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A STRATEGIC ANALYSIS STUDY-BASED APPROACH TO INTEGRATED RISK ASSESSMENT: OCCUPATIONAL HEALTH RISKS FROM ENVIRONMENTAL RESTORATION AND WASTE MANAGEMENT ACTIVITIES AT HANFORD

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EXECUTIVE SUMMARY

The goal of environmental restoration and waste management activities is to reduce public health risks or to delay risks to the future when new technology will be available for improved cleanup solutions. The purpose of assessing risks associated with activities before, during, and after remediation is to provide information that can be used by stakeholders, including decision makers, to determine and manage a preferred approach to environmental restoration and waste management. This includes providing risk information in a form that can be easily compared to cost and schedule information.

Actions to remediate the wastes on the Hanford Site will entail risks to workers, the public, and the environment that do not currently exist. In some circumstances, remediation activities will create new exposure pathways that are not present without cleanup activities. In addition, cleanup actions will redistribute existing health risks over time and space, and will likely shift health risks to cleanup workers in the short term.

Defining and assessing impacts from the activation of new transport and exposure pathways during remediation will form the basis for defining the redistribution or alteration of risk under various cleanup options for the Hanford Site. It is anticipated that atmospheric transport pathways will be a significant contributor to public and worker exposure when hazardous material is dug up or moved around. Because of the immediacy of atmospheric exposures, long-term public risk will be replaced with a combination of potentially more immediate worker, ecological, and public risks.

Because worker health risks are minimal in the absence of either production or cleanup activities, these will be a primary factor in determining the tradeoffs in planning cleanup activities. Thus, assessing occupational health risks during remediation has several objectives:

- Estimate risks to workers from routine operations and from potential accidents associated with various cleanup strategies and options.

- Compare health risk estimates from various waste streams, mission areas, strategies, and options to understand sources and timing of risks and to determine what health risks can be affected by managing the approach to remediation.
- Provide risk information in a manner consistent with cost and schedule information and with public health and ecological risk information so that trade-offs can be evaluated by stakeholders.
- Characterize uncertainties associated with occupational health risk estimates and determine how uncertainties should influence the decision process.

This report describes an approach to occupational risk assessment based on the Hanford Strategic Analysis Study and illustrates the approach by comparing worker risks for two options for remediation of N/K fuels, a subcategory of unprocessed irradiated fuels at Hanford.

The approach is an integrated risk assessment from two perspectives. First, it is integrated with the Hanford Strategic Analysis Study because its basis is information and databases associated with the study that are also used for cleanup cost and schedule projections. Second, whereas the example illustrates the approach for addressing worker health risks as a consequence of environmental restoration, the approach is also intended for use to estimate public health and ecological risks as well. By using a consistent basis for health and ecological risks, inputs to decision-making will have consistent assumptions, models, and data as a basis. Thus, tradeoff evaluations will have greater validity, and resulting decisions will be sound and not created by differences in approach.

In addition, the approach has several advantages. It is flexible and can be applied at different levels of aggregation of geography and of waste sites and streams to support sensitivity analyses. By using detailed temporal information when it becomes available, risks over time can be projected and analyzed to understand the impact of the order of activities. The approach provides information that can be used for setting priorities, for allocating budgets, for justifying decisions, for communicating with stakeholders, and for managing diverse activities.

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1.0 THE HANFORD INTEGRATED RISK ASSESSMENT PROJECT

For a half century, the Hanford Site has been the location of a wide range of defense-related activities that have generated both radioactive and chemical hazardous wastes. The primary mission of the Hanford Site has recently been redirected to clean up these hazardous wastes. Cleanup includes recovery or isolation of wastes associated with existing Hanford facilities and storage systems and the general Site environment. These wastes, if left in place, could pose an unacceptable risk to human health and the environment. By recovering or isolating wastes, risks may be significantly reduced.

One purpose of Hanford Mission Planning (HMP) is to set priorities for Site cleanup activities, including evaluating and selecting effective cleanup strategies. Key inputs into prioritization of cleanup activities are health and ecological risks, cost and schedule of cleanup activities, regulatory requirements, availability and appropriateness of technology needed for remediation activities, plans for future site use, and public considerations. Without proper evaluation of each input, it will be difficult to identify an effective and efficient cleanup strategy.

The integrated risk assessment project is designed to provide comprehensive input on health and ecological risks for prioritization of cleanup activities. Integrated risk assessment deals with public health risk, occupational health risk, and ecosystem risk in an unified manner. Public health risk assessment involves evaluating impacts on individuals and populations from their residency in the region. In addition, public health risks assessments can include evaluating impacts on workers that are not related to Hanford-specific jobs. Occupational health risk assessment involves evaluating job-related impacts on Hanford Site workers. These impacts can involve injuries or fatalities during construction of remediation facilities, routine exposure to wastes during retrieval and processing, industrial accidents, and transportation accidents. Ecosystem risk assessment involves evaluating impacts to local and regional ecosystems, including, but not limited to, endangered and protected species. Ecosystem impacts can also involve indirect impacts on public health.

An integrated risk assessment estimates risks for various aggregations of individual waste components at the Hanford Site before, during, and after completion of remediation activities. Consideration is given to effects from radiation, carcinogenic chemicals, and hazardous noncarcinogens. Risk estimates for individual waste components can be combined to produce overall risk estimates for the entire site. This allows the effect of changes in waste inventories, remediation activities, and cleanup schedules on overall risk to be evaluated.

The goal of the integrated risk assessment project is to provide a complete picture of how risk can change from its present state to a new state during remediation processes to an eventual end state. The risk assessment, in total, will demonstrate which activities lead to a clear reduction in risk, which simply redistribute risk, and which may actually cause an increase in risk. This report illustrates one part of this big picture; it describes and illustrates, by example, an approach to assessing occupational health risks during remediation activities.

In the remainder of this section, we discuss in more detail an integrated risk assessment approach for evaluating baseline risk, risk during remediation, and risk for alternative end states.

1.1 BASELINE RISK ASSESSMENT FOR THE HANFORD SITE

The baseline risk assessment is designed to determine risk associated with maintaining the current status of hazardous wastes at the Hanford Site. The objectives of a baseline risk assessment task are to

- develop a consistent set of measures of the impact of the Site on the public, workers, and ecosystems
- link waste sources with resulting incremental increases in risk
- identify principal exposure pathways and quantify relative importance of each pathway
- clearly delineate types of risks that are present (e.g., acute versus chronic, chemical versus radiological, and fatalities versus other health effects)
- characterize uncertainties associated with information sources

- understand how the "baseline" risk varies with time (e.g., low public health impacts on the current generation, with potentially increasing impacts on future generations).

A comprehensive baseline risk assessment will provide a reference case required to identify specific waste problems that may pose the greatest increases in incremental risk. Results can be used in assigning higher priority to cleanup activities that will provide greatest reductions in risk.

As part of the baseline analysis, detailed information is needed on potential environmental releases (i.e., source terms) and exposure pathways for each class of waste and on current storage/containment methods. Parts of this existing information have been obtained from studies on environmental pathways and analyses that focus on particular issues (e.g., the Hanford Defense Waste Environmental Impact Statement, grout performance assessment, single-shell tank risk-based chemical characterization analysis, and emergency response analyses for atmospheric releases). These separate studies have not been integrated to provide a site-wide perspective on the inventory of radionuclides and chemicals. In addition, these studies often do not provide information in a form that can be applied to evaluate specific cleanup strategies and options.

