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A METHODOLOGY FOR COMPARING THE HEALTH EFFECTS OF ELECTRICITY GENERATION FROM URANIUM AND COAL FUELS

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A METHODOLOGY FOR COMPARING THE HEALTH EFFECTS OF ELECTRICITY GENERATION FROM URANIUM AND COAL FUELS*

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ABSTRACT

A methodology was developed for comparing the health risks of electricity generation from uranium and coal fuels. The health effects attributable to the construction, operation, and decommissioning of each facility in the two fuel cycles were considered. The methodology is based on defining (1) requirement variables for the materials, energy, etc., (2) effluent variables associated with the requirement variables as well as with the fuel cycle facility operation, and (3) health impact variables for effluents and accidents. The materials, energy, etc., required for construction, operation, and decommissioning of each fuel cycle facility are defined as primary requirement variables. The materials, energy, etc., needed to produce the primary variable are defined as secondary requirement variables. Each requirement variable (primary, secondary, etc.) has associated effluent variables and health impact variables. A diverging chain or tree is formed for each primary variable. Fortunately, most elements reoccur frequently to reduce the level of analysis complexity.

1. INTRODUCTION

A methodology for comparing the health risks of electricity generation from uranium and coal fuels was developed by the authors (El-Bassioni et al., 1980) under contract to the Oak Ridge National Laboratory for the U.S. Nuclear Regulatory Commission (NRC). This paper describes the methodology, the preliminary results obtained, and the problems encountered.

2. STUDY BOUNDARIES

The NRC reviews the environmental impacts of proposed nuclear reactor power plants and prepares an environmental impact statement as required by the National Environmental Policy Act (NEPA). One important consideration in such a review is the assessment of alternatives to the proposed action, and one prime alternative to a proposed nuclear power plant is production of electricity by a coal-fueled power plant. Although both alternatives may have acceptably low risks, one method of comparing alternatives is to compare the health effects attributable to the entire fuel cycle of both alternatives, while assuming that both produce the same benefits. Thus, an appropriate basis for this comparison is the occupational and public health effects per unit of electricity supplied to the utility grid.

In order to reflect the current national electricity production and state of technology, the model facilities in each of the two fuel cycles were based, to the extent possible, (1) on either the newer operating facilities or those under construction and (2) on current operating data. Both power plants were assumed to have a power output of 1000 MW(e), and data were normalized to a unit energy production of 1000 MW(e)-yr.

As shown in Figure 1, the uranium energy production cycle was based on mining, milling, conversion, enrichment, fabrication, power production, reprocessing, and waste disposal. Transportation between stages is indicated by the capital T. The fuel cycle for light water reactors can be operated in a once-through mode, a uranium-recycle mode, or a uranium/plutonium-recycle mode. In 1979, the uranium/plutonium-recycle mode was not considered as a currently viable mode by NRC; hence, it was not considered in the study. The coal fuel cycle is shown in Figure 2 and consisted of mining, coal processing, coal storage, power production, and

