidified within 5 years of their generation and that these wastes be disposed of within 10 years of their generation. Most of the waste from reprocessing plants will be disposed of at Federal repositories.

D. The Model Reactor and its Fuel Cycle Requirements

For the purposes of developing the values in Table S-3, a model light water reactor was defined in WASH-1248 as a 1,000 MWe reactor assumed to operate at 80% of its maximum capacity for one year, thus producing 800 MW-yrs of electricity annually.[9] The fuel cycle requirements averaged over a 30-year operating life for this reactor were labelled an annual fuel requirement (AFR) in WASH-1248. Since that time, the AFR acronym has been used to characterize away-from-reactor storage of spent fuel. In NUREGs-0116 and -0216 the terminology "reference reactor year" (RRY) was employed to describe the fuel cycle requirements of a model 1000-MWe reactor operating for one year. The same terminology will be utilized in this narrative.

The front end of the fuel cycle, as described in WASH-1248, covers the supply of fuel for the model reactor; 91,000 metric tons of ore (containing 2 parts of U_3O_8 per 1,000 parts of ore) are required per RRY. Milling of the ore

produces 182 metric tons of yellowcake,* which in turn is converted into 270 metric tons of natural UF_6. In the enrichment operation, much of this natural UF_6 feed material is rejected from the fuel cycle as enrichment plant tails. Of the 270 metric tons of UF_6 feed, 218 metric tons are rejected from the fuel cycle as depleted uranium tails. The remaining 52 metric tons of enriched uranium product is the feed for the fuel fabrication plant and contains enough uranium for 40 metric tons of UO_2 fuel (35 metric tons of contained uranium). This amount of fuel is required annually by an LWR producing 800 MW-years of electricty.[10]

The back end fuel cycle steps, described in NUREGs-0116 and -0216, handle the post-fission products and wastes, including the spent fuel. The spent fuel, which still contains about 34 metric tons of uranium,[11] is removed from the reference reactor annually. (Approximately one metric ton of uranium has been converted to fission products and actinide elements.) The fresh and spent fuel is in the form of fuel assemblies, each containing between about 0.2 and 0.5 metric tons of uranium.[12] Hence, the number of fuel assemblies handled in each reactor reload ranges from about 70 to 180, depending on the type of reactor. For the once-through fuel cycle, this fuel is stored under water for periods of time in excess of 5 years, either at the reactor site or at offsite facilities. Following the storage period, the spent fuel will be disposed of at a Federal repository.[13]

*Varying fuel cycle operating conditions including reactor parameters, yellowcake purity, enrichment tails assay, etc. effect the yellowcake RRY requirement which is thus subject to considerable variation.

For the uranium-only recycle option, the spent fuel is reprocessed to recover uranium. Plutonium (about 0.35 metric tons per RRY[14]) may be recovered as plutonium oxide in a separate stream. The fission products, other actinide elements, and activation products are concentrated into one or more solid waste products which are disposed of together with any plutonium stream.

To develop the values in Table S-3, the environmental effects resulting from operating the model fuel cycle facilities were estimated. These effects were then normalized to reflect the effects attributable to the processing of fuel for a single year's operation of a model reactor (RRY).

E. Fuel Cycle Facility Descriptions

To provide a perspective on the nature of the LWR fuel cycle operations, and the types of environmental effects resulting from these operations, brief descriptions are given below for the model fuel cycle facilities used to derive the environmental effects given in Table S-3.

1. The Front End of the Fuel Cycle (WASH-1248)

a. Uranium Mining[15] and Milling[16]

For this segment of the fuel cycle, a combined mine-mill complex was selected as the model since it is representative of a significant portion of the current and developing industry.

(1) Mining

The commercial uranium ore deposits in the United States generally occur in the Western States. Uranium mining in the United States is generally

accomplished by one of two methods. Open pit mining, accounting for 53% of the ore produced in this country in 1971, is used when the ore body lies under material that is easily broken up and is found at depths up to several hundred feet. Underground mining is used when the ore body is located at depths greater than about 400 feet, or when it lies under rocks that require a great deal of blasting to break up.

An open pit mining operation in a Western State was selected for the model uranium mining operation since the environmental effect in terms of total volume of earth disturbed is greater in open pit mining than in underground mining, and since about half of the known ore reserves in the United States are located in relatively shallow sedimentary formations less than 400 feet deep.[17] The model mine has a capacity of 1600 metric tons (MT) of ore per day, which is equivalent to a yield of approximately 960 MT of U_3O_8 per year, sufficient to supply the fuel for 5.3 LWR RRYs.

The dominant potential environmental effects from uranium mining include disturbances of the natural terrain, an effect common to most mining operations; releases of radon;* and pumping mine drainage water from the mine.

(2) Milling

As in a number of existing production complexes, the model mill, located adjacent to the model uranium mine, utilizes the acid leach process, since that process accounts for about 90% of the total U_3O_8 production.[18] The mill produces a uranium concentrate containing about 960 MT U_3O_8 per year.

*Radon releases are not given in Table S-3.

In the milling operation, uranium is extracted from the ore and is concentrated as a semirefined product that is sold in terms of its U_3O_8 content. The product, which is principally ammonium diuranate, can be any one of several uranium compounds and is commonly called yellowcake.

Both mechanical and chemical processes are involved in the milling operation. Initially, the ore is crushed and ground, after which it is leached with either sulfuric acid or sodium carbonate solutions to extract the uranium. The leach liquors are purified and concentrated, and the uranium is recovered by chemical precipitation with the solid product calcined, pulverized and drummed for shipment as yellowcake. Nearly all of the ore processed by the mill ends up as tailings, a fine sand-like material, in the tailings pond, together with large amounts of water and chemicals used in the process. The water eventually dissipates, largely by natural evaporative processes. The tailings have the potential to cause the largest environmental effects from the milling operation.

b. Uranium Hexafluoride Production[19]

The yellowcake must be converted to a product (uranium hexafluoride, UF_6) which is volatile at a slightly elevated temperature for enrichment by the gaseous diffusion process. Two processes are used for UF_6 production, a dry process (hydrofluor) and a wet process. The processes differ primarily in the technique used for purification. In the dry process, fractional distillation is employed after conversion, while in the wet process, high purity uranium

feed is provided by a solvent extraction step. Roughly equal quantities of UF_6 feed to the enrichment plants are produced by each method.

The effluents from the two processes differ. The bulk of the impurities entering with the crude uranium feed is rejected from the dry process as solids; in the wet process, the bulk of the yellowcake impurities is rejected as dissolved solids in a raffinate stream. The model UF_6 production plant is assumed to produce one-half of its output by the dry process and one-half by the wet process, so that its environmental effects properly reflect those of the average industry. The model plant consists of a 5,000 MTU/yr plant and is capable of supplying the fuel for 27.5 RRYs.

A number of process off-gases are generated in the preparation of UF_6 from crude uranium feed. Most of these are combustion products from the production of heat, but some are volatilized solids and gases evolved during calcining and fluorination. Fluorides and oxides of nitrogen are the more significant sources of potential adverse environmental impact.

There are two major aqueous waste streams associated with UF_6 production. Many of the contaminants in the wet process are contained in a raffinate stream which is not released but held indefinitely in sealed ponds. The second aqueous waste stream is made up mostly of cooling water and dilute scrubber solutions. Some of these aqueous effluents are treated with calcium to precipitate calcium fluoride and then diluted with all other clear water

waste streams prior to release from the plant. The solid calcium fluoride is recovered from settling ponds, packaged, and ultimately buried.

Small amounts of natural uranium are released from the plant in ventilation exhaust air as dusts and volatile UF_6, and in liquid effluents. Radioactive material in the solid ash residue from fluorination is largely from thorium and amounts to about 0.86 Ci per RRY for the hydrofluor process. In addition, radioactive materials entering with the yellowcake appear in the solid residues for the dry process operations.

c. Uranium Enrichment[20]

Isotopic enrichment of uranium-235 is necessary to provide fuel for a light-water moderated nuclear reactor. The concentration of uranium-235 in natural uranium is about 0.7%, and the enriched uranium content for the current generation of reactors is 2-4%. The facilities are large in size because a large number of separation stages are required to attain the necessary enrichment. The present plant facilities are owned by the United States and operated by private industry under contracts with the Department of Energy. There are three facilities currently operating in the country. The model used in this study is a scaled-down model of the entire complex.

The primary sources of environmental effects associated with the effluents from enrichment of uranium are related to the gaseous effluents from the coal-fired stations used to generate the electrical energy required to operate the enrichment facility. The effluents associated with production of fuel per

RRY year are equivalent to the gaseous effluents released annually by a 45-MWe coal-fired plant.[21] The discharge of heat to the environment, both at the enrichment plants and the sites of individual electric generation plants, is also related to the power requirements of the enrichment plant.

d. Fuel Fabrication[22]

The feed material for the fabrication of fuel for the model LWR is enriched UF_6. The UF_6 is converted to UO_2, which is formed into pellets and then calcined and sintered at high temperatures. Finished pellets are loaded into Zircaloy or stainless steel rods, fitted with end caps and welded. The completed fuel rods are assembled in fixed arrays to be handled as fuel elements or assemblies.

In defining a representative model fuel fabrication plant, the conventional ammonium diuranate process was selected for conversion of UF_6 to UO_2. The capacity was chosen to be 3 MTU per day, a large plant by 1972 industry standards, with an annual production of approximately 26 RRY of fuel.

A major consideration in assessing environmental effects of fuel fabrication results from the fact that all of the fluorine introduced into the fuel cycle during the UF_6 production phase becomes a waste product during the production of UO_2 powder. Gaseous fluorine wastes generated are effectively removed from the air effluent streams by water scrubber systems. Calcium (lime) treatment is used on scrubber system wastes and process liquid wastes to remove fluoride ion as calcium fluoride (CaF_2) precipitate.

Other significant chemical species in liquid effluents are nitrogen compounds that are generated from the use of ammonium hydroxide in the production of UO_2 powder and from the use of nitric acid in scrap recovery operations.

2. The Back End of the Fuel Cycle (NUREGs-0116 and 0216)

a. Once-Through Fuel Cycle

Several operations comprise the back end of the once-through fuel cycle. These are: storage of spent fuel, encapsulation of spent fuel after storage, and disposal of spent fuel; disposal of low-level wastes; and the decontamination and decommissioning operations. The environmental effects of all of these operations have been aggregated and are given in Column H of Table S-3A.

(1) Spent Fuel

Spent fuel assemblies are stored in water basins for the order of 5 or more years after their removal from the reactor. These storage basins may be located at the reactor site or at offsite facilities. Storage would be followed by an encapsulation operation, in which individual assemblies are packaged, possibly in helium-filled steel canisters. The encapsulated assemblies would be disposed of in a Federal repository, the final step in the once-through fuel cycle.[23]

Environmental effects of spent fuel storage include heat releases, water use, release of small amounts of gaseous radionuclides, and generation of solid radioactive wastes. These wastes arise from such operations as water purification.

Fuel canisters are assumed to be disposed of in a bedded salt repository, the model repository defined in NUREG-0116. Operations of the repository for the once-through option are similar to those of the uranium recycle option (see below), although 11 times as many canisters would be required for spent fuel as for high-level wastes.[24]

The environmental effects of spent fuel disposal are similar to those of high-level waste disposal, except that in the once-through fuel cycle the remaining, undecayed, gaseous radionuclides (tritium, carbon-14, krypton, and iodine) are assumed to be released at the repository prior to its being sealed, whereas in the uranium recycle fuel cycle these isotopes are assumed to be released at the reprocessing plant. Long-term impacts from the repository will be nonexistant if the repository performs as expected and maintains the waste in isolation.[25] On the basis of the analysis presented in NUREG-0116, the staff has rationalized, for both fuel cycles, that the releases from the repository after it has been sealed, if it performs as expected, will be small and, when normalized to an RRY, will be insignificant.*

(2) Low-Level Wastes

Low-level wastes containing small quantities of radionuclides are produced in the normal operation of nearly all fuel cycle facilities, including reactors (for example, used filters from process ventilation systems, materials used in cleaning up spills of radionuclides, or in decontamination operations). Low-level wastes are normally packaged for disposal by surface burial at a

*The reader is referred to Section III3 for a discussion of the possible release of radionuclides from a waste repository in the event that a number of unlikely natural processes are encountered.

low-level waste disposal facility; the environmental effects of low-level waste management and burial are included in the total shown for each of the fuel cycle modes.