1.2 RISK ASSESSMENT FOR REMEDIATION AND RESTORATION ACTIVITIES

The objective of remediation activities is to reduce risks to human health and ecosystems. In attempting to achieve reductions in overall risk, many remediation activities transfer aspects of risk from the public to workers from one time period to another, or from one geographic location to another. For example, retrieving tank wastes should significantly reduce public health risks to future generations. However, in doing so, occupational health risks may increase (e.g., as a result of construction accidents, from worker exposure to low levels of radiation during retrieval and processing activities). Public health risks to the current generation may also increase (e.g., as a result of atmospheric releases of radioactivity during waste processing). In other cases, remediation activities may increase overall risks. If remediation activities are conducted on a waste source that has a low baseline risk, the increase in occupational health risks associated with cleanup may exceed the overall risks associated with a baseline strategy.

Through this sort of analysis, an integrated risk assessment can illustrate benefits, liabilities, and tradeoffs associated with various remediation activities. This information, in turn, can be used by decision makers in evaluating cost, schedule, compliance, and risk impacts between various cleanup approaches.

In addition to redistributing risk, remediation activities may modify existing environmental pathways or create new exposure pathways that are not present in the baseline system. For example, research indicates that remediation activities may tend to increase risks associated with atmospheric transport pathways (via contaminant exhuming and waste processing) and decrease risks associated with groundwater pathways (via removing waste sources).

Occupational health risks depend on the approaches to cleanup employed (which in turn determine the dominant means of worker exposure), required construction and transportation, level of automation and required worker involvement during the remediation processes, and levels to which cleanup is being implemented. It also depends on the numbers of workers employed, and the diversity and levels of exposures of each worker.

1.3 RISK ASSESSMENT OF ALTERNATIVE END STATES

The purpose of developing comprehensive risk assessments for the time period after the completion of remediation activities is to estimate health and environmental risks from residual contamination. End-state risks depend on residual contamination levels, future land use categories, final waste forms (e.g., glass or grout), dominant exposure pathways, and health and environmental risks. The objective of end-state risk assessment is to develop a systematic and defensible basis for establishing cleanup criteria (i.e., residual concentration limits for principal contaminants of concern) given any one of several possible future land use and final waste form scenarios. This task develops insight into principal determinants of risk (e.g., most critical pathways to risk, types of mitigating strategies likely to be most effective, which wastes dominate risk estimates).

The risk assessment of alternative end states utilizes procedures similar to baseline and remediation risk assessments. A difference between this task and the previous two is that for an end-state assessment we start with selected health risk levels and attempt to determine (through back calculation) how much residual waste could remain without causing particular risk levels to be exceeded.

1.4 OVERVIEW OF REPORT

This report illustrates how risk assessments tie to a systems analysis study; it focuses on assessments of risks during remediation activities. Companion reports will illustrate the concept for baseline and end-state risk assessments.

This report provides a quantitative illustration of assessing risks during remediation for workers and compares two cleanup options. Section 2 describes the Hanford Strategic Analysis Study, and Section 3 focuses on general and specific data requirements. Section 4 presents detailed preliminary work for N/K fuels (a subcategory of irradiated fuels at Hanford) to compare occupational health risks that arise from two different strategies and options. Strategy IX, option 2 of the Hanford Strategic Analysis Study is to oxidize and repackage fuel then dispose of wastes; option 3 is to separate uranium and plutonium from the fuel, repackage the fuel, and dispose of wastes. Section 5 presents conclusions and recommendations based on the N/K fuels example of the adequacy of the Hanford Strategic Analysis Study as a basis for risk assessment and the adequacy of data and methods available to support further risk assessments. Section 5 also presents conclusions from the N/K fuels example.

2.0 RELATIONSHIP TO HANFORD STRATEGIC ANALYSIS STUDY

The Hanford Strategic Analysis Study (Pajunen et al. 1993) provides a general tool for evaluating technical alternatives available for completing cleanup of the Hanford Site integrated across five Site mission areas (nuclear materials, tank waste, solid waste, environmental contamination, and retired facilities). The study develops alternative material flow paths through integrated Site configurations of major processing systems. Based on material flow estimates, various consequences of cleanup are estimated for comparison of alternatives.

Comparisons evaluated by the Strategic Analysis Study focus on characteristics related to material flow (e.g., waste volumes ending up in different locations, final projected location of radionuclides, flow of material through a particular facility type) and relative cost to complete a cleanup strategy. However, material flow information has wider application as a basis for calculating additional implications from cleanup, such as estimates of comparative risk associated with alternative strategies.

2.1 MOTIVATION FOR BASING RISK ASSESSMENTS ON HANFORD STRATEGIC ANALYSIS STUDY

Based on resources available from the Hanford Strategic Analysis Study, risks can be assessed for an entire Site, for a mission area, for a waste stream, or for a specific site or facility. Risks can be assessed at these levels for various strategy and option combinations. The risk assessment process requires minor modifications in assumptions for application at these various levels. The advantage of this approach is that it allows systematic identification of waste streams or facilities that are sources of greatest potential risk. This is of particular value to the decision-making process.

There were several other reasons, in addition to this flexibility, for tying the risk assessment to the Hanford Strategic Analysis Study. First, and most importantly, a primary use of results will be to compare worker risks, public risks, and ecological risks with each other, and with cost and schedule projections. To ensure that these comparisons allow tradeoff decisions to be made on a sound and consistent basis, underlying assumptions must be compatible. Differences in assumptions and methodology must not be mistaken for differences in risk. Because process flow diagrams are being used to generate costs and schedules, it was logical to also use them as the basis for assessing risk. In addition, these diagrams and associated supplementary information are the most complete multi-mission data available for Hanford that link current wastes with remediation and end states.

Second, even though information for assessing risk using process flow diagrams is not complete, little other information is available. As more information becomes available, risk assessments, either entirely or in part, will be updated. In addition, the approach is flexible, and results can be easily updated to correspond to more detailed information on proposed environmental restoration technologies, end states, options, strategies, costs, or schedules.

2.2 DESCRIPTION OF HANFORD STRATEGIC ANALYSIS STUDY PRODUCTS USED IN RISK ASSESSMENTS

Specific products available from the Hanford Strategic Analysis Study include the following:

- process flow diagrams for each strategy/option combination
- mass balance charts to provide waste inventories for each stream pathway in the process flow diagrams
- information on process additives for key waste processing operations
- assumptions used to generate the mass balance chart
- information on construction, testing, operation, and decommissioning schedules and on costs for waste processing facilities and operations.

2.2.1 Process Flow Diagrams

Process flow diagrams provide information on processes, facilities, and transportation pathways. An example of this information is presented in Figure 2.1.