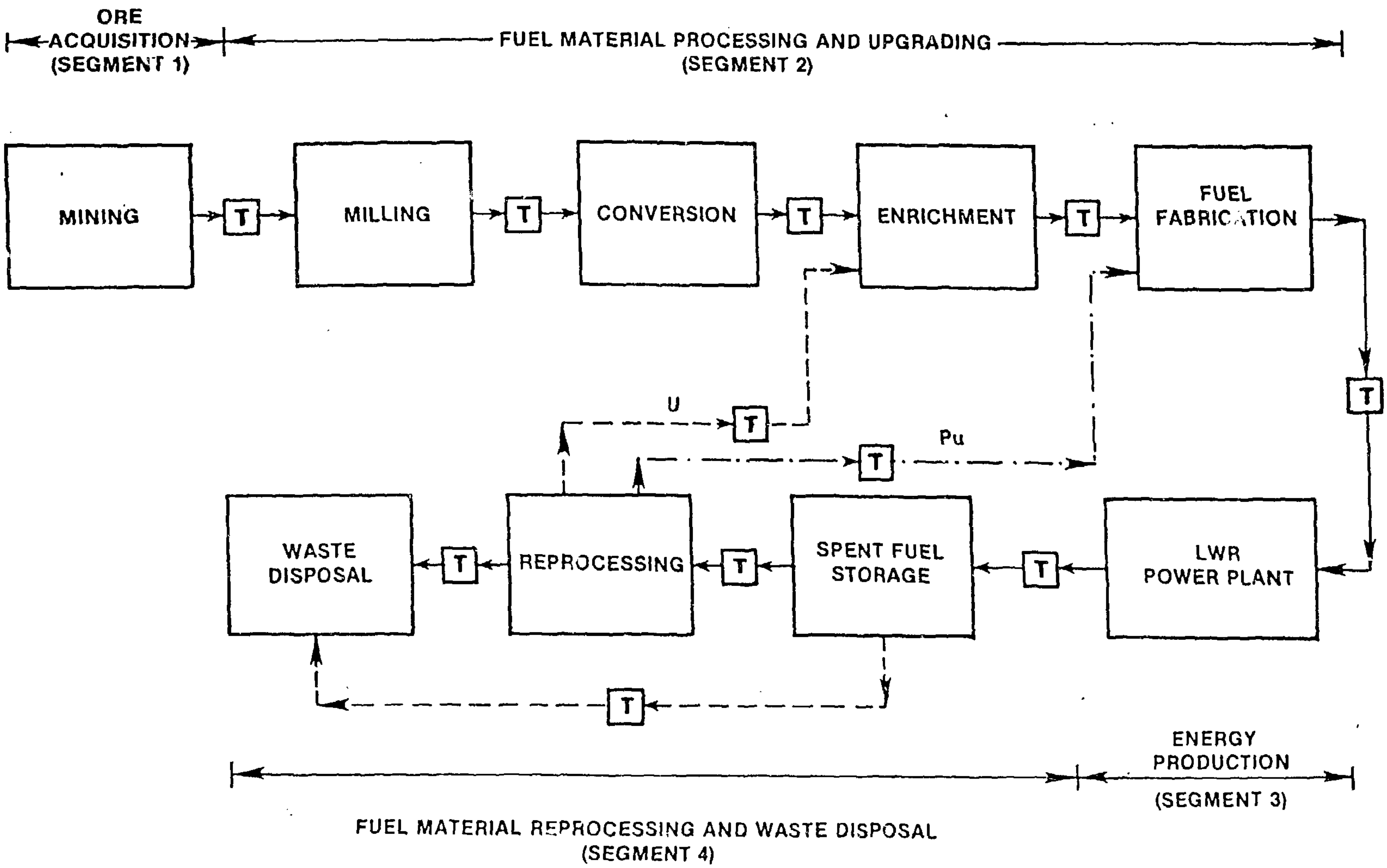


FIGURE 1. THE URANIUM FUEL CYCLE

SOURCE: NUREG/CR-1539, p.11

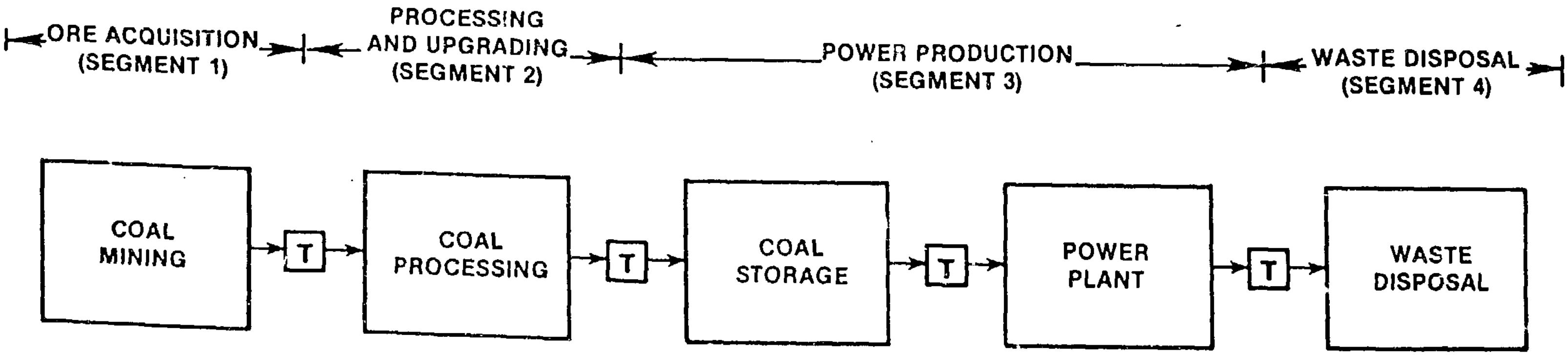


FIGURE 2. THE COAL FUEL CYCLE

SOURCE: NUREG/CR-1539, p.12

waste disposal. For both fuel cycles, the life cycle of each stage was assumed to consist of material and energy acquistion, construction, operation, and decommissioning as shown in Figure 3.

3. FORMAL METHODOLOGY

If the direct impact of the operation of a facility is considered as the first-order effect, and the impact of material acquisition, construction, etc. is considered as the second-order effect, then the third-order effect is the material acquisition, construction, operation, etc. required to produce the plant which produces the material. As will be shown below, this higher-order treatment rapidly escalates the complexity of the methodology. Fortunately, the major segments keep reappearing as building blocks.

Three basic sets of variables were defined: requirement (R) variables, effluent (F) variables, and health impact (P) variables. Requirement variables indicate the magnitude of the materials, equipment, energy, labor, and services such as transportation, which the activities of a fuel cycle stage require. Figures 4, 5, and 6 show three typical primary requirement variables: material requirement (RM); equipment requirement (RQ); and transportation requirement (RT). Secondary requirement variables (energy (RE), transportation (RT), and manpower (RL) in case of Figure 4) required to produce the primary variable also are shown. Requirement variables tend to form a divergent chain, or tree, with the primary variable as the first level of the tree. The three trees in Figures 4, 5, and 6 are used as building blocks to structure the analytical models. Note that the RM and RT trees appear as secondary variables in the RQ tree and that the RM and RQ trees appear as secondary variables in the RT tree. As will be seen later, many of the elements can be combined to reduce the level of complexity for secondary effects.

The energy requirement variable is supplied partly as electricity and partly by fossil fuel combustion in the model facilities. The electric energy requirements are supplied by coal-fired plants, LWRs, a combination of both, or a combination including other electric energy sources. Thus, the coal and nuclear cycles interact through the electric energy requirement variable. This interaction is mathematically treated as:

$$P = (I-A)^{-1} Po$$

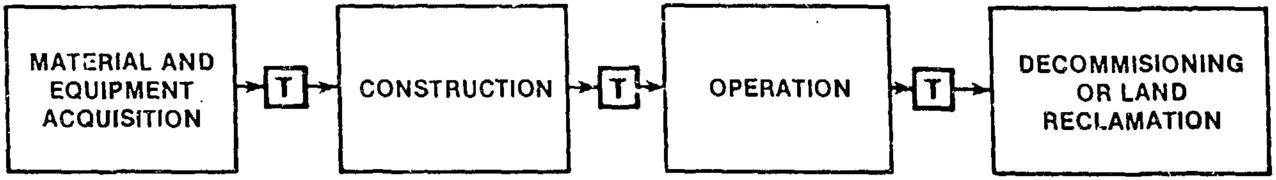


FIGURE 3. THE LIFE CYCLE OF A TYPICAL STAGE

SOURCE: NUREG/CR-1539, p.13

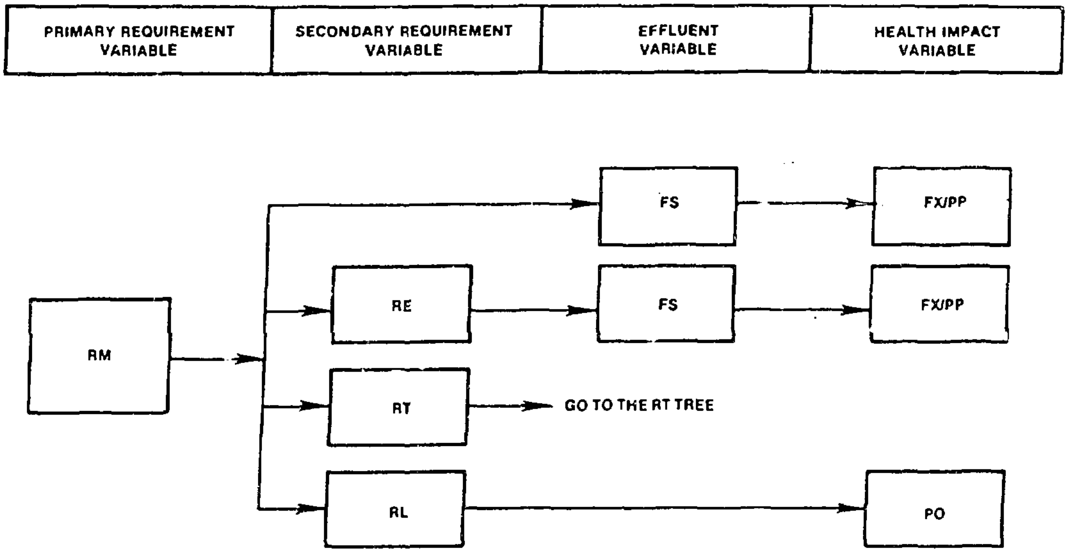


FIGURE 4. MATERIAL REQUIREMENT TREE

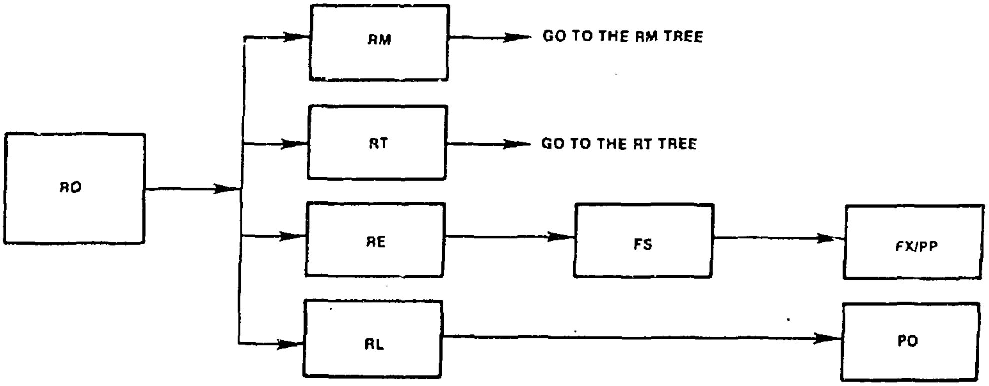


FIGURE 5. EQUIPMENT REQUIREMENT TREE

SOURCE: NUREG/CR-1539, p.39

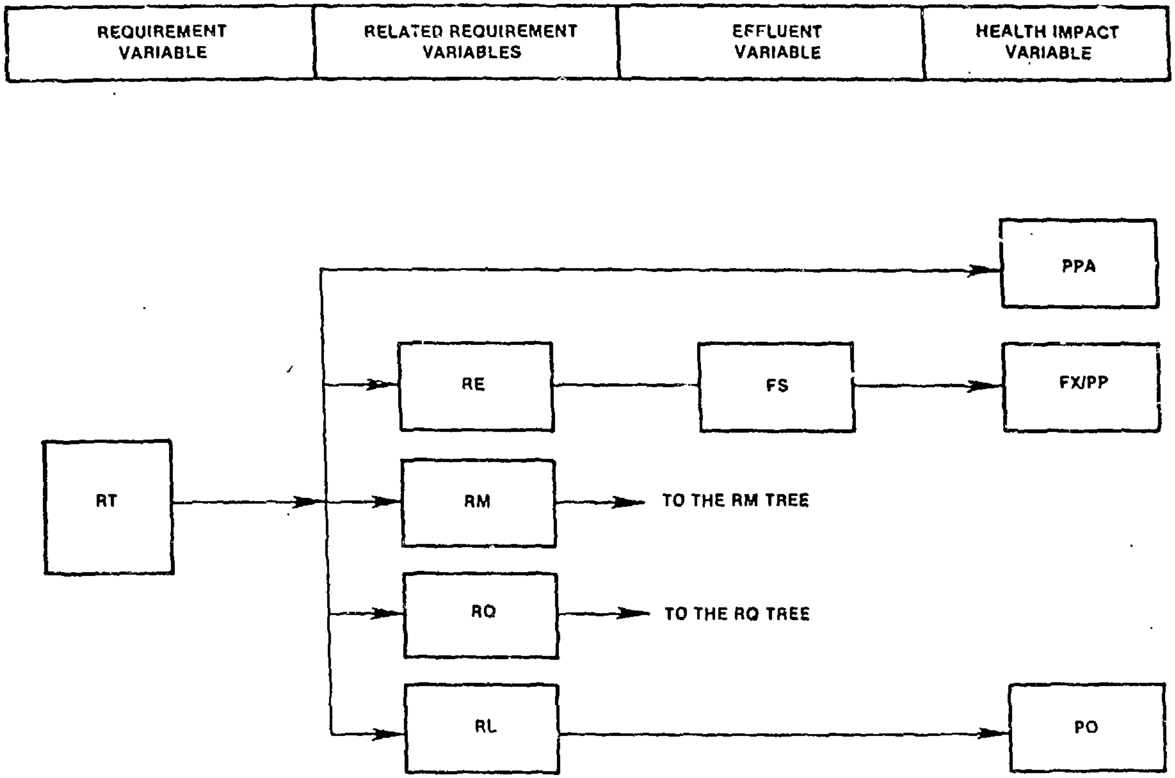


FIGURE 6. TRANSPORTATION REQUIREMENTS TREE

SOURCE: NUREG/CR-1539, p.31

where

$\underline{Po}$ is a vector whose i^{th} component, Po_i, is the health effect associated with the i^{th} cycle when the health impact of electric energy requirements for secondary activities is ignored;

$\underline{P}$ is a vector whose i^{th} component, P_i, is the total health impact of the i^{th} cycle including the electric energy requirements; and

A is a matrix whose elements are the interaction coefficients (a_{ij} is the sum of the energy requirements for secondary activities in the i^{th} cycle which is provided by the j^{th} cycle).

In the special case where the nuclear (i=1) and coal (i=2) cycles are assumed to be isolated from other energy sources, A will be a simple 2 x 2 matrix. The net health effect expressed in terms of the health effects in the two cycles excluding the secondary electric energy requirement is given by

$$\begin{pmatrix} P_1 \\ P_2 \end{pmatrix} = \frac{1}{(1-a_{11})(1-a_{22}) - a_{12}\, a_{21}} \begin{pmatrix} 1-a_{22} & a_{12} \\ a_{21} & 1-a_{11} \end{pmatrix} \begin{pmatrix} Po_1 \\ Po_2 \end{pmatrix}$$

which is the formulation suggested by Dorfan (1979).

No interaction between two cycles is equivalent to setting $a_{12} = a_{21} = 0$; and in this special case

$$P_1(1-a_{11}) = Po_1$$
$$P_2(1-a_{22}) = Po_2$$

Figure 7 shows a simplified material production cycle. This cycle comprises three typical segments; ore acquisition, processing, and production, with transportation links between the segments in the cycle. Some of the materials have an all-domestic cycle while others are complicated by the presence of imports and recycle.

In general, effluents are released during the process of producing the primary and secondary requirement variables. Amounts of effluents are