(3) Decontamination and Decommissioning

At the end of their useful operating lifetimes, all types of fuel cycle facilities must be decommissioned in ways that assure protection of public health and safety. In NUREG-0116, it was assumed that facilities would be decontaminated to remove potentially hazardous radionuclides and that the radioactive wastes would be removed from the site. The largest impacts of decontamination and decommissioning result from the disposal of low-level wastes and wastes contaminated with transuranic elements (elements with atomic numbers above 92). Decontamination and decommissioning impacts were not considered in WASH-1248 and, therefore, are not included in the impacts of the individual types of facilities in Table S-3A, but are included in Waste Management, column H, of Table S-3A.

b. Uranium-Only Recycle

The operations comprising the back end of the uranium-only recycle option can be grouped into two major categories - reprocessing and waste management operations. Environmental effects from the reprocessing facility include those of the reprocessing operation, high-level liquid waste storage, high-level waste solidification, and the short-term storage of solidified high-level waste at the reprocessing plant.

Environmental effects of waste management include those from any interim HLW storage (see below), transuranic waste processing, high-level and TRU waste disposal, low-level waste disposal, and decontamination and decommissioning.

In the uranium recycle fuel cycle, the plutonium formed in the reactor is considered to be a waste material and is transferred to a Federal repository for disposal. All wastes to be disposed of at the repository will be treated at the reprocessing plant or other operations to produce stable materials suitable for final disposal.

(1) Reprocessing[26]

Following their use as fuel in the nuclear power plant, spent fuel assemblies are stored under water at the reactor to permit decay of the short-lived isotopes and to reduce the heat generation rate. After cooling, the assemblies are transported to a reprocessing plant for recovery of the residual, slightly enriched uranium.

The chemical process for separating the usable uranium from plutonium and unwanted fission products or actinides (wastes) is assumed to be the Purex solvent extraction process, which has been the most widely used method for recovery of fissile values from spent fuel for many years. In the fuel reprocessing plant, the spent fuel assemblies are sawed or chopped into sections and the fuel is then dissolved by nitric acid and separated into uranium, plutonium and waste streams. These streams are processed into physical and chemical forms either for disposal or for shipment and further use in the fuel cycle. Environmental effects from reprocessing facilities have been derived

principally from data gathered in many years of experience in Federal government plants. The major environmental effects from reprocessing result from the assumed release of gaseous fission products and activation products from the spent fuel.[27]

High-level wastes (HLW) produced at the reprocessing plant contain the highly radioactive fission products from the spent fuel. These wastes require a system for their management that provides radiation shielding, protection against release, and a means of heat dissipation.

The reference system for HLW management at the reprocessing plant includes the following steps: short-term storage as liquid in tanks; solidification; short-term storage as a solid. Provision for a longer-term interim storage before disposal could be necessary; its potential impacts have been included in the impacts of HLW disposal.

Temporary storage of liquid HLW in tanks has been practiced for over 30 years. The most modern tank designs, which would be required for commercial fuel cycle operations, have proven virtually free of leaks and operational problems. Tanks of similar design have been in operation at government facilities for more than ten years and have been storing commercial reprocessing wastes at West Valley, New York, for more than five years. The tanks are assumed to be stainless steel, located in stainless steel-lined concrete vaults with equipment for heat removal. These tanks are an integral part of the reprocessing plant, and all effluents from the tanks are treated in plant systems together

with effluents from the rest of the plant. Their impacts are included among the impacts listed for reprocessing.[28]

To prepare HLW for shipment and disposal, and generally to reduce the risk of its dispersal, the HLW must be solidified as required by 10 CFR Part 50, Appendix F. A number of technologies exist for solidification; reduction of the waste to a glass form has been selected in this analysis as the model process for solidification.* The process assumed for production of glass from liquid HLW is a two-step process: first, producing a calcine, and second, melting it together with glass-forming materials to produce the glass. The product of the solidification process is a glass in a sealed canister ready for shipment, storage or disposal. The environmental effects of operation of the solidification facility are included in the estimates for the reprocessing plant.[29]

If the solidified HLW is not to be shipped to a Federal repository soon after solidification, a storage capability at the reprocessing plant must be provided. Facilities similar to spent fuel storage pools are assumed for this purpose in the analysis. Shielding, confinement, and removal of decay heat are the major functions of this facility. During normal operations, only minor increments of heat release and water usage are added to the impacts of the reprocessing facility.[30]

*The present licensing staff position is that a number of alternative waste forms should be characterized before one is selected for use in the repository.

(2) Waste Management

(a) Interim Storage of High-Level Wastes at a Retrievable Surface Storage Facility[31]

If final geologic disposal facilities are not available for receipt of solidified HLW within 10 years after it has been generated, a facility must be available for interim HLW storage. One such conceptual facility is the retrievable surface storage facility (RSSF). The impacts for an RSSF have been conservatively included in the summation of waste management effects (given in column H of Table S-3A (see below)). Land use for the RSSF would be committed only temporarily, and effluents from normal operation would be very small.

In the event that extended storage might be needed, a sealed storage cask concept has been used to evaluate the environmental effects of extended storage. Waste canisters are placed in thick-walled, high-integrity overpacks; this package is then placed inside concrete cylinders which provide shielding and channeling for natural-draft air cooling. This concept has low vulnerability to accidents.

(b) Transuranic-Contaminated Wastes (TRU Wastes)

Among the nuclides produced in nuclear reactor fuel are transuranics (TRU), radionuclides having atomic numbers higher than uranium, which may be parents of long-lived decay chains (tens of thousands of years). Waste materials containing significant quantities of these long-lived elements will be confined and consigned to the Federal repository.

Solid wastes contaminated with TRUs are derived primarily from the operation of the fuel reprocessing plant. Wastes included in this category are solidified liquids, filters, cladding hulls and other fuel hardware, and general trash. Overall management involves processing TRU wastes to a stable form, packaging the product in a high-integrity container, storing the packages onsite at the fuel reprocessing plant for up to 20 years, and finally shipping to a Federal repository for long-term storage or geologic disposal. Environmental effects from management of TRU-contaminated waste were found to be too small to be detectable in the totals in Table S-3.[32]

(c) Disposal of HLW and TRU Wastes at a Federal Repository

HLW and TRU wastes, including plutonium, comprise the materials from the nuclear fuel cycle that would be disposed of at a Federal repository. Deep emplacement in a stable geologic medium (bedded salt) under the continental United States was the repository model used in this evaluation. Although knowledge about the impacts of other alternatives is limited, the potential impacts from bedded salt disposal are believed to be reasonably representative impacts that would result from any appropriately designed geologic emplacement.*

The repository facility will be designed and the waste emplaced to keep the wastes and the surrounding geologic media below temperatures which could result in nuclide migration or impair the structure of the geologic formation. The mine will be constructed using existing technology to prevent flooding

*The present licensing staff position is that three to five sites in several geologic media should be fully characterized before selection of a medium for a repository.

and/or collapse during operation. Engineering features will be built into the facility to provide containment of waste materials. Operational (waste emplacement) lifetime of the facility will be between 20 and 30 years. At that time the facility will be backfilled and sealed.*

Effects from routine operation of the facility before decommissioning (including sealing of the underground shafts and tunnels) have been found to be small and comparable to those of the RSSF. Effluents (except for the large volumes of salt from excavation) have been projected to be very low. Radiological effluents from routine package inspection and repair activities are quite small relative to those from major fuel cycle facilities (e.g., reprocessing).[33]

(d) Low-Level Wastes

Low-Level wastes from the facilities of the front end of the fuel cycle are essentially the same for both the once-through fuel cycle and the uranium recycle mode. The additional back end facilities for reprocessing and waste treatment in the uranium recycle mode produce slightly larger quantities of low-level wastes than would result from spent fuel storage and disposal in the once-through fuel cycle. The impacts are included in column H of Table S-3A (see below).[34]

(e) Decontamination and Decommissioning of Uranium Recycle Facilities

The additional impacts from the reprocessing and other back end facilities for uranium recycle are included in column H of Table S-3A (see below). Impacts

*The present licensing staff position is that the option to retrieve the wastes should be maintained for 50 years following operation to allow monitoring and corrective actions if required.

from decommissioning the front end facilities are essentially the same for both fuel cycles and are also included in column H rather than in the columns for the individual facilities.[35]

3. Transportation

Seven steps in the transportation of materials to and from facilities involved in the nuclear fuel cycle have been considered in determining environmental effects of the LWR fuel cycle. For the front end of the fuel cycle, three steps--shipment of ore from mine to mill, shipment of uranium concentrate from mill to UF_6 production plant, and shipment of natural UF_6 to the enrichment plant--involve the transport of low specific activity material. Two additional steps in the front end of the fuel cycle--shipment of enriched UF_6 to the uranium dioxide (UO_2) plant and shipment of UO_2 to the fuel fabrication plant--involve the transport of potentially fissionable, low specific activity material. (The latter transportation step is not required for fabrication plants which incorporate the UF_6 to UO_2 conversion process.) In addition, the shipment of wastes from UF_6 plants, waste from fuel fabrication plants, and certain wastes from fuel reprocessing plants to commercial land burial sites involves the transport of radioactive low-level solid wastes.[36]

In the back end of the once-through option, potentially fissionable spent fuel is shipped to storage or disposal. In the back end of the uranium-only recycle fuel cycle, the shipments from the reprocessing plant involve the transport of recovered uranium as UF_6 to an enrichment plant, and the transport of solid, high-level waste material and plutonium to a Federal waste storage facility. For all fuel cycle options, the three steps (shipment of fuel to, irradiated

fuel from, and waste from reactors) covering the transportation of materials to and from nuclear power plants are considered in Table S-4 of 10 CFR 51.20 and are not included in Table S-3.[37]

Packaging and transport of radioactive materials are regulated at the Federal level by the Nuclear Regulatory Commission (NRC) and the Department of Transportation (DOT). Certain aspects, such as limitations on gross weight of trucks, are regulated by the individual States. The regulations are designed to protect employees, transport workers, and the public from external radiation and exposure to radiation and radioactive materials as a result of normal and accident conditions of transport. The requirements for packaging of low specific activity material are such that it is most unlikely that a person could ingest or inhale a mass of material that would result in a significant radiation hazard under any circumstances arising in transport. Shipments of fissile materials are limited by the packaging designed to ensure nuclear criticality safety under both normal and accident conditions of transport. Containers of solidified high-level wastes must be designed to withstand the effects of severe accidents.

The environmental effects of the shipment of materials in the nuclear fuel cycle are those which are characteristic of the trucking industry in general. The increase in density of truck traffic from fuel cycle shipments will be small compared with total truck traffic.[38]

Section I - References

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3. U.S. Nuclear Regulatory Commission, "Public Comments and Task Force Responses Regarding the Environmental Survey of the Reprocessing and Waste Management Portions of the LWR Fuel Cycle," NUREG-0216, March 1977.

4. U.S. Nuclear Regulatory Commission, "Staff Recommendations for Minor Adjustments to Table S-3," submitted by James Lieberman, Counsel for NRC Staff, Docket RM 50-3, January 19, 1978.

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6. NUREG-0116, p. S-12.

7. "U.S. Nuclear Regulatory Commission, Final Generic Environmental Statement on the Use of Recycle Plutonium in Mixed Oxide Fuel in Light Water Cooled Reactors", Office of Nuclear Material Safety and Safeguards, NUREG-0002, August 1976.

8. WASH-1248, p. S-2.

9. Ibid., p. S-5.

10. Ibid.

11. NUREG-0002, Table IV C-9, p. IV C-75.

12. Ibid., Section 3.2.6, p. 3-8.

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20. Ibid., Chapter D, p. D-1 ff.

21. Ibid., p. D-4.

22. Ibid., Chapter E, p. E-1 ff.

23. NUREG-0116, Section 3.1.1, p. 3-1 ff.

24. Ibid., Section 4.6.3, p. 4-113 ff.

25. Ibid., pp. 2-10, 2-11.

26. NUREG-0002, Chapter IV, Section E, p. IV-E-20 ff.

27. NUREG-0116, Section 4.1, p. 4-4 ff.

28. Ibid., Section 2.2.1, p. 2-4, and Section 4.2.1, p. 4-14 ff.

29. Ibid., Section 2.2.2, pp. 2-4 and 2-5, and Section 4.2.2, p. 4-18 ff.

30. Ibid., Section 4.2.3, p. 4-24 ff.

31. Ibid., Section 4.2.5, p. 4-29 ff.

32. Ibid., Secton 2.3, p. 2-6 ff, and Section 4.3, p. 4-39 ff.

33. Ibid., Section 4.4, p. 4-71 ff.

34. NUREG-0116, Section 2.7, pp. 2-13, 2-14, and Section 4.7, p. 4-117 ff.

35. Ibid., Section 2.8, p. 2-15, and Section 4.8, p. 4-129 ff.

36. WASH-1248, Section H, p. H-1.

37. U.S. Atomic Energy Commission, "Environmental Survey of Transportation of Radioactive Materials To and From Nuclear Power Plants," WASH-1238, 1972, Section II, pp. 5-10.