On process flow diagrams, processing of waste is represented by the labelled rectangular blocks. Each block contains several key words that describe the waste processing operation (e.g., remote material processing). A functional block number identifies the process; this number is located in the

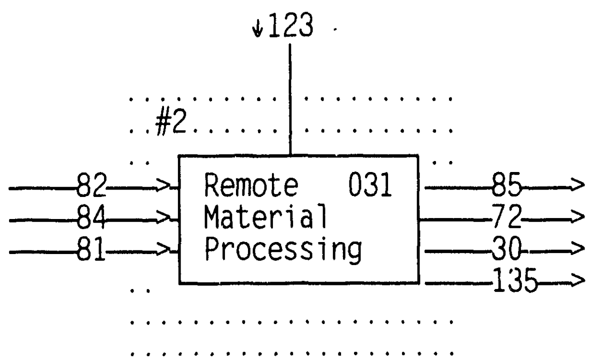


FIGURE 2.1. A portion of a process flow diagram. The diagram shows waste streams #81, 82, and 84 entering facility #2 to undergo remote material processing through process #031. Additives are shown being added at stream #123. Material leaves the facility by waste streams #30, 72, 85, and 135.

upper right hand corner of the block (e.g., 031). The perimeter of one or more blocks may be surrounded by a dotted rectangle to indicate that the facility is a waste treatment facility. The facility number is found in the upper left hand corner of the dotted rectangle (e.g., #2). Material inputs and outputs are identified by one or more incoming or outgoing streams (e.g., input #84 and output #85, both of which are surrounded by a hexagon on the actual process flow diagram).

2.2.2 Mass Balance Charts

Mass balance charts are used to provide information on quantities of wastes involved in stream pathways in process flow diagrams. A small portion of a mass balance chart is given in Table 2.1. These charts present the mass or activity of key products within a waste stream. Data are for a particular mission area; when a stream contains wastes from several mission areas (e.g., tanks, environmental restoration, N/K Fuels), charts provide information only on the portion of the waste stream directly attributable to the mission area being considered (e.g., N/K and PWR Fuel). Values are given for volume of material (m^3), total mass flow (metric tons, MT), other (MT), process additives (MT), Cs (curies, Ci), H_2O (MT), Na (MT), ^{239}Pu (MT), Sr (Ci), Tc (Ci), and U (MT).

TABLE 2.1. A portion of a mass balance chart. The chart provides information on components of waste streams #82, 83, 84, and 85. For the indicated strategy, option, and waste mission area, waste streams #82 and 83 do not contain any listed components.

Summary data - strategy IX, option 2, N/K fuel

STREAM NAME	82	83	84	85
COMPONENT				
Volume, Cubic Meters			4.338E+02	
Total Mass Flow (MT)			2.603E+03	2.603E+03
Other (MT)			3.177E+02	3.177E+02
Proc Add (MT)				
Cs (Ci)			4.070E+07	4.070E+07
H2O (MT)			1.800E+02	1.800E+02
Na (MT)				
Pu-239 (MT)			4.500E+00	4.500E+00
Sr (Ci)			2.224E+07	2.223E+07
Tc (Ci)			2.736E+03	2.736E+03
U (MT)			2.100E+03	2.100E+03

Some boxes in mass balance charts have not yet been filled in (e.g., #82 and 83 in Table 2.1). A blank next to a component in a partially filled-in box is equivalent to a "0" (e.g., in Table 2.1, waste stream #84 can be assumed to contain no Na).

2.2.3 Chemical Additive Information

Information on chemical additives used to process wastes is available for key streams. These additives may consist of acids, bases, water, air (i.e., O_2), grout, and processing chemicals. The catch-all category of "other" is used to represent such things as concrete, rebar, heavy metals, and miscellaneous chemicals.

An example of a process additive chart is presented in Table 2.2. The first three columns on the chart show the functional block, facility, and chemical stream number associated with each waste stream. The fourth column lists individual components of process additives, without consideration of the

TABLE 2.2. A portion of a process additive chart. The chart contains lists of process additives for the N/K fuel mission area under strategy IX, option 1.

Functional Block Number	Common Facility Number	Chemical Addition Stream Number	Components	Options
22	6	114	Grout	1,2,3
23	3	115	None	1,2,3
24	4	116	Ion Exchange Basin NaOH HNO_3 Na_2CO_3 $NaHCO_3$ FeSA $NaTi_2O_5H$ $H_2C_2O_4$ Ascorbic Acid THFTCA Crown Ether TBP CMPO NPH	1,2 1,2 1,2 1,2 1,2 1,2 1,2 1,2 1,2 1,2 1,2 1,2 1,2 1,2
25	5	117	Glass Formers	1,2,3
26	15	118	None	1,2,3

quantity of material in the waste stream. The final column indicates options for which associated material is included in the process stream.

Process additive components are grouped according to characteristics, not in order of the quantity found in the waste stream. Specific quantities of most process additives are only available on special request from the Hanford Strategic Analysis Study research team.

2.2.4 Assumptions

Appendix C to the Hanford Strategic Analysis Study provides information on assumptions used to generate the mass balances (WHC 1993). The appendix gives assumptions used for each functional block. Using this information, validity of assumptions can be assessed. In addition, this information is expected to play an important part in quantifying the uncertainty involved in risk assessment estimates.

2.2.5 Cost and Schedule Information

Preliminary information on construction, testing, operation, and decommissioning schedules and costs for waste processing facilities and operations are available from the Hanford Strategic Analysis Study. Figures A.1 and A.2 in Appendix A illustrate the type of data available on facilities (facility specification sheets) and projects (project life-cycle worksheets).

2.3 USE OF INFORMATION FOR RISK ASSESSMENT

Information from the Hanford Strategic Analysis Study is used to assess risk based on the U.S. Environmental Protection Agency (EPA) paradigm that consists of four steps: 1) hazard identification, 2) exposure assessment, 3) dose-response modeling, and 4) risk characterization.

2.3.1 Use of Process Flow Diagrams and Supplemental Information

Risk is estimated for each box (facility) and each arrow (transport between facilities) in the process flow diagrams from the Hanford Strategic Analysis Study. Some arrows are assumed to connect contiguous facilities so there is no transport and, thus, no risk. Associated with each box, potential exists for exposure to workers, both routine and accidental, and for accidental release of contaminants to the ambient environment by various pathways. The public and ecosystem are potentially exposed to these accidental releases.

The supplemental information from the Hanford Strategic Analysis Study is used in combination with the process flow diagrams. This includes information from mass balance charts, on chemical additives, and on cost and schedule.

2.3.2 Use of Cost Information

The risk assessment approach developed uses cost information on facilities proposed in process flow diagrams. Because numbers of workers and specific jobs are not yet defined, cost information is used as a surrogate to estimate expected numbers and types of workers. We have assumed that the costof a person-year is $120,000 and that there is no escalation in future years. These assumptions were used by Westinghouse Hanford Company in producing facility costs.

Facility cost information and data on percent of facility construction and operating budgets for various categories of DOE facilities that have been allocated to various skill levels (DOE/MA-0063 1982) were used to estimate numbers of workers in manual labor occupations in each facility. Manual laborers are expected to receive much of the exposure and to account for the majority of injuries in the Hanford remediation work force. Estimates were also available on specific types of manual labor, but this information was not used in the current example because types of labor in proposed facilities could not be identified. Labor details will be used for future risk assessments, however, when information on specific processes in proposed facilities will allow assessment of exposure by manual labor category.

Two facilities were used to represent the general categories of facilities to be constructed and operated at Hanford: a shielded facility and an unshielded facility. For example, the Remote Materials Processing Facility (RMPF or facility 2 in strategy IX, options 2 and 3) is considered similar to the uranium conversion facility (DOE/MA-0063 1982). Both are shielded facilities. The other facility information that was used is for a uranium enrichment-diffusion facility. This was considered representative of non-shielded facilities.

Use of cost information in risk assessment was designed to be flexible and to accommodate changes in response to updated cost information. When better data on specific numbers or types of occupations becomes available, this will be used in conjunction with the cost data. Using cost information as one input to risk assessment allows the decision maker to better understand how management decisions that affect cost also affect risk.