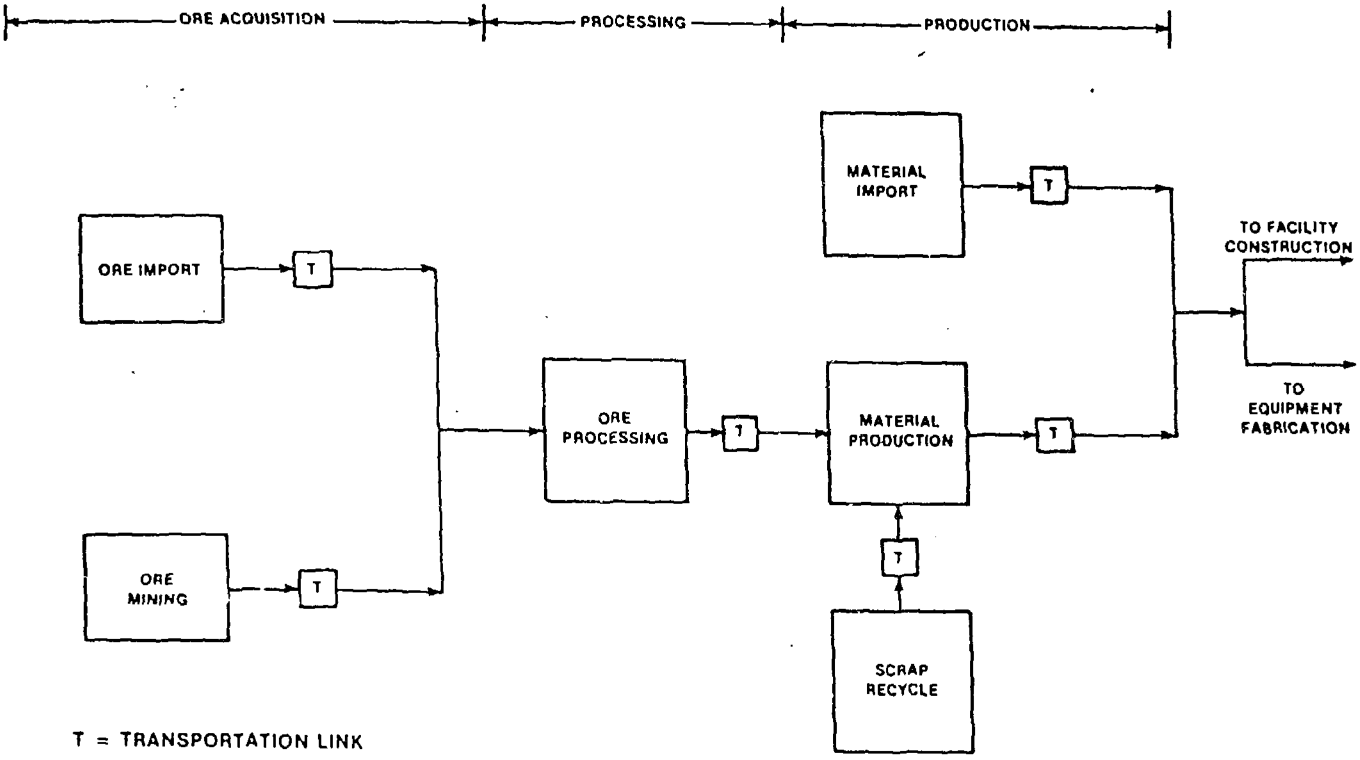


FIGURE 7. SIMPLIFIED MATERIAL PRODUCTION CYCLE

SOURCE: NUREG/CR-1539, p.453

referred to as the FS variables and are used to define the effluent source terms in the calculational model. These source terms include normal as well as properly weighted accidental or uncontrolled release components. The FS variables are used to compute the effluent exposure (FX) variables.

The health impact variables have two major components. The first is occupational (PO) which is directly related to the requirement variables. The second component impacts public health (PP) and is mainly derived from the effluent exposure variables (FX) by using exposure-health impact models. Requirement variables have either a direct impact on health, as in the case of occupational hazards and traffic accidents, or an indirect impact through polluting the biosphere with effluents that have a potentially adverse effect to human health.

In summary, each stage is considered for the requirement variables which describe the input to the stage and for the stage output, effluent variables, and health impact variables. Figure 8 shows the typical inputs and outputs for a stage.

Seldom does a stage consist of a single type. That is, the mining stage may consist of underground and surface mines, each with its own distinct occupational data. Therefore, except in the rare case that a particular stage was dominated by one type of facility, a linear composite model was utilized as shown in Figure 9. The composite facility combines several alternative processes, each fed with the similar inputs and producing similar outputs. The ratio of surface to underground mines, for example, is not held constant; rather, the composite model coefficients can be varied for sensitivity studies.

Figure 10 summarizes the general methodology showing the role played by various variables. Each activity is measured by a set of requirement variables; each requirement variable is associated with some direct health impact which is either occupational (PO) or nonoccupational (PP). The process of supplying a requirement variable is also associated with releases ($FS_1 \ldots FS_m$) that are referred to as release source terms. A release source term is used to calculate its corresponding exposure variable FX which in turn is fed into an exposure-health effect model to assess its health impact.