38. NUREG-0116, section 2.9, pp. 5-15, 2-16.

Section II. Environmental Effects of the LWR Fuel Cycle

A. Environmental Data

Table S-3, Table of Uranium Fuel Cycle Environmental Data, is a summary of environmental considerations attributable to the uranium fuel cycle, normalized to the annual fuel requirement in support of a model 1,000-MWe LWR. Data from the "front end" of the uranium fuel cycle, based on WASH-1248, have been combined with data from the "back end," which is based on NUREGs-0116 and -0216 and the remanded proceeding (Docket No. RM-50-3). Table S-3A, which follows, sets forth the contributions by the various segments of the fuel cycle to the total values given in Table S-3. In general, Table S-3 presents the sum of the higher values taken from either the once-through fuel cycle or the uranium-only recycle option. The following is a brief discussion of the environmental considerations related to the "back end" of the once-through fuel cycle and the uranium-only recycle option.

1. Back End of the Once-Through Fuel Cycle

At present, spent fuel discharged from LWRs is being stored in the United States pending a policy decision whether to dispose of the irradiated spent fuel as a waste product--the once-through fuel cycle--, or to reprocess spent fuel and recover the residual fissile values for recycle as fuel in power reactors, in this case, --the uranium-only recycle option. In the once-through fuel cycle, the storage and disposal of spent fuel as waste, along with other waste management activities, constitutes the "back end" of the uranium fuel cycle.[1]

The environmental considerations related to the once-through fuel cycle are summarized in column F of Table S-3A. It is expected that spent fuel will remain in interim storage facilities for periods of up to 10 years or more to reduce radiation and heat emissions prior to packaging and disposal, and because facilities for the permanent disposal of spent fuel are not yet available.[2] Thus, column F includes the environmental impacts of extended pool storage as well as spent fuel disposal in a deep salt bed, geological repository. Low-level wastes, and decontamination and decommissioning wastes, from all segments of the fuel cycle are also included in column F.[3] There are no significant amounts of transuranium (TRU) wastes generated in the once-through fuel cycle.

It has been assumed that spent fuel or high-level wastes will be disposed of in a geologic, bedded salt, repository.[4] Operation of repository facilities is similar for both spent fuel or high-level waste, and it has been assumed that a repository in bedded salt will be designed and operated so as to retain the solid radioactive waste indefinitely. However, the radiological impacts related to the geological disposal of spent fuel are based on the assumption that all gaseous and volatile radionuclides in the spent fuel are released before the geologic repository is sealed.[5] Since the gaseous and volatile radionuclides are the principal contributors to environmental dose commitments, this assumption umbrellas the upper bounds of the dose commitments that may be associated with the disposal of spent fuel.

2. Back End of the Uranium-Only Recycle Fuel Cycle Option

At present, there are no spent fuel reprocessing plants in the United States that can reprocess LWR spent fuel. Moreover, if a policy decision is made to permit reprocessing of spent fuel, the capability to reprocess spent fuel in the United States may not be available until about the early 1990s. However, if LWR spent fuel is reprocessed, the environmental impacts from reprocessing and related waste management activities are nearly identical for both recycling of uranium and plutonium, or recycling of uranium-only, as fuel in nuclear power reactors. Whether plutonium will be used as a fuel in LWRs, or breeder reactors, or both, is a separate issue that will be resolved in connection with the policy decision whether to resume reprocessing in the United States. For this purpose, to cover the contingency that at some future date spent fuel from LWRs may be reprocessed, it has been assumed that only the uranium that is recovered from the reprocessing of spent fuel from LWRs will be recycled as fuel to LWRs; and the plutonium is not used for its fuel value in LWRs. Instead, it becomes a by-product waste that may be disposed of in a manner similar to that for high-level waste.[6] This is called the uranium-only recycle option, and its environmental considerations are summarized in columns G (Reprocessing) and H (Waste Management) of Table S-3A.*

* It should be noted that column F, and columns G and H, are not added together to arrive at totals, but are presented as alternatives. The higher value from these two alternative fuel cycles is added to arrive at totals.

With respect to waste management activities associated with the uranium-only recycle option (column H), the environmental considerations include the geologic disposal of high-level wastes (HLW), transuranic wastes (TRU), plutonium, low-level or nontransuranic wastes, and the disposal of wastes from decontamination and decommissioning of fuel cycle facilities.[7] The environmental considerations relevant to waste management activities directly related to reprocessing, such as storage of liquid wastes in tanks, waste solidification and packaging, and interim storage of solidified wastes at the reprocessing site, are included in column G.

It has been assumed that a geologic repository will be designed and operated so as to retain solid radioactive waste indefinitely. However, to umbrella the upper bounds of the dose commitments that may be associated with reprocessing and waste management operations related to the uranium-only recycle option, it has been assumed that all of the gaseous and volatile radionuclides contained in the spent fuel are released to the atmosphere prior to the disposal of the wastes.[3] The gaseous radionuclides (tritium, carbon-14, and krypton-85) and the volatile radionuclide iodine-129 are the principal contributors to environmental dose commitments from the "back end" of the uranium fuel cycle.

B. Environmental Considerations

This section is a brief discussion of the environmental considerations of the uranium fuel cycle, which are summarized in Table S-3 and Table S-3A. It also provides a brief explanation of how the values in Table S-3, which has been normalized to a model 1,000-MWe reference reactor year (RRY), can be converted

TABLE S-3A

Summary of Environmental Considerations for LWR Fuel Cycle by Component
Normalized to Model LWR Reference Reactor Year

Natural Resource Use	A Mining	B Milling	C UF_6 Prod.	D Enrichment	E Fuel Fab.	F Spent Fuel Storage & Disposal	G Reprocessing	H Waste Mgmt. for Uranium Recycle	I Transportation	Total
Land (Acres)										
Temporarily Committed	55	0.5	2.5	0.8	0.2	7.7	32	9.0	-	100
Undisturbed Area	38	0.2	2.3	0.6	0.16	7.5	28.5	8.6	-	79
Disturbed Area	17	0.3	0.2	0.2	0.04	.192	3.5	0.35	-	22
Permanently Committed	2	2.4	0.02	0.0	0.0	7.7	0.12	0.4	-	13
Overburden moved (millions of MT)	2.7	-	-	-	-	.001	0.1	0.0015	-	2.8
Water (millions of gal.)										
Discharged to air	-	65	3.3	84	-	11.4	6.6	0.69	-	160
Discharged to water bodies	-	-	23.0	11,006	5.2	.05	54.8	-	-	11,090
Discharged to ground	121	-	-	-	-	3.1	-	3.5	-	127
Total Water	121	65	26.3	11,090	5.2	14.5	61.4	4.2	-	11,377
Fossil Fuel										
Electrical energy (thousand MWh)	0.25	2.70	1.70	310	1.7	1.9	4.0	2.3	-	323
Equivalent Coal (thous MT)	0.09	0.97	0.62	113	0.62	0.7	1.5	0.82	0.016	118
Natural Gas (million scf)	-	68.5	20.0	-	3.6	12	28.6	14	-	135

TABLE S-3A (cont.)

Summary of Environmental Considerations for LWR Fuel Cycle by Component
Normalized to Model LWR Reference Reactor Year

	A	B	C	D	E	F	G	H	I	
	Mining	Milling*	UF_6 Prod.	Enrich-ment	Fuel Fab.	Spent Fuel Storage & Disposal	Reprocess-ing	Waste Mgmt. for Uranium Recycle	Trans-portation	Total
Effluents										
Chemical (MT)										
Gases (MT)										
SO_x	0.5	37.0	29.0	4,300(1)	23	0.035	5.4	0.06	0.045	4,400
NO_x	5.0	15.9	10.0(2)	1,130	6	0.04	21.9	0.065	0.62	1,190
Hydrocarbons	0.3	1.3	0.8(3)	11	0.06	0.0004	0.5	0.02	0.062	14
CO	0.02	0.3	0.2	28	0.15	0.026	0.5	0.029	0.38	29.6
Particulates	-	9.7	7.6	1,130	6	0.000008	0.6	0.02	0.012	1,154
Other Gases										
F	-	-	0.11	0.5	0.005	-	0.05	-	-	0.67
Cl	-	-	-	-	-	0.013	0.0006	0.013	-	0.014
Liquids										
$SO_4^=$	-	-	4.5	5.4	-	-	<0.02	-	-	9.9
NO_3	-	-	0.1	2.7	23	-	-	-	-	25.8
Fluoride	-	-	8.8	-	4.1	-	-	-	-	12.9
Ca	-	-	-	5.4	-	-	-	-	-	5.4
Cl	-	-	0.2	8.2	-	-	0.09	-	-	8.5
Na^+	-	-	3.9(4)	8.2	-	-	<0.02	-	-	12.1
NH_3	-	-	1.5	-	10.0	-	-	-	-	10.9
Fe	-	-	-	0.4	-	-	-	-	-	3.4
Tailings Solutions (thousands)	-	240	-	-	-	-	-	-	-	240
Solids	-	91,000	80	-	26	-	-	0.42	-	91,000

TABLE S-3A (cont.)

Summary of Environmental Considerations for LWR Fuel Cycle by Component
Normalized to Model LWR Reference Reactor Year

	A	B	C	D	E	F	G	H	I	
	Mining	Milling	UF_6 Prod.	Enrich-ment	Fuel Fab.	Spent Fuel Storage & Disposal	Reprocess-ing	Waste Mgmt. for Ura- Recy-	Trans-portation	Total
Effluents (cont.)										
Radiological (curies)										
Gases (including entrainment)(5)										
Rn-222	-	-	-	-	-	-			-	-
Ra-226	-	0.02	-	-	-	4.5×10^{-7}	-	4.5×10^{-7}	-	0.02
Th-230	-	0.02	-	-	-	4.5×10^{-7}	-	4.5×10^{-7}	-	0.02
Uranium	-	0.03	0.0015	0.002	0.0002	7.3×10^{-6}	0.000039	7.3×10^{-6}	-	0.034
Tritium (thousands)	-	-	-	-	-	14	18.1	6.8×10^{-9}	-	18.1
C-14	-	-	-	-	-	19	24	-	-	24
Kr-85 (thousands)	-	-	-	-	-	290.70	400	1.1×10^{-7}	-	400
Ru-106	-	-	-	-	-	-	0.14	-	-	0.14
I-129	-	-	-	-	-	1.3	0.01	-	-	1.3
I-131	-	-	-	-	-	.003	0.83	-	-	0.83
Fission Products and Transuranics	-	-	-	-	-	.001	0.203	3.1×10^{-3}	-	0.203
Liquids										
Uranium & Daughters	-	2	0.044	0.02	0.02	5.9×10^{-6}	-	5.4×10^{-6}	-	2.1
Ra-226	-	-	0.0034	-	-	-	-	-	-	0.0034
Th-230	-	-	0.0015	-	-	-	-	-	-	0.0015
Th-234	-	-	-	-	0.01	-	-	-	-	0.01
Tritium (thousands)	-	-	-	-	-	-	-	-	-	-
Fission and Activation Products	-	-	-	-	-	5.9×10^{-6}	-	4.5×10^{-6}	-	5.9×10^{-6}
Solids (buried onsite)										
Other than high level (shallow)	600	-	0.06	-	0.23	4700	0.52	10,700	-	11,300
TRU and HLW (deep) (millions)	-	-	-	-	-	11	-	11	-	11
Thermal (billions of Btu)	-	69	20	3200	9	750	76.5	689	0.014	4,863

TABLE S-3A (cont.)

Summary of Environmental Considerations for LWR Fuel Cycle by Component
Normalized to Model LWR Reference Reactor Year

(1) Estimated effluents based upon combustion of equivalent coal for power generation.

(2) 25% from natural gas use.

(3) Combined effluents from combustion of coal and natural gas and process tankage; contains 0.2 MT of Hexane.

(4) Contains about 80% Potassium.

(5) In the "uranium recycle" case, gaseous radionuclides are assumed to be released in reprocessing, and the releases are shown in the "Reprocessing" column (G). In the "once through" case, where spent fuel goes to geologic disposal, gaseous radionuclides are assumed to leak out of the fuel at the repository; the amounts are shown in column F. Only the larger of the two values is added into the "Total" column, since they represent alternative cases.

* Numbers presented for uranium milling are taken from WASH-1248. They are not necessarily consistent with more recent staff analyses, e.g., those presented in NUREG-0511, "Draft Generic Environmental Impact Statement on Uranium Milling," published in April 1979.

into the cumulative environmental effect over the 30-year reference reactor lifetime, and in turn converted into the cumulative environmental effect related to a prospective nuclear power forecast.* The narrative is drawn primarily from the WASH-1248, NUREG-0116, and NUREG-0216 documents, and the S-3 hearing record. References to applicable sections of these documents are included in the narrative.