2.3.3 <u>Use of Schedule Information</u>

In the current risk assessments, limited schedule information was available. When construction was projected to take 10 years, construction costs and associated person-years of manual labor were divided equally across the 10 years. This is unlikely to be the actual labor distribution, particularly when specific job categories are considered. As planning for remediation becomes more specific, a schedule will evolve. Scheduling information will be included in future risk assessments to produce time-phased risks similar to those illustrated below.

As noted above for costs, the proposed risk assessment approach can be changed to respond to changes in scheduling information. This allows the decision maker to understand how management decisions with respect to schedule also affect risk.

2.4 EXPECTED ITERATIVE NATURE OF OCCUPATIONAL HEALTH RISK ASSESSMENT

Assessing risk for purposes of future planning and decision making is iterative. It differs from more traditional risk assessments that are retrospective in nature, for which much of the specific information required is already available, for which an investigation of a disease cluster has led to identification of a problem and, thus, for which fewer assumptions are required.

Currently, the source term is not fully defined in process flow diagrams and mass balance charts, although masses of selected contaminants of particular concern are estimated. In addition, proposed processes are not defined in sufficient detail to assess exposure. This lack of information makes it difficult to identify possible points of both routine and accidental exposure, and thus, makes assessing risk difficult. Assumptions replace a rigorous exposure assessment.

Because some specific information required to assess risk accurately is unavailable does not mean that risk assessments are not useful. Knowledge can be gained from conducting assessments using the best available information and making reasonable assumptions as required. Such efforts will produce data, tools, and methodology that can be used to factor risk into environmental management decision making. As better information becomes available, estimates of risk can be improved. The risk assessment is seen as an iterative process, one which increases in accuracy over time as missing or estimated data are either identified or better estimated.

In addition, preliminary risk assessments can be used to focus data collection. Sensitivity analysis can be conducted to determine data that are most important in driving risk assessment results. These sensitivity analyses can in turn be used to determine the most useful information to collect to reduce uncertainty in results from a decision-making perspective.

3.0 DATA REQUIREMENTS FOR OCCUPATIONAL RISK ASSESSMENT

This section discusses general data requirements for occupational health risk assessment, then focuses on specific requirements for the Hanford Site in three parts. In Section 3.2, health endpoints evaluated in the example, and that will be considered in future occupational health risk assessments of remediation, are presented. In Section 3.3, sources of occupational exposure assessment information are discussed. Finally, in Section 3.4, examples are given of information available from the Hanford Strategic Analysis Study.

3.1 GENERAL REQUIREMENTS

Estimating worker risks associated with Hanford Site cleanup requires understanding complex issues surrounding waste sources and processing. Below we describe issues that must be understood to develop a risk characterization. The approach will be comparable, in terms of issues that need evaluation, for all wastes and for all processing and disposal options. It will also be similar for public health and for ecological risks.

Information from the Hanford Strategic Analysis Study that is key to risk assessment includes process flow diagrams, supporting facility specification sheets, mass balance charts, and cost and schedule information (see Section 3.4.1). The level of detail and accuracy, and the inclusion of uncertainty in the resulting risk characterization, depend on input data characteristics. Major input data needs for occupational risk assessment are associated with the following questions:

- Wastes: What wastes are being stored and need to be processed? What are the quantity and toxicity of wastes? What are process outputs? What are the quantity and toxicity of outputs?
- Facilities: Where are wastes processed?
- Transportation: How do wastes get to processing facilities? How do wastes get between steps in processing? How are wastes transported to the final place of storage?
- Processes and Process Additives: What is the waste processing operation?

- Worker Activities: Who does processing and what is the level of effort? What are regulatory limits on exposure?
- Worker Exposure Pathways: What are potential pathways of exposure? What are levels of exposure by pathway?
- Endpoints: What are health endpoints?
- Rate of Hazards: What are rates of potential health hazards?
- Risk Characterization: What are estimated quantitative health risks? How certain are they, based on the certainty of the information above?

Each of these is discussed in the following sections.

3.1.1 <u>Wastes</u>

Key hazardous wastes that must be processed, repackaged, disposed of, and/or stored are defined in process flow diagrams and mass balance charts from the Hanford Strategic Analysis Study. Alternative approaches are described in various strategies and options. Key variables that must be known about wastes include their amounts and characteristics and their current location. Level of contamination is an important concern when dealing with liquid wastes and contaminated soil or with solid wastes that become volatile during processing.

Process flow diagrams and mass data charts describe amounts of wastes to be transported between facilities and to be processed at each facility. Data from the Hanford Strategic Analysis Study are total amounts, so determining material flow requires distributing wastes over operating lifetimes of facilities. An important assumption from the risk assessment perspective is that these wastes are homogenous with respect to contamination. If wastes with a greater activity or concentration of hazardous wastes are processed during a particular time period, it is expected that risks are increased during that time period.

3.1.2 <u>Facilities</u>

Each waste stream to be processed as part of environmental restoration will follow a sequence of steps specified in process flow diagrams among facilities where various stages of waste processing activities take place. Alternative cleanup strategies and options differ in terms of facilities and processes involved.

In determining health and ecological risks, it is essential to understand activities that occur in facilities during the remediation process. Significant aspects of the facilities themselves are the basic design involved (i.e., shielded or non-shielded), existing facilities that provide an appropriate comparison for structure and processes, location of an existing or proposed facility, and whether a single structure will house more than one process. Also of importance is the length of time a facility will operate and its annual throughput. As an alternative to this information, amounts of wastes to be processed over the proposed operational lifetime of a facility are necessary to estimate annual material throughput.

3.1.3 Transportation

An understanding of the transportation system is necessary to determine potential injury risks and exposure pathways. Potential risks associated with transportation occur along each sequential step in process flow diagrams. In determining these risks, it is essential to know distances that specific wastes are moved at each stage: current site to initial processing facility, between each pair of facilities in the processing sequence, and to storage either onsite or offsite. If offsite storage is used, distances to site boundaries and to long-term storage locations need to be determined and specified separately.

In addition to the distance that wastes are transported, it is necessary to consider methods of transportation, for example by truck or rail, as well as the route of transportation. For many waste streams, transportation may be of liquid or slurry in a pipeline or along an enclosed conveyor belt system. Also, demographics of proposed shipping routes must be known.

Finally, with regard to transportation, methods of containment during shipment need to be considered to estimate accident risks. Methods of containment include options such as casks or containers for solid wastes, or barrels for liquid waste.

3.1.4 Processes and Process Additives

To assess risk when wastes are processed, it is essential to know the details of this operation, such as: what specific processes are involved, what chemicals are used as process additives, what is the distribution of throughput, and what functions are performed remotely or manually?

The physical nature of the process will have important implications for potential exposure pathways for human and ecological risks. How chemicals are handled in a facility and used in treatment of wastes have important implications with regard to accidental releases, as well as potential for routine worker exposures.

3.1.5 Worker Activities

For each facility, it is important to consider worker activities and risks during four stages: construction, process testing, operations, and deactivation and D&D (decontamination and decommissioning). In each stage, it is necessary to estimate numbers of person-years for various job categories. In addition, particularly during the operational phase, it is important to link workers in a facility with a particular operating process(es).

Information is available on estimated labor costs for proposed facilities, and these labor costs are used to estimate total labor person-years (DOE/MA-0063 1982). Level of effort, in workers per year, is estimated from these labor estimates and divided by the number of years in the stage under consideration. It is more difficult to estimate numbers of persons in specific job categories from available information. However, to accurately assess exposure, such information is required.