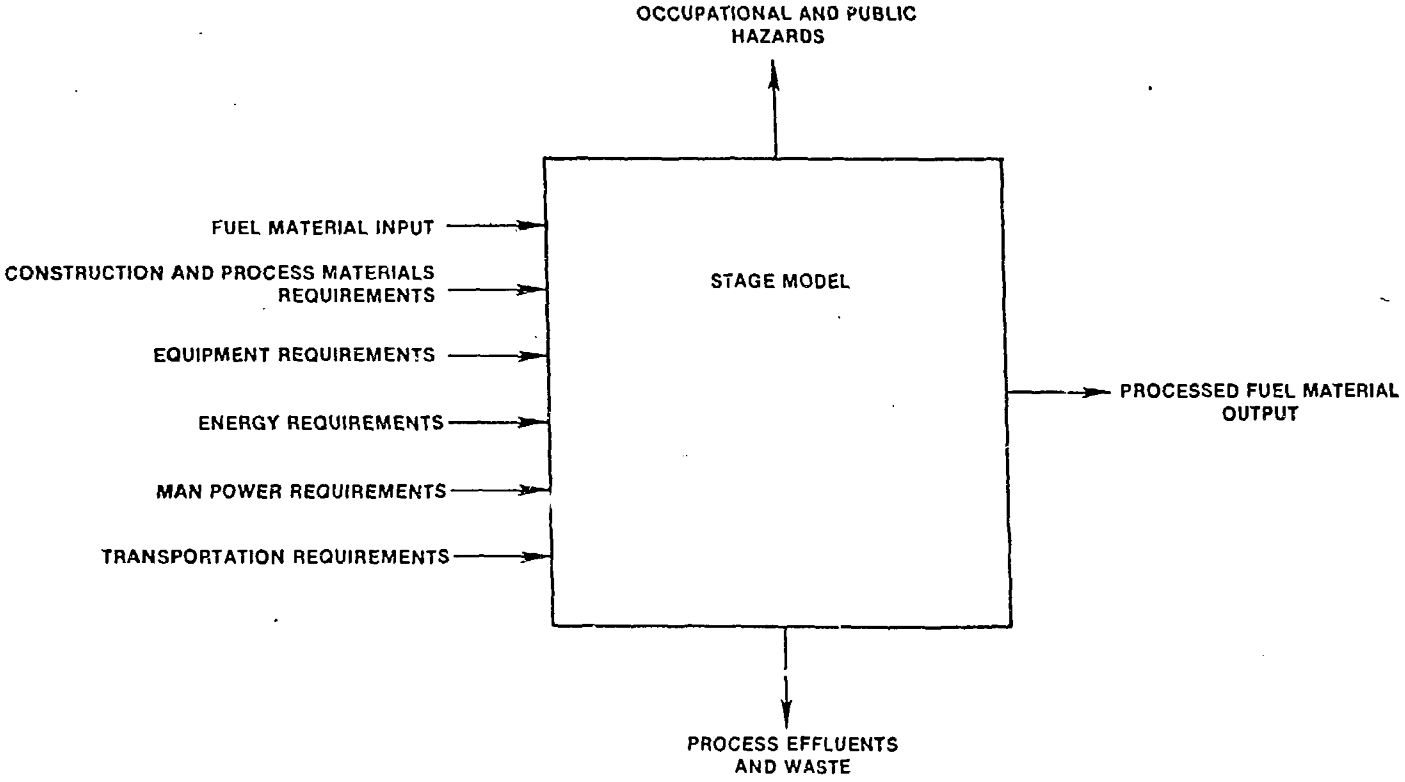


FIGURE 8. TYPICAL ENERGY PRODUCTION CYCLE STAGE INPUT AND OUTPUT INFORMATION

SOURCE: NUREG/CR-1539, p.14

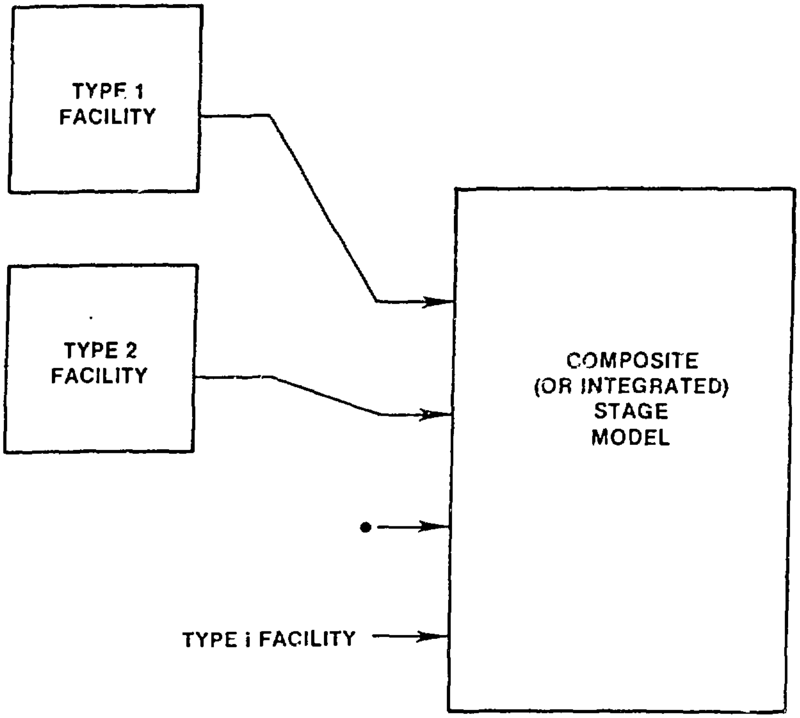


FIGURE 9. ENERGY CYCLE STAGE COMPOSITE MODEL

SOURCE: NUREG/CR-1539, p.18

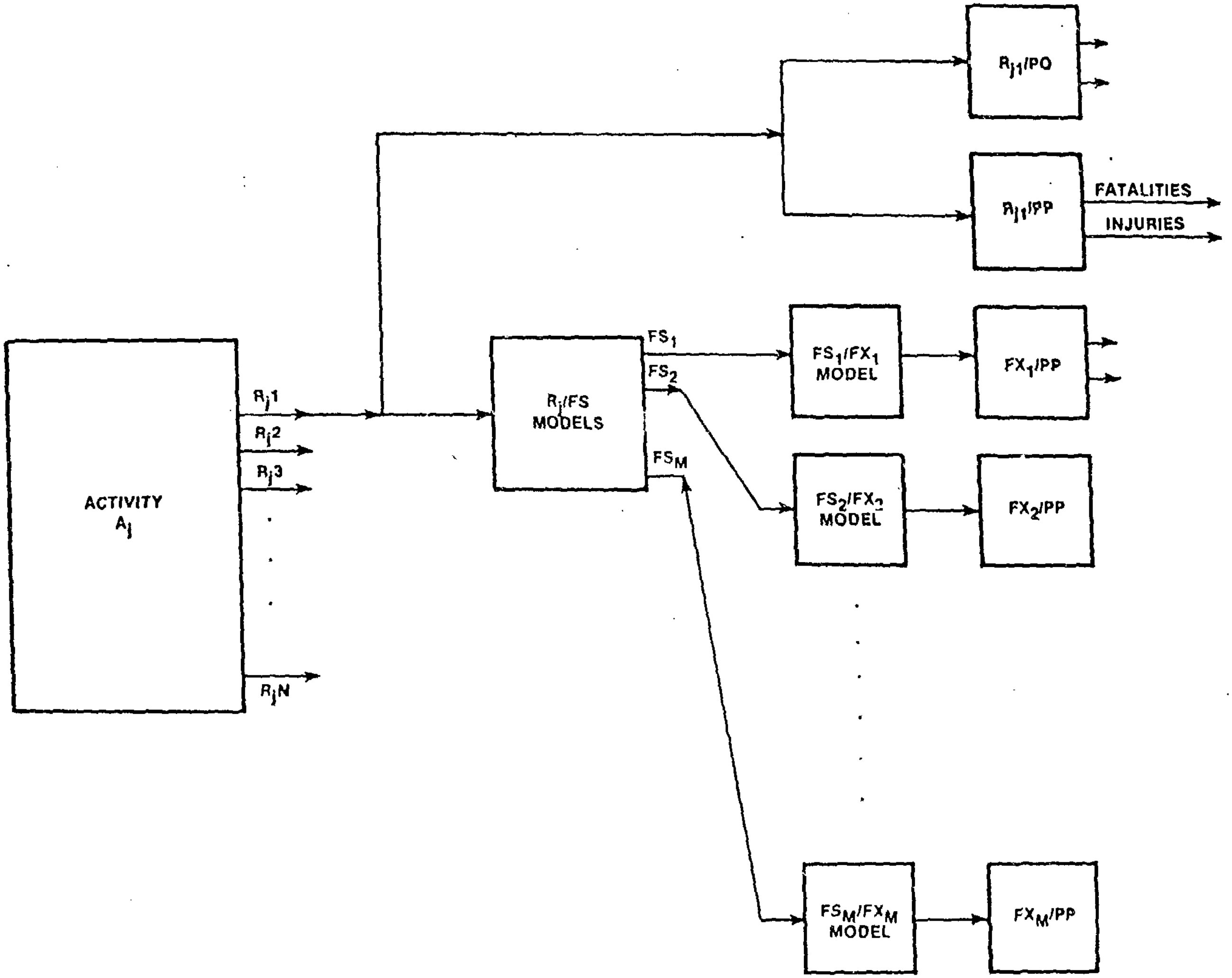


FIGURE 10. GENERAL APPROACH

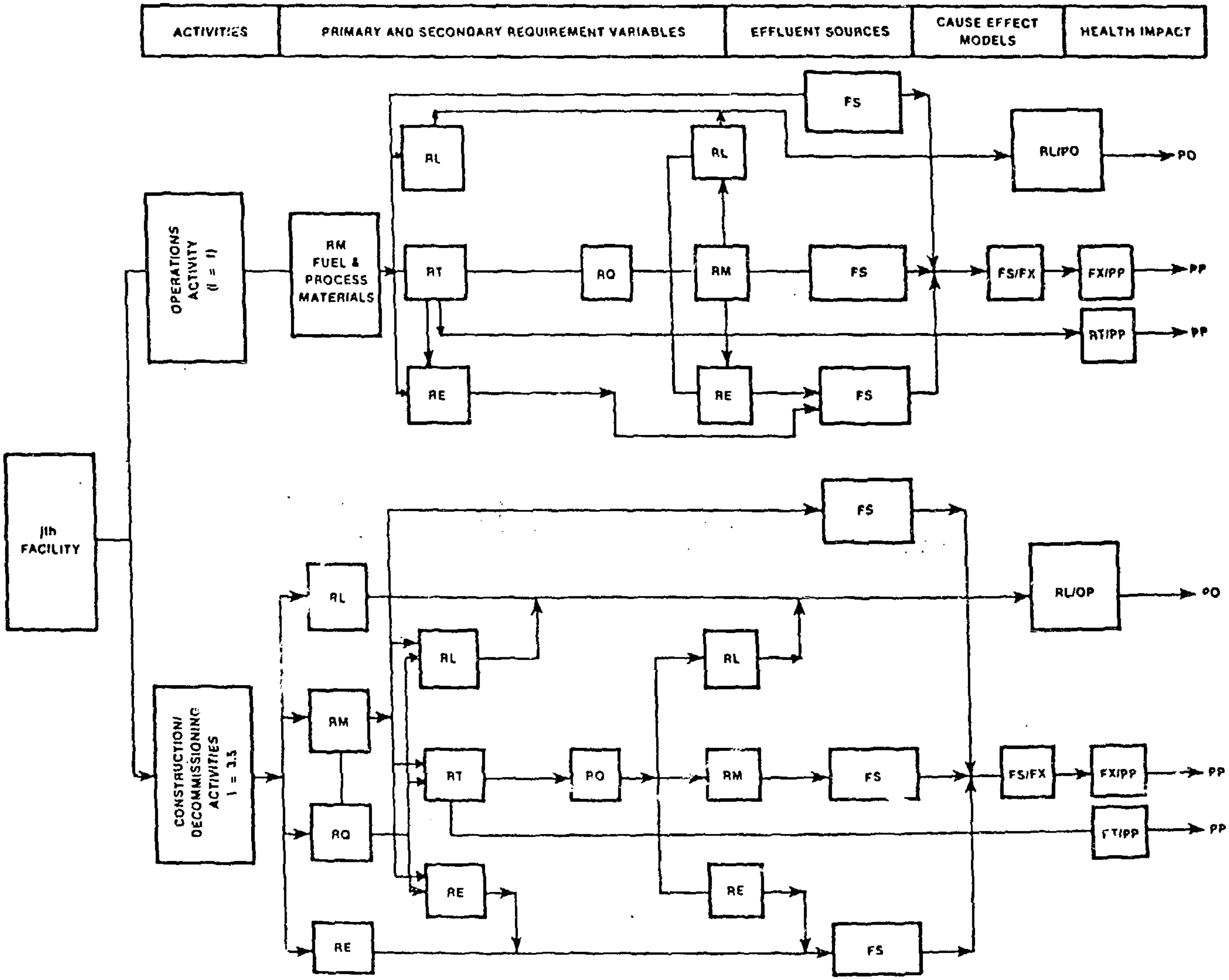
SOURCE: NUREG/CR-1539, p.33

Figure 11 represents a specific application of Figure 10 and shows a typical number of variables that will be calculated for each fuel cycle facility, and how some of them reoccur, i.e. the RE variables appear five times. To the extent that the same energy sources are represented by the RE variable, the effluents can be added as shown in the bottom of the figure so that complexity is reduced.

4. ANALYTICAL PROCEDURE

The analytical procedure chosen to implement the methodology involved four indices (i, j, k and l) which were defined for identification purposes. The first index (i) identifies the fuel cycle and the life cycle phase; the second index (j) identifies the stage in the fuel cycle; and the third (k) and fourth (l) indices are used to identify the nature of the primary and secondary requirements. Table 1 contains a user's key to the identification of the four indices. For example, R(3, 2, 9, 5) represents the amount of electrical energy (l = 5) required for equipment fabrication, (k = 9) for the uranium milling facility (j = 2) in the construction phase (i = 3). (See the definition of i in the table footnote.) A series of algebraic equations was developed based on the stage inputs and outputs. For example, Figure 12 illustrates the eastern coal materials flow to the power plant. Based on the data found in the literature search, the variables were quantified as shown in Table 2, which contains some of the energy requirements for the uranium fuel cycle.