It should be noted that radon emissions from the "front end" of the fuel cycle, and technetium-99 release estimates for the "back end" of the fuel cycle are not given in Table S-3. Accordingly, radon and technetium releases, together with an appraisal of their impacts, may be the subject of litigation in individual reactor licensing proceedings.[9]

1. Natural Resource Use

   a. Land

The total land use per RRY attributable to the uranium fuel cycle in support of a model 1,000-MWe LWR is about 113 acres, of which about 100 acres are temporarily committed, and about 13 acres are permanently committed. About 80% of the temporarily committed land used by fuel cycle facilities is undisturbed land. Temporarily committed land, which is used during the life of specific fuel cycle facilities, can be released for unrestricted use after

*Most effluent values, unless indicated otherwise, can be converted from RRY values to reactor lifetime values by multiplying the value/RRY by 30-years (reactor life).

those facilities are closed down and decommissioned. Permanently committed land is that land which may be used for waste disposal but may not be released for unrestricted use after certain facilities have ceased operating and are decommissioned.[10]

The mining of uranium ore accounts for about 55% of the temporarily committed land use of the entire uranium fuel cycle. Mining operations also account for most of the overburden moved: 2.7 million metric tons compared to a total of 2.8 million metric tons per RRY for the entire fuel cycle. Next to mining, reprocessing and waste management operations use most of the remaining temporarily committed land attributable to the uranium fuel cycle. Of the permanently committed land use attributable to the uranium fuel cycle, mining and milling operations account for about 35%, and most of the remaining 65% is used for the disposal of radioactive wastes (8.5 acres/RRY).

To determine the cumulative land use effect related to a prospective nuclear economy, one must first convert the land use per RRY to land use per model 1,000 MWe LWR lifetime (30 years), and then multiply that value by the equivalent number of model 1,000-MWe LWRs projected (GWe). The weighted average factor to convert land use per RRY to land use per model LWR life is about 40.

The conversion factor of 40 is a weighted average that results from consideration of three factors: land use for facilities; land use for waste management, which increases with time; and ore depletion and mill recovery performance over the life of the reactor. In WASH-1248, uranium mining and milling operations were based on an average ore grade of 0.2%, and 100% mill recovery,

which represented current operations. However, a later analysis developed for NUREG-0002 indicated that when ore depletion and mill recovery performance is considered over the years 1976-2000, it would be more appropriate to use an average ore grade of 0.1%, with 90% mill recovery, over the life of a LWR. Thus, to convert land use per RRY to land use per LWR life committed to mining and milling, the land use per RRY should be multiplied by 67. Added to this value is the land use per RRY for UF_6 production, enrichment, fuel fabrication and reprocessing; and 30 times the land use per RRY for waste management operations. For the reason given above, since most of the "overburden moved" is related to the mining of uranium ore, the factor used to convert MT/RRY of overburden moved to MT/LWR life is 67.

Environmental Effects: The land use requirements related to the fuel cycle in support of a model 1,000-MWe LWR do not represent a significant impact. A 1,000-MWe coal-fired power plant that uses strip-mined coal requires the disturbance of about 200 acres of land per year for obtaining coal alone. Thus, for comparison, the coal plant disturbs about 10 times as much land as the disturbance attributable to the entire fuel cycle in support of the model 1,000-MWe LWR.

b. Water

The principal use of water in the fuel cycle supporting a model 1,000-MWe LWR is for cooling. Of the total 11,377 million gallons of water use per RRY, about 11,000 million gallons are required to remove heat, by once-through cooling, from the power stations that supply electrical energy for uranium

enrichment. The discharge of water to surface streams is in accordance with the National Pollutant Discharge Elimination System Permits issued by EPA and the states. Drainage water pumped out of uranium mines (123 million gallons/RRY) and from waste management operations (3.5 million gallons/RRY) is discharged to the ground. Of the 160 million gallons of water evaporated per RRY, about 65 million gallons of water are evaporated from mill tailings ponds, and the other 95 million gallons of water are evaporated from cooling water from fuel cycle facilities.

To determine the cumulative water use effect related to a prospective nuclear economy, one must first convert water use per RRY to water use per model 1,000-MWe LWR lifetime (30 years), and then multiply that value by the equivalent number of model 1,000-MWe LWRs projected (GWe). The factor used to convert water use per RRY to water use per model LWR life is 30. However, to determine the water use evaporated or discharged to ground, the conversion factor for mining and milling operations is 67; and the factor for other fuel cycle operations is 30.

Environmental Effect: The water use requirements related to the fuel cycle in support of a model 1,000-MWe LWR do not represent a significant impact. If all plants supplying electrical energy used cooling towers, the water use of the fuel cycle would be about 6% of that required by the model 1,000-MWe LWR. The evaporated water loss of the fuel cycle is about 2% of the evaporated water loss of a model 1,000-MWe LWR cooling tower.

c. Fossil Fuel

Electrical energy and process heat are used in the fuel cycle. The electrical energy (323 thousand MWh/RRY), of which about 96% is used for uranium enrichment, is produced by conventional, coal-fired, power plants.[12] Most of the process heat used in the fuel cycle is supplied by the combustion of natural gas (135 million scf/RRY). In general, about 50% of the natural gas is used for yellowcake drying,[13] 15% is used in UF_6 production, 3% is used in fuel fabrication, 22% is used in reprocessing, and 10% is used in waste management operations.

To determine the cumulative fossil fuel use effect related to a prospective nuclear economy, multiply the fossil fuel per RRY value by 30 to convert to the fossil fuel use over the 30-year life of the model 1,000-MWe LWR, and then multiply that value by the equivalent number of model 1,000-MWe LWRs projected (GWe).

Environmental Effect: The fossil fuel use requirements related to the fuel cycle in support of a model 1,000-MWe LWR do not represent a significant impact. The electrical energy needs of the fuel cycle are only about 5% of the electrical energy produced by the model 1,000-MWe LWR. If the natural gas consumed by the fuel cycle were used to generate electricity, it would contribute less than 0.4% of the electrical energy produced by the model LWR.

2. Effluents - Chemical

a. Gases

The gaseous chemical effluents from the fuel cycle result, for the most part, from the combustion of fossile fuel to provide electrical energy or process heat for fuel cycle facilities.[14] To determine the cumulative gaseous chemical effect related to a prospective nuclear economy, perform the calculation in a manner similar to that given above for fossil fuel.

Environmental Effect: The gaseous chemical effluents related to the fuel cycle in support of a model 1,000-MWe LWR do not represent a significant impact. Based on data in a Council on Environmental Quality report,[15] these emissions represent a very small addition (about 0.02%) to emissions from transportation and stationary fuel combustion in the United States.

b. Other Gases

Small amounts of halogen compounds are released as gaseous effluents to the environs, primarily as fluorides from UF_6 conversion and uranium enrichment operations.

Environmental Effect: Measurements of fluorine in unrestricted areas indicate concentrations below the level at which deleterious effects have been observed.[16] Moreover, long-term observations have not revealed any adverse effects attributable to fluoride releases from UF_6 conversion, uranium enrichment, and fuel fabrication facilities.

c. Liquids and Solids

Some liquid chemical effluents are released to surface waters from UF_6, enrichment, and fuel fabrication facilities. Tailing solutions from the uranium mill account for the bulk of mass of liquid (240 thousand MT/RRY) and solid (91 thousand MT/RRY) effluents from the fuel cycle. However, the tailing solutions are slowly dissipated by natural processes, principally through evaporation, leaving the tailings solids for eventual disposal.[17]

There are two major aqueous waste streams associated with the wet UF_6 conversion process.[18] One is made up of dilute scrubber solutions which are treated with lime to precipitate calcium fluoride, and is then diluted with cooling water effluent before it is released. The other is a raffinate stream which is held in sealed ponds and the water is allowed to evaporate. The solids which are recovered from the settling ponds are packaged and ultimately buried. The discharged of water to surface streams is in accordance with a National Pollutant Discharge Elimination System Permit issued by EPA and the state.

A number of chemicals (primarily calcium, chlorine, sodium, and sulfate ions) are present in the liquid effluent from the enrichment plant. Water treatment and dilution by the receiving river reduces the concentration of chemicals to a small fraction of the recommended permissible water quality standards.[19]

The liquid effluent from fuel fabrication facilities contains nitrogen compounds resulting from the use of ammonium hydroxide in the production of UO_2 powder.

and from the use of nitric acid in scrap recovery operations. The fluorine introduced into the fuel cycle during UF_6 production becomes a waste product during the production of UO_2 powder. The gaseous fluoride is removed from the effluent air streams by water scrubber systems.[20] The scrubber system wastes are treated with lime to precipitate calcium fluoride, which is filtered from the waste effluent stream and packaged (about 11 cubic yards/RRY) for disposal.[21] The discharge of water to surface streams is in accordance with a National Pollutant Discharge Elimination System Permit issued by EPA and the state.

To determine the mass of tailing solution and solid tailings related to a prospective nuclear economy, which are a function of the average grade of ore processed, multiply the values for tailings solutions and solids in Table S-3 by 67 to obtain the mass of tailings solution and tailings generated over the model LWR lifetime.

Environmental Effect: The liquid and solid chemical effluents related to the fuel cycle in support of a model 1,000-MWe LWR do not represent a significant impact. All liquid discharges from fuel cycle facilities into the navigable waters of the United States are subject to requirements and limitations set forth in the National Pollutant Discharge Elimination System Permit issued by an appropriate state or federal regulatory agency. When milling activities are terminated, the tailings pile may be graded, covered with earth and topsoil, and seeded to reduce radon emanation.*

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*At this time, radon emissions are excluded from the S-3 fuel cycle rule. Proposed regulations related to the disposal of mill tailings were published in the Federal Register on August 24, 1979.

3. Effluents - Radiological

a. Gases and Liquids

Table S-3 summarizes (except for radon-222 and technetium-99) the curies of radioactivity released per RRY in the gaseous and liquid effluents from the uranium fuel cycle in support of a model 1,000-MWe LWR. In general, the natural radionuclides (radium. thorium and uranium) are released from the front end, and the others are released from the back end of the fuel cycle.

In the front end of the fuel cycle, small amounts of radium, thorium and uranium are released to the environment in the gaseous process effluents and in the ventilation air discharged to the atmosphere from milling, UF_6 production, enrichment and fuel fabrication facilities. Small amounts of uranium and its daughters also are released in the liquid effluents from these facilities, but most of these radionuclides become part of the solid waste collected in the tailings pile from milling operations or in settling ponds associated with the other front end operations.

In the once-through fuel cycle, the spent fuel is stored for five or more years and then disposed of in a geologic respository when the repository is available to receive spent fuel.[22] During interim storage prior to sealing of the repository, some of the gaseous and volatile radionuclides contained in the spent fuel may escape due to the failure of the fuel element cladding and leakage of the spent fuel disposal containers.[23]

About 50% of the krypton, 10% of the carbon-14, and 1% of tritium and iodine contained in spent fuel exists within the gas space in the fuel rod and is likely to be released from the fuel rod if the cladding fails. However, the curies of tritium, carbon-14, krypton-85 and iodine-129, given in Column F of Table S-3A represent the total curies of each contained in 35 mitric tons of spent fuel (the annual reference reactor fuel requirement), irradiated to 33,000 MWd/MT, and aged 5 years. Since the site and method for spent fuel disposal have not yet been defined, the NRC staff cannot determine what amounts of radionuclides may eventually escape from the repository or when they may enter the environment. However, the NRC staff made a generic assessment, based on a reference repository, to identify which radionuclides have the higher probability of migrating from a repository, and which of these radionuclides are the principal contributors to environmental dose commitments if they do eventually enter the biosphere. In general, the gaseous radionuclides that escape from failed fuel rods, or leaking waste canisters, before the repository is sealed, and the very long-life radionuclides that have low retardation in soils, such as iodine-129, which may migrate with ground water and eventually reach the biosphere, are the principal contributors to environmental dose commitments. Accordingly, to umbrella the upper bounds of prospective dose commitments, it was assumed that all of the tritium, carbon-14, krypton-85, and iodine-129 contained in 5-year-old spent fuel per RRY was released to the environment.

In the uranium-only recycle option, the spent fuel is reprocessed. During reprocessing, the gaseous radionuclides (tritium, carbon-14 and krypton-85) are released to the atmosphere; however, most of the iodine is removed from

the process effluents.[24] The radiological effluents related to the uranium-only recycle option are given in column H of Table S-3A. These values, per RRY, are based on the reprocessing of six month old spent fuel.

Since the radiological effluents given in Table S-3 are based on the higher values taken from either fuel cycle, the radiological considerations related to the back end of the fuel cycle are based on 100% release of the tritium, carbon-14, krypton-85, and iodine-129 contained in six month aged spent fuel, and small amounts of other fission product and transuranic radionuclides that may be released if spent fuel were reprocessed.

Environmental Effect: Excluding radon, the radiological effluents released per RRY from the fuel cycle in support of the model 1,000-MWe LWR result in an estimated 100-year environmental dose commitment to a U.S. population of 300 million persons of about 660 person-rem, of which about 550 person-rem is attributable to gaseous effluents and about 100 person-rem is attributable to liquid effluents. Of the dose commitment attributable to gaseous effluents, about 42% is from tritium, 31% is from carbon-14, 5% is from krypton-85, 10% is from iodine, and the balance (12%) is from all other radionuclides, which contribute primarily to the local population dose commitment.