3.1.6 Worker Exposure Pathways

Processes in a facility are carried out that involve chemical or physical actions on wastes that enter the facility through an identified stream. Resulting revised waste then enters a new stream and goes to the next facility or process on the process flow diagram. A key question is: at what points in this process are there potentials for worker exposure; that is, what are the worker exposure pathways? It can be argued that facilities are designed to reduce or eliminate exposure of workers. For this reason, it is difficult to estimate worker exposure without either clearly established exposure pathways or information from personal dosimeters in the case of radiation exposure, or from industrial hygiene monitoring in the case of chemical exposures.

Once facilities are specified, existing data on similar facilities may be available to estimate likely exposure of workers by job category. In the absence of data, exposure limits specified by DOE orders, federal statutes, or facility exposure design limits can be used to establish maximum exposure. This is problematic in that other risks are based on average rates rather than on maximum exposures, and because there are sometimes lower administrative limits enforced.

Because of particular assumptions required to assess worker exposures, and because of the critical nature of this step, Section 4.3 discusses options for assessing worker exposures.

3.1.7 Health Endpoints

Various health endpoints must be considered in a risk assessment. These endpoints are indicators of effects from exposure. While it is desirable to combine all endpoints to get a single "risk," methods for combining, for example, numbers of deaths and numbers of diseases are problematic, and such diverse endpoints are reported separately.

Health endpoints considered in risk assessments should include the following:

- risks of fatal cancer from exposures during routine operation
- risks of accidental injury or death; these are of interest during construction, operation, and D&D
- transportation accidents, including injury or death, and exposures from accidental releases of hazardous substances during transportation
- fatal cancer risks from accidental releases of hazardous substances during routine operations
- risks of adverse reproductive outcomes
- risks of morbidity (primarily neurological or immunological impairment), including treatable cancer.

In the risk assessment example in this paper, only the first three health endpoints are included and are discussed in more detail in the next section.

3.1.8 Rate of Hazards

Many wastes included in process flow diagrams, or indicated as chemical process additives, have been identified as causing an increase in the incidence of some adverse health endpoint. Quantifying the relationship of exposure or dose and effect forms the basis for risk assessment.

In health risk assessment, the dose-response relationships, or hazards, are described by risk coefficients, which are analogous to the slope in a linear, no threshold (intercept) dose-response relationship. In many instances, information on dose-response is based on extrapolation from animals to humans and/or from high to low dose. The best risk estimates (including some dose-response relationships that are nonlinear) are produced from life-span animal or human epidemiologic studies using modern statistical methods for analysis (Gart et al. 1988). For other types of risks, historical data are used to estimate rates (e.g., transportation accidents and their consequences).

For exposures to mixed wastes, risk coefficients are assumed to be additive. Additivity is based on the assumption that the effects of exposure are independent. Additivity is frequently a conservative assumption that results in overestimates of risk, although certain counter examples exist (e.g., radon and cigarette smoke). Additional research is required to understand more about when the additivity assumption is reasonable and when it overestimates or underestimates risk.

Information on dose-response relationships for human risk from exposure to certain chemicals and radionuclides is available from the EPA IRIS database. These data include estimates of both cancer mortality and noncancer morbidity risks.

Risks of injury must be considered along with risks due to exposures to chemicals and radionuclides. Injury risks can be estimated on the basis of injury rates for similar occupational groups and rates from existing facilities at the Hanford Site. Because there has been limited construction at the Hanford Site in the recent past, construction risks (injuries and fatalities) should be based on other sources of information.

3.1.9 Risk Characterization

By knowing the kinds and amounts of wastes moving through a facility, processes involved, and chemicals used in processing, numbers of workers and their specific activities, and pathways of exposure, an exposure assessment can be conducted. Note that, on the basis of the discussion above, for some of these parameters, reports and documents are available that allow estimates to be made if one is willing to make various assumptions. This information, which completes the process of "exposure assessment" in the terminology of quantitative risk assessment, is then combined with data on rates of health and ecological risks to characterize the risks associated with a specific facility and waste stream. This is referred to as "risk characterization." The outcome is a quantified estimate of health and ecological risks.

A risk characterization must present and discuss assumptions that were used in conducting the risk assessment. The characterization must identify alternatives considered, basis of choice, and sensitivity analyses conducted to evaluate different alternatives and their impact. If appropriate, the basis for the assumptions should be given. This includes any values of variables and mathematical calculations that were used. Often, an assumption (e.g., water and food consumption) is vital to those using or adapting results.

A risk characterization is incomplete without an indication of uncertainty. In the future, such information will be incorporated into risk assessments of environmental restoration and waste management at the Hanford Site. Uncertainty information is important in use of risk assessment data in risk management for several reasons. Quantitative uncertainty information allows the conduct of rigorous statistical tests for differences in risks. It also allows a quantitative estimation of the value of additional data or of different assumptions. Qualitative uncertainty information allows the reader to interpret better the meaning of risk results. In both cases, uncertainty information allows judgement by the stakeholder or decision maker in interpretation and use of risk results.

3.2 OCCUPATIONAL HEALTH ENDPOINTS

In assessing worker risks from Hanford waste remediation activities, seven categories of worker risk are considered:

- accidents during facility construction
- routine radiological exposure during remediation operations
- routine hazardous chemical exposure during remediation operations
- injuries during remediation operations in the absence of radiation or hazardous chemical exposure
- accidents during remediation operations that result in exposure to radiation, hazardous chemicals, or mixed wastes
- accidents during transport activities in the absence of radiation or chemical exposure
- accidents during transport activities that result in exposure to radiation, hazardous chemicals, or mixed wastes.

We discuss each category in the following sections.

3.2.1 Facility Construction - Accidents Without Radiation or Chemical Exposure

Construction of a facility, roadway, or waste storage area involves an element of worker risk from dangers inherent in operation of heavy equipment, movement of building materials, fall hazards, spill hazards, etc. Because of this, there is a chance that workers will be injured or killed during a construction project. Information on the probability of injuries and deaths during large construction projects is available from various federal and state agencies and from labor unions. This information can be used to estimate risk to workers during construction of proposed waste remediation facilities. Such worker risks for serious injury and death will be evaluated for all major construction projects.

Accidents during construction activities may have more severe societal impacts than routine or accidental exposure to wastes. Injuries and deaths during construction accidents are immediate, as compared to a delayed impact from most routine or accidental exposures to radiation or hazardous chemicals. As a result, a worker injured during construction accidents, and his or her family, may suffer the consequences of such an injury for a longer period of time than a worker who develops an occupational-related illness after many years. Similarly, deaths from construction accidents tend to occur suddenly in contrast to the long latency period of deaths from occupational exposures to hazardous materials.

3.2.2 Remediation Operations - Routine Radiological Exposures

During remediation, workers may be routinely exposed to low levels of ionizing radiation. Radiation exposure will be monitored and operations will be conducted so exposure is "As Low As Reasonably Achievable (ALARA)." Although exposure limits establish an acceptably low level for worker risk, there is still some implied risk from radiological exposure.

Certain waste remediation options are associated with higher levels of worker exposure to ionizing radiation (this may involve higher average levels of exposure per worker or exposure to a greater number of workers). Potential benefits must be considered in light of the potential increased risk to workers during remediation activities.