Tables 3 through 6 illustrate the linear composite process and the determination of materials required to support a fuel cycle; in this case construction and consumable materials used in the transportation of nuclear materials in the uranium fuel cycle. Tables 3 and 4 contain reusable package requirements, and Table 5 contains disposable requirements. In these tables the values for fuel assembly strongbacks, spent fuel casks, and reactor low level waste packages are each based on a linear composite of the spectrum of packages available for transport of each waste. For example, Table 6 is a list of reactor spent fuel casks. A composite rail cask and a composite truck cask were determined based on the current distribution of licensed casks within each type. An overall composite was determined based on an assumed utilization of 50% rail and 50% truck casks.



SOURCE: NUREG/CR-1539, p.34

FIGURE 11. METHODOLOGY TREE

TABLE 1
VARIABLE IDENTIFICATION KEY

j (Stage)		k (Primary Requirement)		l (Secondary Requirement)	
Uranium	Coal	Uranium	Coal	Uranium	Coal
				0 For Primary Variable	0 For Primary Variable
1 Mining	1 Mining (east)	1 Input	1 Input	1 Gross Weight	1 U. G. Coal
2 Milling	2 Processing (east)	2 Stage Output	2 Stage Output	2 Weight With Cask	2 Open-Pit
3 Conversion	3 Storage (east)	3 Non-Electrical Energy	3 Non-Electrical Energy	3 Non-Electrical Energy	3 Non-Electrical Energy
4 Enrichment	4 Power Plants (east)	4 Waste	4 Waste	4 Waste	4 Waste
5 Fuel Fabrication	5 Mining (west)	5 Electrical Energy	5 Electrical Energy	5 Electrical Energy	5 Electrical Energy
6 LWR	6 Processing (west)	6 Manpower	6 Manpower	6 Manpower	6 Manpower
7 Reprocessing	7 Storage (west)	7 Transportation	7 Transportation	7 Transportation	7 Transportation
8 Waste Disposal	8 Power Plant (west)	8 Materials	8 Materials	8 Materials	8 Materials
	9 Waste Disposal	9 Equipment	9 Equipment	9 Equipment	9 Equipment

i = 1, 3, 5: Operations, construction, and decommissioning phases, respectively, of the uranium fuel cycle.
i = 2, 4, 6: Operations, construction, and decommissioning phases, respectively, of the coal fuel cycle.