Although radon effluents are excluded from Table S-3, the dose commitment from radon has to be added to the above fuel cycle environmental dose commitment to arrive at the estimated dose commitment attributable to the entire fuel cycle. Based on recent studies, the 100-year environmental dose commitment per RRY attributable to radon emissions from mining and milling is about 220 person-rem.

On this basis, the 100-year environmental dose commitment attributable to the entire fuel cycle is about 860 person-rem per RRY. For comparison, the annual dose commitment to a U.S. population of 300 million from natural background radiation is about 3,000,000 person-rem. Thus, the dose commitment per RRY from the fuel cycle is about 0.03% of the dose commitment to the U.S. population from natural background radiation. Section III contains an assessment of the environmental dose commitment to the U.S. population attributable to the radiological effluents, except radon, released from the uranium fuel cycle.

b. Solids

The curies per RRY of radionuclides in buried radioactive low-level, high-level and transuranic waste materials are given in Table S-3. As discussed above, it is assumed that there will be no release of solid radionuclides to the environment from buried solid waste materials. Moreover, the radiological effluents from waste management are so small in relation to the other segments of the fuel cycle that they do not show up in the totals presented in Table S-3.[25]

About 10,700 curies of mixed radionuclides are buried per RRY at low-level waste land burial sites. Of this total, 9,100 curies comes from LWR low-level waste;[26] 1,500 curies are attributable to decommissioning of nuclear facilities, including the reactor;[27] and the balance, about 100 curies, is generated by the uranium fuel cycle operations in support of the LWR. About 600 curies of uranium and its daughters are added per RRY to the tailings pile at the mill site.[28]

The high-level radioactive waste from the once-through fuel cycle is the spent fuel assemblies, which will be packaged and disposed of in a geologic repository. The radioactive waste from the uranium-only recycle option consists of the fuel assembly hulls, the high-level and intermediate-level wastes from reprocessing, and the plutonium waste. These wastes will be disposed of in a geologic repository in the form of solids which will have chemical and physical properties that mitigate the release of radionuclides to the environs. It is assumed that the geologic repository will be designed and operated so that the solid radioactive wastes are confined indefinitely.

Environmental Effect: There are no significant releases of solid radioactive materials from shallow land-burial facilities, or from the geologic repository, to the environment.

4. Effluents - Thermal

The uranium fuel cycle in support of a model 1,000-MWe LWR discharges approximately 4 trillion Btu of heat per RRY into the environs. Most of this heat, about 80%, is rejected to the atmosphere at the power plants supplying electrical energy to the enrichment plant or at the enrichment plant itself.[29] Waste management and spent fuel storage contribute about 18% of the heat rejected to the environs. This heat results from the decay of radionuclides. The rejection of process heat from fuel cycle facilities accounts for the remaining 2% of the thermal effluent from the fuel cycle.

To determine the heat rejection by the fuel cycle over the model LWR lifetime, multiply the thermal effluent value per RRY by 30.

Environmental Effect: The thermal effluents related to the fuel cycle in support of a model 1,000-MWe LWR do not represent a significant impact. The thermal effluent of the fuel cycle is only about 3% of the heat dispersed to the environs by the model LWR.

5. Transportation

The dose commitment to workers and the public related to the transport of nuclear materials in support of a model 1,000-MWe LWR is estimated to be about 2.5 person-rem per RRY.[30]

To determine the transportation dose commitment over the model LWR lifetime, multiply the dose commitment per RRY by 30.

Environmental Effect: The transportation dose commitment related to the fuel cycle in support of a model 1,000-MWe LWR does not represent a significant impact. Compared to natural background radiation, this dose commitment is small.

6. Occupational Exposure

The occupational exposure value given in Table S-3 (22.6 person-rem) represents an upper exposure value related to reprocessing and waste management activities

associated with the back end of the fuel cycle, if the model 1,000-MWe LWR is operated on the uranium-only recycle mode. Most of the occupational exposure attributable to the back end of the fuel cycle results from the variety of operations associated with reprocessing and related waste management activities involving the disposal of irradiated spent fuel. For comparison, the occupational exposure related to the "back end" of the "once-through" uranium fuel cycle is estimated to be 7 person-rem per RRY. The occupational exposure attributable to the entire uranium fuel cycle in support of a model 1,000-MWe LWR is estimated to about 200 person-rem per RRY.[31]

Environmental Effect: The occupational exposure attributable to the fuel cycle in support of a model 1,000-MWe LWR is acceptable. NRC regulations limit the permissible occupational exposure of any individual to 5 rem annually.

Section II - References

1. NUREG-0116, Section 2.6 and 4.6.
2. Ibid., p. 4-109.
3. Ibid., 4-117.
4. Ibid., Section 4.4.
5. Ibid., p. 4-114.
6. Ibid., Section 2.5 and pp. 4-100.
7. Ibid., Section 2.2, 2.3, 2.4 and 2.5, and Section 4.4.
8. Ibid., p. 4-114.
9. Federal Register, 44, p. 45371.
10. WASH-1248, p. S-9.
11. Ibid., p. S-16.
12. Ibid.; p. D-14.
13. Ibid., p. B-10.
14. Ibid., p. S-18.
15. U.S. Council on Environmental Quality, "The Seventh Annual Report," September 1976, Figures 11-27 and 11-28, pp. 238-239.
16. WASH-1248, p. S-18.
17. Ibid., p. B-9.
18. Ibid., p. C-4.
19. Ibid., pp. D-18, 19.
20. Ibid., p. E-3.
21. Ibid., p. E-3.
22. NUREG-0116, p. 4-109.
23. Ibid., pp. 4-110 and 4-115.

24. Ibid., p. 4-9.

25. Ibid., p. 4-84, Table 4.16.

26. NUREG-0216, p. H-17, Table VII.

27. Ibid., p. H-18, Table VIII.

28. WASH-1248, p. S-24.

29. Ibid., p. S-24.

30. NUREG-0116, p. 4-150, Table 4.35.

31. NUREG-0216, p. I-2.

III. Calculated Population Dose Commitments and Health Effects of the Uranium Fuel Cycle

In the Federal Register Notice promulgating the final fuel cycle rule (44 FR 45362), the Commission stated, in note 35, that one important issue to be addressed in the narrative is the question of the time period over which dose commitments from long-lived radioactive effluents should be evaluated. In particular, how dose commitment evaluations over extended periods of time might be performed and what their significance might be are subjects that the Commission directed be addressed in this narrative.

This portion of the narrative has been developed to meet the above Commission directive. Section A contains a discussion of the population dose commitments and health effects calculated to result from the radioisotope releases given in Table S-3 when integrated over 100 years.* Section B contains a discussion of the period of time that the waste in a Federal repository may represent a significant potential hazard, the incremental radioisotope releases from the repository which might occur during that period, and the period of time for which calculations may provide meaningful information. Section C contains a discussion of how very long-term (thousands of years) dose commitments and health effects attributable to long-lived radioisotopes released to the environment might be calculated, and what the significance of the calculations might be.

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*WASH-1248 and Table S-3 did not address the question of population dose commitments or potential health effects. However, these topics were discussed in considerable detail in NUREGs-0116 and -0216 (Supplements 1 and 2 of WASH-1248). These reports present a detailed reevaluation of the "back end" of the uranium fuel cycle.

A. 100-year Environmental Dose Commitments

The environmental models used to calculate the transport of released radioactivity to man and to estimate the potential somatic and genetic health effects used in the following discussion are the models discussed in the GESMO Hearings.[1] The models have been described in some detail in Appendix C of NUREG-0216. Basically, the models account for the dispersion of radioactivity released in the environment, the bioaccumulation in food pathways, the uptake by man and the dose commitments resulting from that uptake. There are two types of population dose commitments calculated: the 50-year dose commitment from continued external exposure and uptake of the radioisotopes released in a 1-year period, and the environmental dose commitment (EDC). The EDC represents the sum of the 50-year dose commitments for each year of a specified period during which the radioactivity is released or remains in the environment.

In practice, it is impossible to estimate realistically the complete EDC for very long-lived nuclides, such as iodine-129 (17 million years half life). There is no way to predict with any degree of certainty the many variables that affect such estimates so far into the future, e.g., the growth of human population, technological advances, the environmental behavior of long-lived radionuclides, and the occurrence of catastrophic climatic and geologic changes. (See Section C for a discussion of how long-term dose commitments might be calculated.)

NRC, EPA, and other agencies use a so-called incomplete EDC. In GESMO,[2] the length of the incomplete EDC selected was 40 years for a total U.S. population of 250 million. Thus, 50-year population doses were calculated for each year

of the 40-year exposure period and summed (i.e., the total length of time covered was 40 + 50, or 90 years). These calculations have been modified to extend the population dose integration period to 100 years, as recommended by the S-3 Hearing Board. Since each year's exposure is calculated for 50 years, the total time covered is 150 years. For the overall fuel cycle, the total body exposure is projected to be 550 person-rem/RRY for an assumed stable U.S. population of 300 million.

It should be noted that for tritium and krypton-85 (two of the major dose contributors), there is little difference between a 40-year and a 100-year EDC, since about 90% of both nuclides will decay within the first 40 years. Furthermore, much the same is true of most of the fission and activation products released from the nuclear fuel cycle (e.g., iodine-131, ruthenium-106, strontium-90, cesium-137). For this reason, increasing the length of the EDC from 40 to 100 years results in much less than a doubling of the estimated dose commitments and potential health effects; not much additional change would occur if the EDC were extended beyond the 100 years for most isotopes. However, for the very long-lived radioisotopes such as carbon-14 and iodine-129, among others, and the special case of 3.8-day radon-222 which continues to be formed by decay of long-lived parents, the EDCs continue to increase with time and the calculated health effects also continue to increase. (See Section C for a discussion of very long EDCs.)

In the area of health effects, it is possible that even the 40-year EDCs calculated for the S-3 hearings overestimated the impacts of the releases

The health effects models represent a linear extrapolation of effects observed at high dose rate (e.g. Japanese nuclear bomb survivors) to potential effects at low doses and low dose rates. In addition, the assumption is made that there is no dose below which effects cannot occur. It is believed that the use of such models, although useful for regulatory purposes, tends to overestimate the effects of exposure to low-level ionizing radiation. Most animal and cellular studies indicate reduced somatic and genetic effects as the doses are reduced. Further, at low dose rates, the effects per unit of radiation dose for somatic effects may decline due to cellular repair and other mechanisms.

The health risk estimators from the GESMO[3] studies are as follows:*

total body dose:	135 cancer deaths per million person-rem
	258 genetic effects per million person-rem
thyroid dose:	13.4 cancer deaths per million person-rem
lung dose:	22.2 cancer deaths per million person-rem
bone dose:	6.9 cancer deaths per million person-rem

Although the risk of a genetic effect occurring is about twice that of a cancer death, most of the genetic effects (assumed to be occurring at the equilibrium rate which requires about 5 generations) would not be fatal.

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*The conclusions in the S-3 narrative concerning potential biological effects are based on risk estimators in the BEIR I Report modified to reflect more recent radiobiological data in WASH-1400. The BEIR III, which reevaluates the risk estimators presented in BEIR I, recently has been published (July, 1980). Although the NRC staff review is still underway, the range of risk estimators for low level radiation presented in BEIR III appear to be essentially the same numerically or less than those presented in BEIR I for whole body exposures. However, in some cases the cancer risk estimators for specific organs in BEIR III appear to be different from (somewhat higher than) those in BEIR I and those in the S-3 narrative. Thus, cancer risk estimators for some specific organs could be somewhat underestimated in the S-3 narrative. However, since the bulk of the collective population doses from the uranium fuel cycle (excluding radon) are whole body exposures, the conclusions of the S-3 narrative would be changed only slightly, if at all, if the BEIR III risk estimators were to be used.

Because there are higher dose commitments to certain organs (e.g., lung, bone, thyroid) than to the total body, the total risk of radiogenic cancer is not addressed by the total body dose commitment alone. By using the risk estimators presented above, it is possible to estimate the whole body equivalent dose commitments for certain organs. The sum of the whole body equivalent dose commitments from those organs was estimated to be about 100 person-rem. When added to the above value, the total 100-year environmental dose commitment would be about 650 person-rem/RRY.