3.2.3 Remediation Operations - Routine Hazardous Chemical Exposure

During remediation, workers may also be exposed to low levels of potentially hazardous chemicals. Volatile organic compounds, acids, bases, and other chemicals will be used routinely in processing of wastes. Although use of hazardous chemicals will typically be confined to environmentally isolated areas with limited workers access and with appropriate worker protection, there is a risk of worker exposure during routine transfer of chemicals and during addition and removal of chemicals from process streams.

Some systems being proposed for various waste remediation options involve the use and destruction of potentially hazardous chemical compounds within a sealed system (i.e., without routine venting to the atmosphere). Although such systems reduce risks of routine exposure, they may be so prohibitively expensive that financial resources may be better deployed to reduce risks in other areas. In such circumstances, low concentrations of hazardous chemicals may be released to the atmosphere following standard industrial procedures used by chemical manufacturing and processing industries. In such a situation, workers may be exposed to these low levels of chemicals as they work or travel outside of the facility. In addition, depending on the characteristics and locations of rooftop vents (or stacks), building air supply intakes, and local meteorological conditions, some exhaust chemicals could enter a facility's general air supply and circulate throughout the facility. Although guidelines and equipment exist to minimize the possibility for intake of air with low levels of hazardous materials, there is a likelihood that a low-level chemical exposure will occur to workers as exhaust material enters building air supplies.

Certain waste remediation options are associated with higher levels of worker exposure to hazardous chemicals (either higher average levels of exposure per worker or exposure to a greater number of workers). Benefits of a remediation activity must be weighed against this potential for increased risk to workers.

3.2.4 Remediation Operations - Injuries in the Absence of Radiation or Chemical Exposure

Operation of any waste remediation facility or process involves a certain element of worker risk from dangers inherent in operation of machinery and heavy equipment, power supplies, steam lines, fall hazards, spill hazards, and travel within and between facilities. Because of this, there is a small probability that workers will be injured or killed during various aspects of a waste remediation operations, even in the absence of exposure to radiation or hazardous chemicals. Information on the probability of injuries and deaths that can occur during these operations can be obtained by comparison with accident statistics for comparable facilities.

Worker risk during some higher risk remediation activities (i.e., operation of heavy equipment) may be a tolerated part of the job; however, actions are required to minimize such risks and to reduce the potential severity of job-related injuries. Worker risk due to industrial accidents needs to be assessed to identify potential risk reduction activities or to select remediation options that involve less risk.

3.2.5 Remediation Operations - Accidents that Result in Radiation, Hazardous Chemical, or Mixed Wastes Exposure

During waste remediation operations, workers may routinely be exposed to low levels of ionizing radiation, hazardous chemicals, or combinations of these. In addition, certain accident scenarios may expose one or more workers to high levels of radiation, hazardous chemicals, or mixed wastes that could result in an increased lifetime cancer risk, illness, sudden injury, or death. Operational procedures, equipment, and safety devices are designed to minimize the probability of such exposures, but certain remediation activities have a risk of accidental exposure that can not be eliminated. The probability of various accident scenarios and worker health implications of these accidents must be assessed to quantify worker risk properly.

3.2.6 Transport Activities

Some waste remediation activities will involve transfer of wastes and other chemicals from facility to facility. Some transport pathways are between adjacent facilities or use sealed systems that virtually eliminate the potential for exposure to workers of radioactive or hazardous compounds. Other transport pathways use rail or truck transportation.

Although accident rates during transportation are generally low, risk data for transportation accidents are included in the overall assessment of risks associated with waste remediation activities. Transportation accidents, independent of any exposure to radioactive or hazardous chemicals, have an associated probability that workers will be injured or killed. Similarly, risks from exposure of workers during transport activities are included. Transport accidents that would expose workers to ionizing radiation, hazardous chemicals, or mixed wastes also have a finite associated probability. By identifying transportation risks, steps can be taken to optimize risks or select alternatives with lower risks.

3.3 OCCUPATIONAL EXPOSURE ASSESSMENT

Collective occupational dose projections for a facility are determined by the level of detail and amount of data available on the process or activity conducted in the facility, including

- existing facilities and processes or proposed modifications to existing facilities and processes
- proposed new facilities or processes similar to existing ones

- new facilities and processes significantly different from existing ones.

Each of these is discussed in the following sections.

3.3.1 Existing Facilities and Processes or Proposed Modifications to Existing Facilities and Processes

If a facility has actual occupational exposure data from operations, these data would be used as an initial input for occupational exposures from future operations. When analyzing these data, the level of activity or concentrations and operating history would be compared to the proposed activity. Staffing levels, unique characteristics of operating campaigns, and major modifications would be considered. For radiation, the collective dose projection would also consider the likelihood that individual occupational radiation dose limits will be reduced from the existing 5 rems per year to 2 rems per year. Reductions in individual occupational dose limits and a design objective of maintaining individual doses to less than 500 mrem per year could affect the staffing levels of the facility. Similar considerations would be made for chemicals.

In the case of an existing facility, Safety Analysis Reports (SARs) and Environmental Impact Statements (EISs) are good sources of information. Radiological design reviews provide information on design dose rates, occupancy factors, and frequency of activities such as filter changes. Similar reviews provide information on chemical exposure information. Flow procedures, if available, would also be useful in identifying significant sources of occupational dose and opportunities for collective dose reduction.

For radiation, an approach similar to the one outlined in U.S. Nuclear Regulatory Commission Regulatory Guide 8.19, Occupational Radiation Dose Assessment in Light-water Reactor Power Plants - Design Stage Man-rem Estimates (NRC 1979) would be used to project occupational collective dose.

3.3.2 Proposed New Facilities or Processes Similar to Existing Ones

Without detailed design information for proposed and existing facilities or processes, it would be necessary to identify similar processes or facilities (i.e., a reference facility or process) to be used as a surrogate. Then, occupational collective dose projections in the EIS would be used as a first approximation. These projections could be modified to take into account differences in throughput, size, or other characteristics between the reference facility or process and the proposed one.

3.3.3 New Facilities and Processes Significantly Different from Existing Ones

It would be difficult to perform meaningful dose projections for workers in facilities or processes for which there is no reference case. Such facilities or processes would be evaluated to identify basic hazards and the level of design (e.g., shielded remote versus unshielded) required to assure worker safety.

The proposed approach uses the facility or process source term (i.e., amounts of radioactive or chemical material present) and determines a hazard level based on risk potential.

Potential for external radiation exposure could be based on source-term strengths for radionuclides and a "workload" concept such as NCRP Report 49 on x-ray shielding (NCRP-49 1976). Both quantities are essentially dose-rate-at-a-unit-distance quantities (e.g., rems per hour at one meter). External radiation exposure risk could be characterized by expressing inventories of radionuclides using a system such as the Department of Transportation and International Atomic Energy Agency A_1 system (DOT 1991), including Type A quantities, Type B quantities, and Highway Route Controlled Quantities. Ratings from these systems could be modified based on potential breaches of shielding, procedures, use patterns, etc. for radiation exposure.

Internal radiation exposure risk could be expressed in terms of the annual limit on intake (ALI) as described in ICRP 30. The ALI, a unit of radioactive material which, if taken into the body through occupational routes of exposure, corresponds to a committed effective dose equivalent of 5 rems, allows for the meaningful comparison of radionuclides with significantly different radiotoxicity. ALIs as modified by dispersibility, chemical form, and "high energy" conditions could be used to represent internal exposure risk. "High energy" conditions include the presence of explosives, compressed gases or steam, combustible materials, earthquakes, or severe weather.