SOURCE: NUREG/CR-1539, p.324

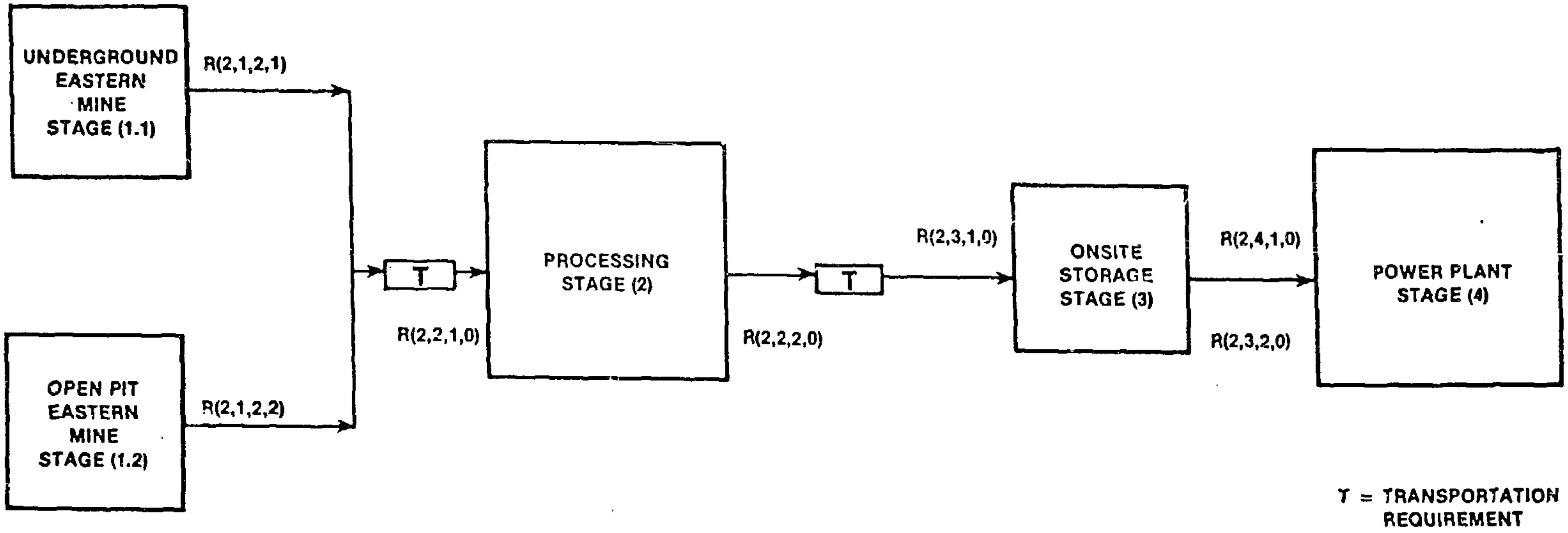


FIGURE 12. EASTERN COAL REQUIREMENT FLOW DIAGRAM

SOURCE: NUREG/CR-1539, p.338

TABLE 2
ENERGY CONSUMPTION RATES IN THE URANIUM FUEL CYCLE

j (Stage)	i (Phase)	Variable	Expression or Value[a]	Units
1. Mining	1	$EE\phi(1,1,2,5)$	$17.78 \ \frac{0.208}{\mathrm{GRADE}} \times \mathrm{EFF}(2) \times (1 - \mathrm{TLOSS}(2))$	MWH/MTU Mined
		$EN\phi(1,1,2,3)$	$23.4 \times 10^6 \ EE\phi(1,1,2,5)$	BTU/MTU Mined
	3	$EEC(3,1,2,5)$	$0.09 \ EE\phi(1,1,2,5)$	MWH/MTU Mined
		$ENC(3,1,2,3)$	$6.36 \times 10^6 \ EE\phi(1,1,2,5)$	BTU/MTU Mined
	5	$EEG(5,1,2,5)$	4×10^{-3}	MWH/MTU Mined
		$ENG(5,1,2,3)$	2.8×10^5	BTU/MTU Mined
2. Milling	1	$EE\phi(1,2,2,5)$	21.38	MWH/MTU
		$EN\phi(1,2,2,3)$	495×10^6	BTU/MTU
	3	$EEC(3,2,2,5)$	0.71	MWH/MTU
		$ENC(3,2,2,3)$	31×10^6	BTU/MTU
	5	$EEG(5,2,2,5)$	1.7×10^{-3}	MWH/MTU
		$ENG(5,2,2,3)$	7.4×10^4	
3. Conversion	1	$EE\phi(1,3,2,5)$	14.5	MWH/MTU
		$EN\phi(1,3,2,3)$	13.4×10^8	BTU/MTU
	3	$EEC(3,3,2,5)$	0.16	MWH/MTU
		$ENC(3,3,2,3)$	7.4×10^6	BTU/MTU

SOURCE: NUREG/CR-1539, p.348

TABLE 3
REUSABLE PACKAGE REQUIREMENTS

Origin	Destination	Commodity	Package	One-Way Miles	Mode	Packages/ Shipment	Materials/ Shipment
Mill	Conversion	Yellowcake	55-gal drum	1000	Truck	40	920 kg steel
Conversion	Enrichment	UF_6	14-ton cylin.	750	Truck	1	2359 kg steel
Enrichment	Fabrication	UF_6	2½-ton cylin.	750	Truck	5	3175 kg steel
			Overpack	750	Truck	5	3950 kg steel and small amounts of rubber and foam
Fabrication	Reactor	Fuel Assembly	Strongback	1000	Truck	6	21600 kg steel and small amounts of neoprene
Reactor	Reprocessing (or Disposal)	Spent Fuel	Cask	1000	Truck/Rail	1	14500 kg steel 42500 kg lead 2500 kg depleted uranium
Reprocessing	Disposal	HLW	Cask	1000	Rail	1	25000 kg steel 75000 kg lead
		Cladding Hulls	Cask	1000	Rail	1	72000 kg steel
		TRU LLW	Overpack	1000	Truck	1	7000 kg steel
		UF_6	14-ton cylin.	1000	Truck	1	2359 kg steel

SOURCE: NUREG/CR-1539, p.437

TABLE 4
REUSABLE PACKAGE LIFE CYCLE PARAMETERS

Commodity	Package	Lifetime	Shipments/Year
Yellowcake	55-gal. drum	12 shipments	
Natural and Reprocessed UF_6	14-ton cylinder	20 yr.	2
Enriched UF_6	2.5 ton cylinder	20 yr.	3
Fresh Fuel	Strongback	20 yr.	55
Spent Fuel	Cask	10 yr.	30
HLW	Cask	10 yr.	30
Cladding Waste	Cask	10 yr.	30

SOURCE: NUREG/CR-1539, p.439

TABLE 5

DISPOSABLE MATERIAL REQUIREMENTS

Shipment	Disposable Material Per Shipment
Reactor Low-Level Waste	600 kg wood, 1225 kg carbon steel, and 190 kg stainless steel (assuming 73% drums, 10% boxes, and 17% resin casks)
Other Low-Level Waste	1875 kg carbon steel
High-Level Waste	2560 kg glass and 2550 kg stainless steel per shipment
Cladding Hulls	540 kg sand and 230 kg stainless steel per shipment

SOURCE: NUREG/CR-1539, p.438

TABLE 6

LICENSED OR PROPOSED SHIPPING CASKS FOR CURRENT-GENERATION LWR SPENT FUEL

Cask Designation	Number of Assemblies		Loaded (Empty) Cask Weight (MT)	Usual Transport Mode[1]	Shielding		Cavity Coolant	Maximum Heat Removal (kW)	Status (NRC Certificate Number)
	PWR	BWR			Gamma	Neutron			
NAC-1 (NFS-4)	1	2	23 (22)	Truck	Lead and steel	Borated water and antifreeze	Water[7]	11.5	Licensed (6698)
NLI 1/2	1	2	22 (21)	Truck	Lead, uranium, and steel	Water and antifreeze	Helium	10.6	Licensed (9010)
TN-8	3		36 (33)	Truck[3]	Lead and steel	Borated solid resin	Air	35.5	Licensed (9015)
TN-9		7	36 (33)	Truck[3]	Lead and steel	Borated solid resin	Air	24.4	Licensed (9016)
TN-12	12	32	98 (90)	Rail	Steel	Borated solid resin	Air	120	Licensed in Europe only
IF-300	7	18	63[4] (53)	Rail[5]	Uranium and steel	Water and antifreeze	Water or air	76[6]	Licensed (9001)
NLI 10/24	10	24	88 (80)	Rail	Lead, uranium, and steel	Water and antifreeze	Helium	97[8]	Licensed (9023)
NAC-3	12	32	100[9] (90)	Rail	Steel	Water and antifreeze	Water or air	100[9]	SAR submitted

[1] Barge transport permissable unless explicitly ruled out by license.