In summary, the potential radiological impacts of the supporting fuel cycle (including fuel reprocessing and waste management but excluding radon emissions from mining and mill tailings) are as follows:

total body person-rem/RRY:	550 (100-year dose commitment)
risk equivalent person-rem/RRY:	650 (100-year dose commitment)*
fatal cancers/RRY:	0.088
genetic effects/RRY:	0.14

Thus, for example, if three light water reactor power plants were to be operated for 30 years each, the supporting fuel cycle would cause risk equivalent whole body population dose commitments of about 59,000 person-rem and a genetically significant dose commitment of about 50,000 person-rem, leading to estimates of 8 fatal cancers and 13 genetic effects in the U.S. population (300 million persons) over a period of 100 years. Some perspective can be added by comparing such estimates with "normal" cancer mortality for the same population. Assuming that future population characteristics (age distribution, cancer susceptibility, etc.) and competing risks of mortality remain the same as today, such projections

*Includes dose commitments to other organs as well as whole body dose.

would predict about 60 million cancer deaths from causes other than generation of nuclear power during the next 100 years. Assuming that the occurrence of genetic effects remains constant, projections would predict about 25 million genetic effects from causes other than generation of nuclear power during the next 100 years.

Using the lifetime risk estimate of 135 cancer deaths per 10^6 person-rem and averaging the 650 risk equivalent person-rem per RRY over the U.S. population of 300 million persons, the average lifetime individual risk in the U.S. from cancer mortality from radioactivity released from the supporting fuel cycle is about 3 chances in 10 billion per RRY. Assuming one RRY supplies electrical power for approximately a million persons and that all of the cancer risk is borne only by those users, the average lifetime risk to this population group would be about 9 chances in 100 million per RRY. This would also be the approximate average lifetime risk per person per RRY from the fuel cycle if all of the electricity used in the United States were produced by nuclear power plants. However, since nuclear power presently provides about 10% of the total electricity generated in the United States, the average lifetime risk per person in the U.S. would be about 9 chances in 1 billion per RRY.

In order to provide some perspectives on the risk of cancer mortality from the supporting fuel cycle, some mortality risks which are numerically about equal to 9 chances in 1 billion are as follows: a few puffs on a cigarette, a few sips of wine, driving the family car about 6 blocks, flying about 2 miles, canoeing for 3 seconds, or being a man aged sixty for 11 seconds.[4] Using electricity generated by any means for typical domestic use results in an

average risk of 6×10^{-5} per year from accidental electrocution.[5] Thus, a risk of 9 in 1 billion would be equivalent to using electricity for about one-half day.

It is believed that the estimated Table S-3 values and the dose and health effects models used by the NRC to develop the above estimates result in conservatively high projections. Therefore, they provide reasonable assurance that the radiological effects resulting from the releases in Table S-3 (as presented in NURECs-01116 and -0216) have not been underestimated.

B. Potential Long-Term Effects of Waste Disposal

NUREG-0116, Environmental Surve of the Reprocessing and Waste Management Portions of the LWR Fuel Cycle, contained estimates of the short-term impacts from waste disposal operations (i.e., those impacts that could result from the waste disposal operation during their operating life). Although NUREG-0116 and NUREG-0216 contained data on potential long-term risks from escape of radionuclides from a repository[6] and from low-level waste disposal operations,[7] no entries were made in Table S-3 for these potential releases because they were judged to be too small to be of significance.

The staff has reviewed the long-term effects of low-level waste disposal and TRU and high-level waste or spent fuel disposal for both of the two fuel cycles covered by the present proceeding--once through and uranium-only recycle. The potential effects resulting from long-term releases of low-level waste have been addressed in NUREG-0216,[8] and no additional consideration of the potential effects of disposal of these types of wastes is believed to be

necessary. Moreover, since it has been assumed that TRU wastes will be disposed of in a repository along with high-level wastes, there is no explicit discussion of TRU wastes because the TRU wastes are considered to be part of the high-level waste.

The wastes from the once through and uranium-only fuel cycles that will be disposed of in Federal repositories differ from one another in several ways as noted below:

- Waste Form - The dominant amount of radioactive waste from the once-through fuel cycle is in the form of spent fuel assemblies, with the fission products and actinides in a UO_2 matrix; while the dominant waste from the uranium-only fuel cycle will be solidified high-level, plutonium, and TRU waste. The latter will be in the form of solids having properties engineered to reduce mobility of fission products and actinides. The NRC cannot at this time describe in any detail the variations in the properties (in terms of better long-term retention of fission products and actinides) of one type of waste form from the other. Hence, for this discussion, the various forms of solid waste have been assumed to have similar nuclide-retention properties.

- Radionuclide Content - The spent fuel contains all of the nonvolatile fission products, transuranic elements, and activation products produced in the course of its irradiation, as well as all the residual uranium. Similarly, the high-level wastes in combination with the plutonium and any TRU wastes from the uranium-only fuel cycle contain essentially all

of the nonvolatile fission products, transuranic elements, and activation products produced in the fuel in the course of irradiation. The main difference between the spent fuel and the wastes from uranium-only recycle is that the wastes from the latter contain only 2-5% of the residual uranium. Thus, on a broad comparative basis, since all other nuclides are present in about equal amounts in both wastes, the spent fuel represents a slightly greater long-term risk because of its larger uranium content.

Since all solidified wastes have been assumed for this study to have equivalent nuclide retention properties, and since spent fuel represents the greater long-term risk, the following discussion is based on spent fuel.

The potential effects from long-term releases of radioisotopes from a repository, require the consideration of two basic issues:

- over what period of time does the waste represent a significant potential hazard, and

- given the state-of-the-art of modeling transport of radionuclides, do calculations provide meaningful information over that period of time?

One way to address the question of time over which the spent fuel in the repository represents a significant hazard is to assess the net potential impact of the disposal of the waste relative to the potential impacts if the charge to the reactors (fresh fuel) had remained in the ore body. For this assessment it is assumed that an engineered system, including waste from

packaging, and the repository, can be expected to confine (isolate) radioactive waste materials at least as well as an isolated ore body. This assumption is believed to be reasonable, based upon the following observations. Ore deposits were located in various geologic settings by natural phenomena and some may be in contact with groundwater, in soils with only moderate retardation of solute movement, and with varying ion travel distances to the biosphere. A repository, on the other hand, will be located in a hydrogeologic setting purposely selected to have no known or pruspective contact with circulating groundwater, high retardation of solute movement and long ion travel distances to the biosphere. In addition, the repository system, including waste form and packaging, will also include engineered features which are intended to prevent or greatly slow the release of the waste to the host media.

For waste placed in a repository system to reach the biosphere, one of two types of events must occur. The first involves essentially common place occurrences and requires: (1) water to infiltrate the repository; (2) the waste container to corrode; and (3) radionuclides to leach from the waste form. Long-lived radionuclides will eventually reach the biosphere by migration of leached radionuclides with the movement of groundwater to a discharge point or to a well. This type of event could expose man to radioactive materials via food chains or other environmental pathways. The second type of event involves unusual occurrences, such as disruption of the respository by man or natural events, which released radionuclides to the biosphere. However, sites for waste repositories will be selected in areas where the probability that a natural event would disturb the repository is extremely low and located away from identified natural resources to minimize the probability that man would

accidentally disturb the repository. An analysis of the consequences of a meteorite strike of the repository, an extraordinary event that would be classified as coming under scenario two, has been given in NUREG-0116.[9] Thus, the analysis here considers primarily the probability of waste reaching the biosphere under the conditions of scenario one.

In the event water infiltrated the repository, it would take a long time for any of the leached radionuclides to be transported to the biosphere by groundwater migration. Movement of groundwater is itself slow, and retarding mechanisms such as ion exchange increase the travel time for most radionuclides such that it might take tens to hundreds of thousands of years for them to reach the biosphere.[10] In this period of time, most radioactive material will have decayed away before it could reach the biosphere. On the other hand, fission products carbon-14, technetium-99, and iodine-129 have a combination of low retardation by ion exchange in soil and long lives. Accordingly, if these radionuclides were leached from wastes by infiltrating water, they could reach the biosphere in relatively small concentrations over a rather long time period. However, in developing the source terms for Table S-3 it was assumed that carbon-14 and iodine-129 were released to the biosphere before the waste was sent to the repository. While not the actual case with respect to the disposal of spent fuel from the once-through fuel cycle, for the purpose of the S-3 rule this assumption bounds the upper limits relevant to releases of carbon-14 and iodine-129 from the uranium fuel cycle. Technetium can exist in several oxide forms. Under the conditions expected for groundwaters not in contact with the atmosphere, insoluble TcO_2 or related hydrated forms should be the solubility-controlling phases, and the concentrations of technetium in

migrating groundwater should be extremely low. However, the oxidation conditions are difficult to predict due to the effects of construction of the repository and due to waste-rock interactions. Therefore, technetium has been considered to be present as the pertechnetate oxyanion (TcO_4^-) which is assumed to migrate to the biosphere with the groundwater.

To determine the time period over which spent fuel might be deemed a significant hazard, we have compared its dilution index with that of unirradiated uranium fuel. The dilution index is a measure of the amount of water required to dilute the concentration of radionuclides to the limits of 10 CFR Part 20 for unrestricted release, which can be used to compare the consequences of ingestion of radioactive materials. From Figure 3, it can be seen that in spent fuel the fission products dominate the dilution index up to about 200 years from reactor discharge. Beyond 200 years to about 50,000 years the transuranic radionuclides and their daughters dominate the dilution index, and beyond 100,000 years uranium and its daughters dominate the dilution index. From Figure 4, it can be seen that the growth of uranium daughters radium and lead dominate the dilution index for aged unirradiated uranium fuel, such that by about 100,000 years the dilution indexes for both spent fuel and unirradiated uranium fuel are about the same, both being dominated by uranium and its daughters. Thus, without consideration of dispersion or retardation relative to groundwater transport time, at about 100,000 years the dilution index of the waste in a repository is about the same as aged unirradiated uranium fuel. Moreover, since plutonium and americium have long delay times during transport from the repository to the environment, the dilution index of those materials in the waste that could potentially be released is about the same as aged unirradiated fuel after 10,000 years.

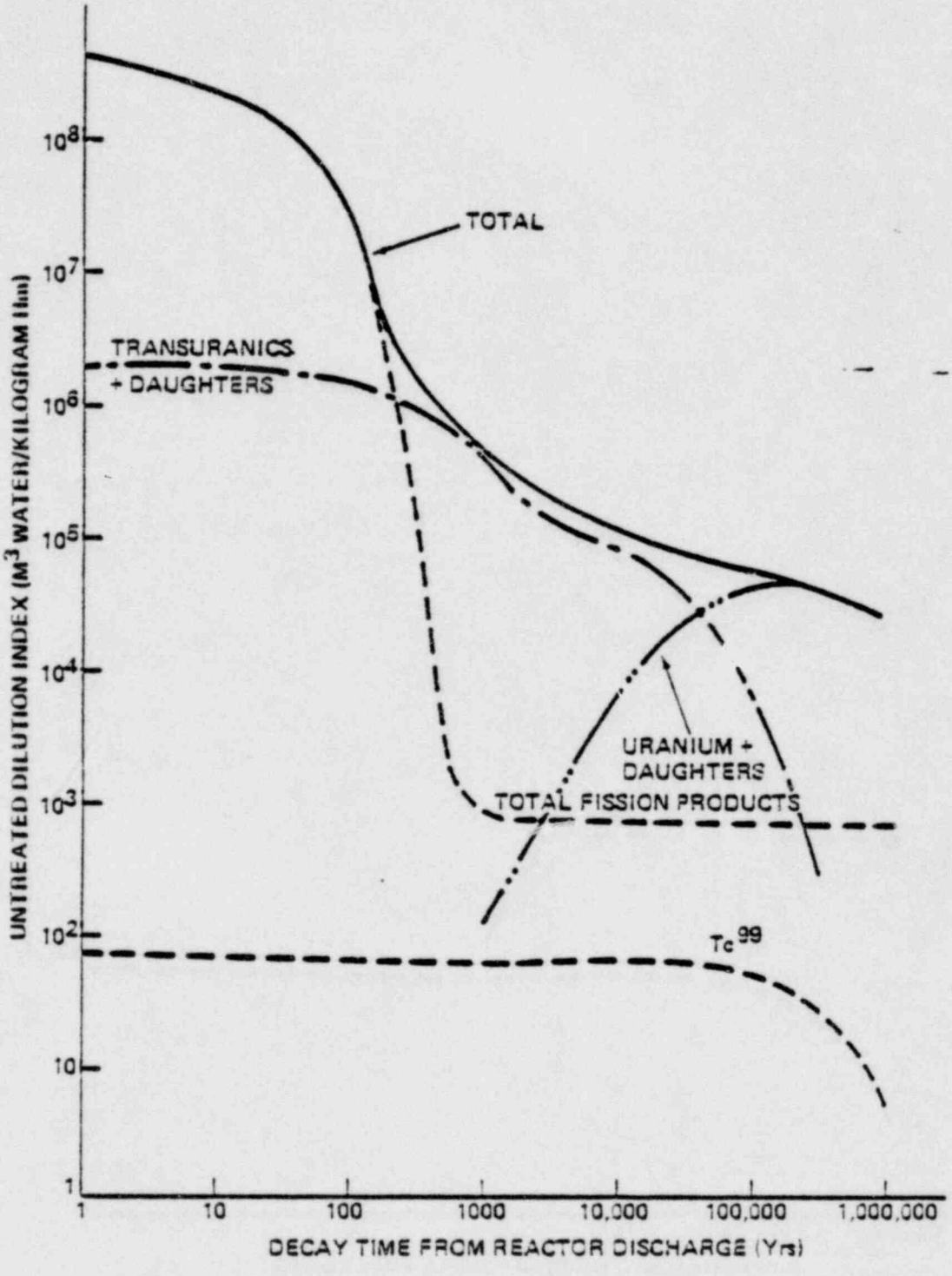

Figure 3 Dilution Index for Spent Uranium Fuel.