4.0 COMPARISON OF RISKS FOR DIFFERENT REMEDIATION STRATEGIES AND OPTIONS: AN ILLUSTRATION USING WORKER RISKS FOR PROCESSING OF N/K FUEL

The following is a quantitative example of assessing occupational risks for N/K fuel. Results are based on numerous assumptions and absolute risk estimates should be viewed from that perspective. Comparative results are likely more meaningful, although even these ratios are highly dependent on assumptions and should be interpreted with caution.

The N/K fuel example is intended to illustrate a process and the resultant products. The example is intended to demonstrate an approach to assessing risk in the absence of exposure information and is expected to be revised when additional information becomes available, particularly exposure information.

4.1 OVERVIEW OF NUCLEAR MATERIALS MISSION AREA AND N/K FUEL WASTE STREAM

The nuclear materials mission area includes separated radionuclides stored onsite. Nuclear materials were subdivided based on anticipated physical attributes associated with cleanup activity processing: irradiated fuel, special nuclear material, unirradiated uranium, and cesium/strontium capsules. The irradiated fuel category includes N/K fuels in interim storage at five sites on the Hanford Site: N-reactor fuel at the 100-Area basins, fuel from the K-reactors at the PUREX plant, Fast Flux Test Facility (FFTF) fuel at the FFTF, and Pressurized Water Reactor (PWR) Core 2 fuel at the 2-T plant.

N/K Fuels represent the residual inventory of unprocessed irradiated production reactor fuel that continues to be stored at the Hanford Site. This is a subset of the total onsite inventory of irradiated fuel, excluding irradiated fuels from operation of the Fast Flux Test Facility, Shippingport Test Reactor, and other sources. Production reactor fuels are basically uranium metal slugs clad in either zircalloy or aluminum, depending on the reactor source. The vast majority of residual fuel results from past operation of N-Reactor.

N-Reactor fuel is uranium metal clad in zircalloy. The fuel assembly has the appearance of two concentric, heavy walled tubes with an outside diameter of 2.4 in. and approximately 2 ft long. It should be noted that residual production reactor fuel is distinctly different in configuration and physical form from typical commercial reactor fuel. However, basic characteristics associated with an irradiated uranium fuel are exhibited by the fuel. Therefore, production reactor fuel has some similarities and marked differences when compared with commercial fuel.

Shippingport fuel generally consists of uranium oxide pellets pressed into Zircalloy metal plates and clad in Zircalloy. FFTF fuel is composed of pellets formed from a mixture of uranium and plutonium oxides and clad in stainless steel tubes.

Fuel is currently stored in canisters located in basins within the 100 Areas at Hanford and will require transportation for remediation. Storage canisters are maintained underwater to provide cooling for the radioactivity and shielding for storage areas which must be entered by operating personnel.

4.2 OVERVIEW OF OPTIONS 2 AND 3 FOR N/K FUEL

The example selected for illustration focuses on selected aspects of occupational health risks associated with processing of N/K fuels via strategy IX, options 2 and 3 of the Hanford Strategic Analysis Study. Strategy IX is the 200 Area disposal strategy, in which the 200 Area will remain an exclusive use zone, and many of the areas outside the 200 Area will be cleaned up for less restrictive uses. In this strategy, wastes within the 200 Area will be considered for either retrieval and processing or for in situ treatment and disposal. Waste from outside of the 200 Area will be retrieved, processed, and disposed of offsite or within the 200 Area exclusion zone. There are three possible options for implementing this strategy; the middle- and higher-cost options (referred to as options 2 and 3, respectively) are compared in our illustration.

In addition, in this example we consider only three sources of occupational risk:

- construction and operational lost workday injuries and fatalities
- routine exposure to radiation during testing and waste processing and during subsequent facility decommissioning and decontamination

- transportation lost workday injuries and fatalities during waste processing.

This limited assessment is intended to illustrate an approach and should not be mistaken for a comprehensive assessment of integrated risk (or even a comprehensive assessment of occupational health risk). At this time, the focus is limited because information required for a more comprehensive assessment of risk is not yet available. Work is being conducted to fill existing information gaps, including information on:

- design and staffing of processing facilities
- processes within facilities
- amount and procedure for handling processing chemicals at facilities
- safety and environmental emissions systems to be employed at facilities
- projected accidental release scenarios and associated environmental pathways.

Alternatives for remediation of N/K fuel that are evaluated in the process flow diagrams are designated as option 2 and option 3. Option 2 prescribes the oxidation of N/K fuel, followed by packaging for repository disposal. Shippingport (PWR Core 2) and FFTF fuel are packaged directly for disposal (strategy IX, option 2). In option 3, all fuels are reprocessed, separating uranium and plutonium and disposing of the reprocessing wastes (i.e., future tank wastes) along with similar wastes existing elsewhere at the Hanford Site. Recovered uranium and plutonium are added to existing inventories for disposition (strategy IX, option 3). Both scenarios require that irradiated fuel be transported from its current location (K basins, FFTF, and T Plant for the Shippingport irradiated fuel) to the Remote Material Processing Facility (RMPF).

Fuel cladding removal and oxidation processes in option 2 have not been specified. The principal public dose contribution during this operation would result from the release of ^{85}Kr. The public dose and associated health risks would be evaluated using source term data for irradiated fuel, historic meteorological data, and atmospheric dispersion models used at the Site.

The fuel reprocessing in option 3 would be performed using a facility similar to the existing PUREX plant. If PUREX were identified as the RMPF, modifications similar to the Process Facility Modifications package would be required to accommodate FFTF and Shippingport fuels and to enhance reliability and performance of RMPF. As in option 2, the principal public dose would result from the release of ^{85}Kr. The reprocessing option would allow recovery of uranium and plutonium and fractionation of other wastes for treatment.

4.3 SOURCES OF WORKER EXPOSURE IN N/K FUEL PROCESSING

This section illustrates assumptions that are expected to be made for assessing risks from radiation, chemicals, and radionuclides in the future. The information is illustrative of the analysis and resulting assumptions that are expected to be used: such an analysis was not used in the N/K fuels example because the remediation process steps are not specified well enough currently.

4.3.1 Radiation

For radiation, most likely sources of worker exposure in environmental restoration are routine exposure in shielded facilities. Exposure at certain points in a facility may be higher depending on the shielding at that point. For instance, the shielding might be light at pipe jumper connection boxes. Workers standing at these locations could receive a higher exposure. Workers standing near cross-Site transfer lines are also more likely to receive a higher dose. The potential exposure illustrated by the two situations is usually minimized through administrative procedures.

The highest exposures are likely to occur during transport and transfer of wastes into and out of a facility. For instance, transporting a cask containing spent N/K fuel might mean a slightly higher radiation dose to those working around the cask and on the truck/train on which the cask is transported. Depending on how transfer of the fuel from the cask to the hot cell is made (remote versus semi-remote), workers may receive higher-than-average doses.

4.3.2 Chemicals

For chemicals, minimal exposure is expected under normal plant operation. However, leaking solvent transfer lines from tank cars to in-plant tanks may cause exposure to solvents. Generally, these solvents have high toxicity thresholds. Likely solvents are TBP, straight chain paraffin hydrocarbons (with more than nine carbons in the chain), etc. Solvents such as CCl_4 are no longer used in these plants.

Exposure to other chemicals is likely to be very low, and handling chemicals such as $NaNO_3$ and $NaNO_2$ does not represent a high toxicity danger. These chemicals are more of a concern in the environment because of ingestion. Most of these chemicals will be radioactively contaminated and, thus, will be handled only remotely. Only an accident will cause contact.