[2] Excludes special trailer weighint 11 MT.

[3] Overweight permit required.

[4] Excludes 16-MT skid.

[5] Truck shipment for short distances with overweight permit.

[6] Licensed decay heat load is 62 kW.

[6] Licensed decay heat load is 62 kW.

[7] Air permissible if heat load is less than 2.5 kW

[8] Licensed decay heat load is 70 kW.

[9] Nominal value.

SOURCE: ORNL/Sub-1381/1, p.161

5. PRELIMINARY RESULTS

The methodology and data base were applied to a demonstration case involving the uranium cycle, where hand-calculated health effects estimates were computed for comparision with other published estimates. Resource limitations prevented similar calculations for the coal fuel cycle. Four materials were selected for inclusion in the demonstration of the methodology: iron, steel, concrete, and aluminum. Iron, steel and concrete were selected due to the magnitude of the uranium cycle requirements for these materials, while aluminum was singled out due to the amount of energy invested in its production. Other materials like copper, zircaloy, lead, etc. were judged to play a less significant role and were not treated in the demonstration stage of this study.

Occupational health effects in the operations phase of the model facilities of the uranium cycle were found to be comparable to previous estimates (Wrenn, 1978). Occupational risks during the construction phase were found to be comparable to those during the operations phase for both the model enrichment facility and the model LWR. Decommissioning risks were found to be comparable to those of the operations phase for the model reprocessing facility, but were about an order of magnitude smaller than those for the model LWR. Corresponding occupational risks for other model facilities were insignificant.

As expected, transportation requirements showed a significant increase when the construction and decommissioning requirements were considered with the largest increase occurring for the model LWR. The major increase was in non-cargo-related transportation risks; whereas, the increase for cargo-related risks was less significant.

Materials requirements effects were dominated by those for the model LWR and the model enrichment facility. Occupational hazards associated with the materials production cycle were found to be relatively low when compared with other risks in the cycle.

As expected, the electrical energy requirements were dominated by the model diffusion facility and drop by more than 80% when a centrifuge enrichment facility is used. Most of the non-electric energy requirement (about 60%) was projected to be consumed during decommissioning, while 30% is consumed during operations.

Impacts on public health were dominated by the model LWR and reprocessing facility. Radiological accidents were found to have a very small health impact, except for the LWR class 9 accidents, where calculations were based on very conservative assumptions.

Although these calculations are preliminary in nature, they yielded valuable information about those factors that can change the value of risk estimates. The use of an improved data base and sensitivity analysis techniques would undoubtedly shed a new light on the relative health impact on the coal and uranium fuel cycles.

6. PROBLEMS ENCOUNTERED

Data

The biggest problem encountered was obtaining consistent input data. This problem is not unique to the methodology presented here; rather, it is generic to comparisons of energy technologies in general. The desired data did not always exist. When data was found, it generally was not consistent with our needs. In the simplest case, it had to be renormalized to a different model facility output level. In the more complex situations, the level of effluent control, the type of fuel used, etc. were not clearly specified; therefore, the applicability of the data was unclear. The extreme case was when two sources of data had conflicting values for the same parameter without an apparent reason for the difference.

Models

Many of the problems encountered involve modelling uncertainties that are generic to comparisons of coal and uranium fuel cycles since the link from the technology to a quantifiable health impact is uncertain and completely missing in some cases. For example, not only is the link between the greenhouse effect and burning of fossil fuels uncertain, but the next link, the impact of the induced temperature rise on human health, is essentially missing. Similarly, although the effects of acid rain on the environment can be observed, the connection to human health is uncertain.

The health-effects model for effluents from the burning of coal used for the numerical results was based on the sulfate model developed at Brookhaven National Laboratory (Morris et al., 1979); however, health effects models for the heavy metals, benzo(a)pyrene, nitrates, etc. had not yet been developed. In addition, synergysism among the coal burning effluents and between these effluents and those of other industries is uncertain.

In the nuclear fuel cycle, the effects of sabotage can be estimated if the threat is well enough defined; however, the probability of the defined threat is sheer speculation. The estimation of consequences from diversion of special nuclear materials is subject to similar uncertanties.

These and other similar considerations deserve considerable research to quantify their effects on human health. Once quantified, the methodology is sufficiently flexible to include these effects.

Effluent Transport

The conceptual methodology calls for the development of effluent source terms for normal and accidental releases which are then converted to health effects internal to the analytical solution. In many cases the exposure/health effects model involves complex environmental pathways and human exposure analysis. Such self-contained completeness is a massive task and is impractical for consideration of energy technology fuel cycle risk evaluations. For example, the health risks from reactor accidents requires a sophistication beyond the requirements for an energy technology comparison. Instead, the results from studies like the Reactor Safety Study (USNRC, 1975) should be put into a transfer function form and inserted as a unit into the algebraic formulation. The general methodology is easily adapted to this change.

Material Production Cycles

Consideration of the production of the materials used in constructing the coal or the uranium fuel cycle facilities introduces a material production cycle for each material to be considered, e.g. concrete, steel, etc. As illustrated in Figure 7, the material production cycles consist of segments similar to the coal and uranium cycles: ore acquisition, processing, and production. Thus, a considerable effort is required for each material to be evaluated. Fortunately, many of the materials of interest occur repeatedly in the methodology tree (Figure 11), and need to be modelled analytically only once. Since resources generally permit only a limited number of material production cycles to be modelled, the analysis generally will be incomplete; however, careful selection of the material cycles to be modelled will minimize the effect of evaluating a limited number of cycles.

7. SUMMARY

In comparing energy technology risks, the implementation of the general methodology, the construction of a data base, and the computation of numerical results is an iterative process. Initial modelling and data are needed to obtain initial numerical results. These numerical results give guidance as to which phenomena are (1) insignificant and do not deserve additional modelling and data collection and (2) those which require or deserve greater attention. In general, simple mathematics applied to complex models is preferred over complex mathematics applied to simple models.

The methodology was found to be flexible and simple, yet systematic and comprehensive for determining the health effects of the uranium and coal fuel cycles. The methodology used in this study is suitable for energy technology comparisons in general.

8. REFERENCES

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