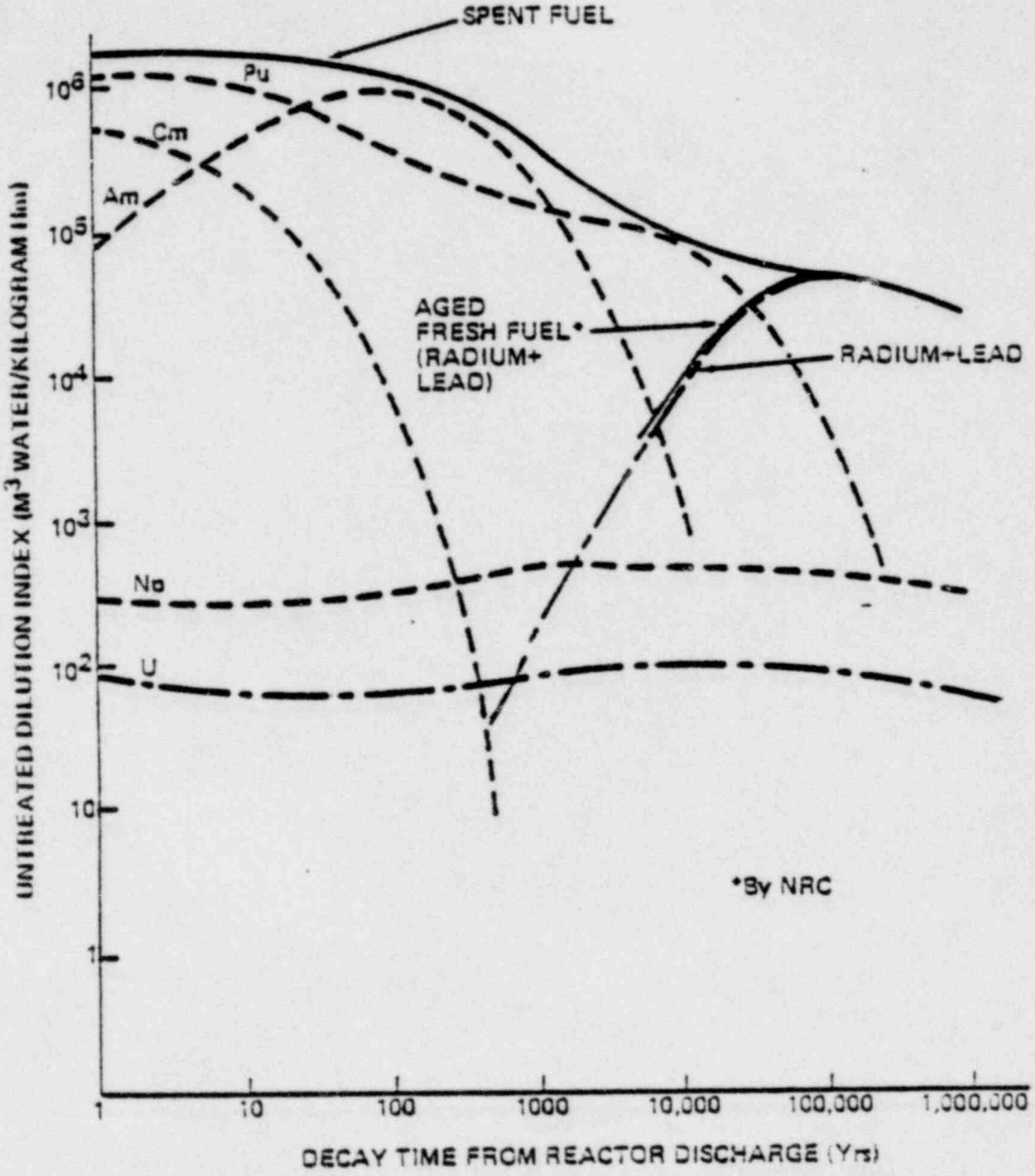

FIGURE 4 Dilution Index for Actinides and Daughters in Spent and Aged Fresh Uranium Fuel

Thus the answers to the previously posed questions concerning the potential long-term effects of waste repositories may be framed as follows:

1. For natural-type releases from a repository, significant net potential impacts of spent fuel relative to aged fresh fuel exist for less than 10,000 years. In natural-type releases, there is a long time delay (N104-105 years) between the time the nuclide (or its parent) leaves the repository and reaches the biosphere. The net impact of such releases can be conservatively (high side) approximated by assuming the complete release of the technetium-99. Given the number of conservative assumptions required to model the releases from a repository under natural-type circumstances and the small potential net impact after 10,000 years, calculating releases for natural-type conditions beyond 10,000 years provides little meaningful information.

2. If disturbances of a repository which could result in the direct release of significant quantities of otherwise immobile isotopes are being considered (well-digging), significant net potential hazards could persist for 100,000 years. The impacts from the disturbance would depend on the time and nature of the action. After 100,000 years, the waste in the repository presents no greater hazards than the original materials charged to the reactor.

C. Dose Commitments and Health Effects from Long-Lived Radioisotopes Released from the Uranium Fuel Cycles

The Commission directed the staff to discuss the time period over which dose commitments should be evaluated, how the dose commitment evaluations over

extended periods of time might be evaluated, and what their significance might be. In Section A, page 56, it was shown that a 100-year EDC was adequate to provide the total dose commitment from most isotopes. Very long-time EDCs are necessary if the complete environmental dose commitments from fuel cycle emissions such as carbon-14 and iodine-129 are to be determined. In addition to these isotopes, the analysis given in Section B showed that a very conservative evaluation of long-term emissions from a repository would show technetium-99 could be released from a repository. Applicable releases for these isotopes are:

Carbon-14	24 Ci/RRY
Iodine-129	1.3 Ci/RRY
Technetium-99	upper bound for long-term releases from the repository is 500 Ci/RRY, 100% of the technetium in fuel.*

Carbon-14 and iodine-129 would be emitted as volatile materials; technetium would be leached from the waste repository and reach the biosphere dissolved in water.

Mathematical models are available for estimating the long-term population doses from carbon-14 and iodine-129. No models are currently available for estimating long-term doses from technetium.

*Environmental Standards being developed by EPA and regulations being developed by NRC are expected to require reasonable assurance that releases of Tc-99 are a small fraction of this quantity.

1. Calculation of Dose Commitments

To calculate dose commitments and health effects over long time periods, one must: (a) predict the population at risk; (b) model the time-dependent behavior of the nuclide in the environment and (c) predict the response of the population to the exposure in terms of cancer mortality and genetic defects.

a. Population at Risk

In considering population at risk over time periods of 100,000 years or more, several gross assumptions must be made. Realistically, geologic history would predict several catastrophes such as ice ages (as many as 10 might occur over 250,000 years)[11] and large fluctuations in population might be expected to be caused by such catastrophes. The staff, for want of a better rationalization, has assumed a stable world population of 10 billion for the first 10,000 years of exposure, with periodic variations of population of from 2 billion to 10 billion as a function of time beyond 10,000 years. Further, the U.S. population was assumed to be a constant 3% of the world population.

b. Models of Nuclide Behavior

(1) Carbon-14

The GESMO and S-3 hearing record do not contain a model that adequately predicts the behavior of carbon-14 in the environment over long time periods. The GESMO model (RABGAD) can be used to estimate the dose commitment to the U.S. population from the initial passage of carbon-14 before it mixes in the world's carbon pool. The carbon-14 model developed by Killough[12] can be modified, using the population variations given above, to obtain long-term dose commitments.

(2) Iodine-129

Appendix C, Section 3.0 of NUREG-0216 provides an adequate model for estimating long-term population doses from iodine-129. The GESMO model (RABGAD) can be used for estimating the U.S. population dose resulting from the initial passage of the iodine-129 prior to mixing in the world pool of stable iodine. For the long-term, the model assumed for the S-3 hearings results in 1.1×10^{-12} rem/year/Ci to each person in the world after the mixing occurs, with the annual dose-rate declining with a half-life of 17 million years. Although removal mechanisms probably exist which would result in an environmental half-life much less than the 17 million year radiological half-life, the environmental half-life was conservatively taken to be the radiological half-life. This conservatism is prudent until better long-term iodine models are developed.

c. Response to Exposure

In considering response of the population to exposure to radioactive nuclides, the staff has no basis to choose any responses other than those estimated currently--135 cancer deaths/10^6 person-rem, and 258 genetic defects/10^6 person-rem.[13] In an attempt to consider the potential effects of advances in technology, three scenarios were used--no cure or preventions for cancer or genetic defects; a possible cure or prevention for cancer and genetic defects in 1000 years; and a possible cure or prevention for cancer or genetic defects in 100 years.

2. Numerical Estimates of Dose Commitments and Health Effects

The models described above, together with the assumptions delineated for population and population response to exposure have been used to calculate long-term dose commitments resulting from carbon-14 and iodine-129 releases. The values are given in Table I (carbon-14) and Table II (iodine-129). It can be seen from Table I that integrating carbon-14 dose commitments over 10,000 years captures essentially the total person-rem dose commitments from carbon-14. These data indicate that the total U.S. population exposure to infinity is about 3-4 times the first-pass exposure and the infinite world population exposure is about 8 times the first-pass world population exposure. If no cancer cure is found, cumulative excess cancer mortalities/RRY of about 0.06 (U.S.) and 1 (world) might be predicted from the carbon-14 releases. If a cancer cure is effected in 1000 years, the excess cancer mortalities/RRY would peak at about 0.02 (U.S.) and 0.3 (world). A cancer cure in 100 years would limit excess cancer mortality/RRY to about 0.02 (U.S.) and 0.1 (world). A cumulative total of about 0.1 (U.S.) and 3 (world) genetic defects RRY would be predicted to result over a period of 100,000 years from the carbon-14 released. If prevention of genetic defects were possible in 1000 years, the cumulative genetic defects/RRY would be about 0.05 (U.S.) and 0.5 (world); with prevention in 100 years, the cumulative genetic defects/RRY would be about 0.04 (U.S.) and 0.2 (world).

It can be seen from Table II that the dose commitments from iodine-129 continue to increase with time, even beyond 250,000 years. Since the model does not incorporate any removal mechanism other than radioactive decay (17 million

Table I

Population Dose Commitments and Potential Health Effects
for 24 Ci/RRY Release of C-14 from the Fuel Cycle

No Cancer Cure or Prevention or Cure of Genetic Defects

Time (years)	Cumulative Person-Rem (T.B. Risk Equivalent*) & Cumulative Genetically Significant Dose (Organ-rem)		Cumulative Cancer Mortality		Cumulative Genetic Defects	
	U.S.**	World**	U.S.	World	U.S.	World
100	150	800	0.02	0.1	0.04	0.2
1,000	180	1,900+	0.02	0.3	0.05	0.5
10,000	390	8,900+	0.05	1.2	0.10	2.3
100,000	440	10,000++	0.06	1.4	0.11	2.7
250,000	440	11,000++	0.06	1.4	0.11	2.7

*Total body dose equivalent is the sum of the total body dose and each organ dose multiplied by the ratio of the mortality risk per organ-rem to the mortality risk per person-rem total body).

**First Pass Dose = 127 person-rem (total body risk equivalent) or organ-rem

+Based on approximation to Killough's C-14 model (ORNL-5269) as follows:

$$\frac{\text{person-rem}}{\text{Ci}} f(t) = 28 + 592\,(1 - e^{-(t-100)(0.693/5{,}600)}) \quad \frac{\text{assumed world population of 10 billion}}{\text{Killough population of 12.21 billion}}$$

++Based on approximation to Killough's C-14 model as follows:

$$\frac{\text{person-rem}}{\text{Ci}} f(t) = \frac{10}{12.21}\,441 + 179\,(1 - e^{-(t\,-\,10{,}000)(0.693/5{,}600)}) \quad \frac{\text{5.2 billion avg.}}{\text{12.21 billion}}$$

Table II

Population Dose Commitments and Potential Health Effects
for 1.3 Ci/RRY Release of I-129 from a HLW Repository

No Cancer Cure or Prevention or Cure of Genetic Defects

Time (years)	Cumulative Person-Rem (total body risk equivalent)*		Cumulative Genetically Significant Population Dose (organ-rem)	
	U.S.**	World**	U.S.***	World***
100	31	40	4.4	5.4
1,000	34	123	4.7	15
10,000	60	950	7.5	109
100,000	175	4800	20.2	530
250,000	390	12,000	43.9	1320

	Cumulative Cancer Mortality		Cumulative Genetic Effects	
	U.S.	World	U.S.	World
100	0.0042	0.0054	0.0011	0.0014
1,000	0.0046	0.017	0.0012	0.0039
10,000	0.0081	0.13	0.0019	0.028
100,000	0.024	0.65	0.0052	0.14
250,000	0.053	1.6	0.011	0.34

* Total body dose equivalent is the sum of the total body dose and each organ dose multiplied by the ratio of the mortality risk per organ-rem to the mortality risk per person-rem (total body).

** First Past Dose = 31 person rem whole body risk equivalent

*** First Pass Organ Dose 4.4 organ-rem

year half-life), the calculations could, in theory, be extended to 200 million years or so to capture the total dose commitments of iodine-129. This has not been done for the present treatment. (A discussion of the significance of long-time calculations is given in Section 3. below.)

The data in Table II show that the 250,000 year dose commitments (whole body risk equivalent) from iodine-129 (390 U.S. and 12,000 world person-rem/RRY) are about equal to the 100,000 year (infinite) dose commitments from carbon-14 (440 U.S. and 11,000 world person-rem/RRY). Cumulative excess cancer mortalities/RRY for a 250,000 year exposure are about 0.05 (U.S.) and 2 (world); cumulative genetic defects/RRY (250,000 year) are about 0.01 (U.S.) and 0.3 (world).

If a cancer cure were achieved 1000 years hence, excess cancer mortalities/RRY from iodine-129 would be limited to about 0.005 (U.S.) and 0.02 (world). For a cancer cure in 100 years, excess cancer mortalities/RRY from iodine-129 would peak at about 0.004 (U.S.) and 0.005 (world). If prevention of genetic defects were possible in 1000 years, genetic defects/RRY would total about 0.001 (U.S.) and 0.004 (world); if genetic defects were preventable in 100 years, genetic defects/RRY would total about 0.001 (U.S. and world).

3. The Significance of Long-Term Dose Commitments

In the above section, at the direction of the Commission, the staff has provided theoretical mathematical calculations for dose commitments and health effects of carbon-14 and iodine-129 for up to 250,000 years. In order to perform

these calculations, the staff has had to make a series of assumptions based upon little foundation and in which it has little or no confidence. Because of the shortness of human life expectancy relative to the much slower changes occurring on earth, such as variations in climate, continental drift, erosion and evolution of species, it is difficult to comprehend the immensity of potential changes over long periods of time.

For comparatively short-lived isotopes, dose commitment integrations can be projected for what amounts to infinite time intervals. For example, an infinite time integration of population dose can be done for tritium or krypton-85 since such a time integration effectively requires consideration of a period of about 100 years or less. However, projecting population at risk, and population response to risk over even such relatively short time intervals requires many assumptions which the staff has reason to question. It is possible, for example, to reasonably postulate the following occurrences during the next 100 years: major changes in the size of the population at risk because of war or global starvation; cures for or prevention of cancer and genetic defects; the onset of the "greenhouse" effect; the depletion of oil, natural gas and mineral resources. Any of these occurrences may have significant effects on worldwide conditions and affect the validity of calculated dose commitments and related health effects.

In addition to changes in the environment, it is also possible that the response of man to exposure to radiation will change either up or down in the future. It is thought-provoking to compare the major health risks in today's America with those at the turn of the last century. U.S. vital statistics[14] show that

in a period of only 70 years, monumental changes have occurred in many health areas. For example, life expectancy at birth has increased from 33.0 years to 65.3 years for non-white Americans and from 47.3 years to 70.9 years for white Americans. This translates to a perceived increased risk of cancers and cardiovascular diseases in recent years simply because more people are living longer than before, and therefore, have a greater probability of contracting such diseases which occur primarily in the later years of life.

In addition, both cancers and cardiovascular diseases have tended to increase simply because of advances in the care, treatment and prevention of many other serious diseases. Since the total lifetime risk of mortality is 1 for everyone, when the statistical probability for mortality from a given cause declines, other probabilities must increase. For example, consider the following changes in death rates for major diseases since the beginning of this century:

Cause of Death	Deaths/100,000 Population		Change in Risk of Mortality by 1970
	1900	1970	
Tuberculosis	194.4	2.6	factor of 75 lower
Typhoid & Paratyphoid Fever	31.3	0.05	" " 600 "
Diphtheria	40.3	0.05	" " 800 "
Cancer	64.0	162.8	" " 2.5 higher
Major Cardiovascular & Renal Diseases	345.2	496.0	" " 1.4 "
Influenza & Pneumonia	202.2	30.9	" " 6.5 lower
Gastritis, Duodenitis, Enteritis & Colitis	142.7	0.6	" " 240 "
Accidents (including motor venicle)	72.3	56.4	" " 1.3 "
Other major diseases	58.4	35.1	" " 1.7 "
OVERALL:	1,150.8	784.4	factor of 1.5 lower

Thus, it is clear that the effective control or elimination of many diseases which, in the beginning of the twentieth century, typically were fatal before people reached an age where the risk of cancer or cardiovascular disease would have become significant has at least partially resulted in an apparent increase in such diseases by 1970. It is also clear, however, that the overall risk of mortality by major causes in the U.S. has declined by about one-third in only the last 70 years. As a result, one might speculate that there may be an "epidemic" of people dying from "old age" in the centuries ahead from causes that are little known or rare by today's standards.

Changes similar to those which have largely occurred in the past as the result dramatic medical discoveries may occur as science continues to seek and discover more effective ways of curing or preventing cancer in the years ahead. The future radiological impact of the nuclear fuel cycle can be affected by such research since latent cancer is the only known serious result of human radiation exposures received at dose rates which do not result in early mortality.

The staff is unable to make any definitive statements about the possible variations in the long-term dose commitments and health effects resulting from potential future happe ings. However, the staff believes that the cumulative combined impacts from long-lived radionuclides such as carbon-14 and iodine-129 are small relative to those from natural background which is about 100,000 billion person rem (world) over a 250,000 year total. The combined impact is only about 10^{-7} percent of natural background.

Section III - References

1. Docket No. RM-50-5, Generic Environmental Statament on Mixed Oxide Fuel (GESMO). Hearing transcripts for January 19, 25 and 26, 1977.

2. NUREG-0002, Chapter IV-J.

3. Ibid., Chapter IV-J, Appendix B, page IV-J (B)-1.

4. Pochin, E. E., "The Acceptance of Risk," Br. Med. Bull., Vol. 31, No. 3, pp. 184-190 (1975).

5. U. S. Nuclear Regulatory Commission, The Reactor Safety Study, Main Report, WASH-1400, 1975. Table G-3.

6. NUREG-0116, page 4-94 ff.

7. NUREG-0216, Appendix H, page H-16 ff.

8. Ibid.

9. NUREG-0116, Table 4-19.

10. Oak Ridge National Laboratory," Siting of Fuel Reprocessing Plants and Waste Management Facilities, ORNL-4451, July 1970.

11. Norwine, J., "A Question of Climate: Hot or Cold?," Environment, 19, #8, p. 7, Nov. 1977, Mitchell, J. M., Jr., "Carbon Dioxide and Future Climate," E.D.S., N.O.A.A., Commerce, March 1977; Calder, N., "Head South with All Deliberate Speed: Ice Age May Return in a Few Thousand Years," Smithsonian, 8, #10, Jan. 1978.

12. Killough, G. G., "A Diffusion-Type Model of the Global Carbon Cycle for the Estimation of Dose to the World Population from Releases of Carbon-14 to Atmosphere," ORNL-5269, May 1977.

13. NUREG-0002, Chaper II-J, Appendix B.

14. U.S. Bureau of the Census, "Historical Statistics of the United States: Colonial Times to 1970," Part I Series B 149-166.

Section IV. Socioeconomic Impacts

Socioeconomic impacts of the uranium fuel cycle can result from increases in levels of employment and public services requirements. Because the topic is so broadly defined, it is desirable to approach it as a series of interrelated subcategories. Briefly, these consist of:

- Population - changes in population resulting from the influx of workers and their families at both the construction and operation stages of facilities.

- Economy - induced changes in income and expenditures, including demands for services, both public and private.

While this factor was not discussed in WASH-1248, it was briefly covered in the instant proceeding on the back end of the fuel cycle, and the following discussion is based on the record of that proceeding.

For the nuclear fuel cycle, population and economic data can be obtained at each stage from mining, milling, and fuel fabrication through waste isolation. The tabulation of conventional socioeconomic impacts at each stage can provide a generic measure of the conventional socioeconomic impacts associated with the entire fuel cycle.

For each stage of the fuel cycle, the character and magnitude of the socioeconomic impacts are site-specific and are determined by the size of the work force, the size of the local populations, the number of incoming workers in

relation to the population size, the capacities of public service facilities impacted, the administrative capability of the impacted political jurisdictions, and other related factors. The size of work forces needed for reprocessing plants and waste-related facilities suggests that socioeconomic impacts should be manageable through proper planning and mitigative efforts. In fact, the socioeconomic effects of establishing reprocessing plants and waste-related facilities are not expected to differ in quantity or quality from those associated with any commercial nuclear power plant. The socioeconomic considerations can be summarized as follows:

> Impacts that can be expected are comparable to or less than those caused by LWR construction activities and could include noise and dust around the site; disruptions or dislocations of residences or businesses; physical or public-access impacts on historic, cultural, and natural features; impacts on public services such as education, utilities, the road system, recreation, public health, and safety; increased tax revenues in jurisdictions where facilities are located; increased local expenditures for services and materials, and social stresses.[1]

With respect to the socioeconomic impacts that may be attributable to reprocessing facilities, NUREG-0116[2] cites TVA information showing the anticipated socioeconomic impacts associated with the construction of an LWR are representative of those socioeconomic impacts which can be expected from construction and operation of a reprocessing facility.

Since a 2,000 metric ton reprocessing plant (the size of the model reprocessing plant) is capable of servicing 57 reactors annually, the socioeconomic impacts from construction of a reprocessing plant attributable to a single reactor can be approximated as less than 2% of those of the reactor.

With respect to the socioeconomic impacts which can be attributed to a high-level waste repository (HLWR), commercial nuclear power plant information was utilized to illustrate the anticipated impacts. The anticipated impacts can be expected to vary depending upon the location of the repository and the size of the surrounding communities.

Preliminary estimates of the construction labor force, developed by the Office of Waste Isolation at Oak Ridge National Laboratory, show a peak number of 800 people, in contrast to the average LWR work force of 2,000. The anticipated socioeconomic impacts of high-level waste repository construction thus could be expected to be less than those of construction of an LWR. Since the proposed repository has the capability of servicing a total of 133 reactors, and can store fuel from 40 reactors (based on 1,200 MRYs over 30 years of operation), the socioeconomic impacts resulting from construction of the repository, when allocated to a single reactor, would be only a few percent of the socioeconomic impact of constructing the reactor.

In terms of operating work force, preliminary estimates developed at the Office of Waste Isolation at ORNL set the number of peak labor force for a high-level waste repository at 1,630, about 10 times that of an LWR work force (170).

An added 1,630 workers to a rural employment base would mean a change in the economy of the area. If the pattern followed the experience of large industrial plants locating in small towns, the following observations could be expected to apply:[3]

1. Rural industrial development seldom produces an unmanageable population growth rate; it provides a stabilizing influence on population;

2. There is a tendency for long distance commuting, which tends to spread out impacts on community facilities;

3. Housing would be a common problem in rural areas.

If the settlement pattern were very concentrated, the impacts on community facilities and housing could be expected to be larger. It is believed that the lead times will be sufficient to allow the potentially impacted communities and the applicant to develop mitigative programs which would allow for an orderly and manageable resolution of potential socioeconomic impacts.

Should the repository be located within a relatively easy commuting distance, it is believed that the surrounding communities should be able to absorb the 1,630 workers with fewer impacts occurring and be able to resolve any potential impacts requiring mitigation in advance of the operation phase.

Based upon these assessments of socioeconomic considerations associated with the construction and operation of reprocessing and waste burial facilities, it

was concluded that when they are spread over many power reactors, they add an insignificant amount to the environmental impacts of an individual reactor. Thus, no specific value for socioeconomic considerations was placed in Table S-3.

In its effort to update Table S-3, the Commission is performing socioeconomic studies which are intended to provide more detailed data on the impacts actually experienced as a result of construction and operation of the facilities involved in each step of the nuclear fuel cycle. The studies may provide information that will permit an incremental assessment of socioeconomic impacts attributed to the fuel cycle activities.

Section IV - References

1. NUREG-0116, Section 4.11.4, p. 4-168.

2. Ibid, p. 4-170.

3. U.S. Nuclear Regulatory Commission, Policy Research Associates, "Socioeconomic Impacts: Nuclear Power Station Siting," NUREG-0150, June 1977.