4.3.3 Radionuclides

Exposure to radionuclides is likely only in accident scenarios. For instance, during oxidation of the fuel, there will be chances for exposure (inhalation) if the filter system fails. However, while the HEPA filters and scrubbers have high efficiencies, some wastes that are supposed to be stopped are allowed to escape. Gaseous radionuclides such as ^{14}C, ^{129}I, ^{85}Kr, etc. in low concentrations may be released to the atmosphere and become diluted.

Decontaminated solutions being converted to grout contain all of the $NaNO_3$ and $NaNO_2$, so there is little risk of human exposure. The main ecological risks are from grout vault failure (>1000 years), pipeline breaks, and spills.

When process water or waste water is released to the environment, the contaminants will only be in concentrations below regulatory drinking water concentrations. The radionuclides are likely to be about $4 \cdot 10^3$ Bq/mL (100 nCi/mL).

4.4 PERSON-YEAR ESTIMATES FOR CALCULATING RISKS FOR N/K FUEL PROCESSING OPTIONS

In this section, numbers of workers at risk are estimated based on information from the Hanford Strategic Analysis study. The unit employed is person-years. One person-year can be the exposure of one person for one year, 12 people for one month, or 365 people for one day. Numbers of workers (or manual workers) at risk are estimated at the facility level without accounting for specific types of work to be performed. More specific information will be used when it becomes available.

To estimate manual worker health risks associated with the N/K irradiated fuel waste stream for strategy IX, options 2 and 3, it is necessary to know numbers of manual workers at risk for each option during construction, testing, operation, deactivation, and site restoration. No estimates of the number of manual workers at risk are currently available. Thus, to demonstrate the process of comparing health risks between two remediation options, estimates of numbers of manual workers at risk are based on process flow diagrams and cost information developed for each facility.

An estimate for the total number of manual person-years required to construct a facility was calculated by multiplying the capital cost of a facility times the proportion of that cost that is labor, times the proportion of the labor cost that is manual labor, and dividing this product by the labor cost per year for a manual worker. Then an estimate of total numbers of manual person-years for the N/K irradiated fuel stream was calculated by multiplying total numbers of manual person-years for that facility times the proportion of the total feed material that is N/K irradiated fuel. That is,

$$p * \frac{C_1 * f_1 * f_2}{C_2}$$

where C_1 = facility cost, C_2 = cost per person year of labor, f_1 = fraction of cost that is labor, f_2 = fraction of labor that is manual labor, and p = proportion of total feed material to the facility that was associated with N/K fuels. Total person-year estimates for the lifetime operation of the facility, deactivation, and site restoration were calculated by the same method, but lifetime operating cost, deactivation cost, or site restoration cost was used instead of capital cost. Annual manual person-years for each phase of a facility were calculated by dividing total numbers of manual person-years by total numbers of years for that phase.

Manual person-year estimates were calculated for N/K irradiated fuel stream facilities identified on process flow diagrams for strategy IX, options 2 and 3. Option 2 capital and operating costs, and the number of years for construction, operation, testing, deactivation, and site restoration used in the person-year calculations, were from the facility specification sheets.

Option 2 costs are unavailable for testing, deactivation, or site restoration. For years that testing overlapped construction, no costs were added for testing. Costs used for the one testing year between construction and operation were assumed to be equal to the annual operating cost. Total cost for deactivation and site restoration was assumed to be 10% of the capital cost of the facility (R.C. Hoyt, Westinghouse Hanford Company, Personal Communication). Labor costs for a manual laborer were assumed to be $120,000 per year (R.C. Hoyt, Westinghouse Hanford Company, Personal Communication). This cost is based on a fully-burdened labor cost of $62.50 per hour, assuming a 40-hour work week for 48 weeks a year and includes costs for vacation, holidays, and sick days.

Costs for option 3 are unavailable. Thus, it was assumed that costs for facility 2 in option 3 increased by a factor of 10 times over the costs of option 2 and that costs of all other facilities remained the same as option 2 (R.C. Hoyt, Westinghouse Hanford Company, Personal Communication). It was also assumed for option 3 that construction of facility 1 was delayed for six years so that the operation of Facilities 1 and 2 started at the same time (A.L. Pajunen, Westinghouse Hanford Company, Personal Communication).

The proportion of capital and operating costs that were labor, and the proportion of labor costs that were manual labor, were assumed to be the same as reported for similar facilities (DOE/MA-0063 1982). Proportions for a liquid water reactor spent fuel reprocessing facility were used for shielded facilities, and proportions for a uranium conversion facility were used for non-shielded facilities.

The proportion of total feed materials from the N/K irradiated fuel stream was calculated from information on facility specification sheets and summary data sheets. Total feed material for each facility for strategy IX, option 2 was reported on facility specification sheets. The amount of N/K fuel that feeds into a facility was reported on N/K fuel summary data sheets for options 2 and 3. The calculation of the proportion for option 2 was straight forward, but the calculation for option 3 was not. Facility specification sheets for option 3 that provide information on total feed material have not been completed. Thus, total feed material for option 3 was calculated by subtracting the amount of N/K material in feed streams for option 2 from the option 2 total and then adding the amount of N/K material in feed streams for option 3.

Tables B.1 and B.2 in Appendix B summarize information used to calculate person-years for each facility for strategy IX, options 2 and 3, respectively. Person-years per year for each facility for the N/K irradiated fuel stream are given in Tables B.3 and B.4 for strategy IX, options 2 and 3, respectively.

4.5 INJURIES DURING THE CONSTRUCTION OF N/K FUEL PROCESSING FACILITIES

Risk estimates for injuries were derived from estimates of person-years of manual labor for each facility in the N/K fuel pathways in strategy IX, options 2 and 3. Annual numbers of person-years of labor during construction were multiplied by the incidence rate for lost workday injuries for 1990 (6.9/100 full-time workers) for nonresidential building construction from U.S. Department of Labor, Bureau of Labor Statistics reports (DOL 1992). This provides an estimate of lost workday injuries for each year of the construction phase of each facility for N/K fuel remediation as shown in Table B.5 in Appendix B.

Estimated fatalities associated with each option were based on the total number of person-years for all facilities. The rate used to estimate construction fatalities was the NIOSH construction mortality rate for Washington State for 1980-85 (NIOSH 1989) for all construction occupations (23.7/100,000 person-years). Because of low occupational fatality rates and lack of actual staffing information, it was not considered appropriate to generate an annualized risk.

When projections are available for staffing of each facility, it will be possible to generate estimates of both lost workday injuries and injury-related fatalities by job code during the construction phase.

4.6 INJURIES DURING N/K FUEL PROCESSING (NO ACCIDENTAL RELEASES)

Risk estimates for lost workday injuries were derived from estimated numbers of person-years of manual labor for each facility in the N/K fuel remediation pathways in strategy IX, options 2 and 3. Annual numbers of person-years of manual labor during the operational phase were multiplied by the incidence rate for lost workday injuries for 1990 for manufacturing chemicals and allied products (2.9/100 full-time workers) from U.S. Department of Labor, Bureau of Labor Statistics reports (DOL 1992). This provides an estimate of numbers of injuries that would result in lost workdays for each year of the operational phase of each facility for N/K fuel pathway, given in Table B.6 in Appendix B.

Estimated fatalities associated with each option were based on total numbers of person-years for all facilities. The rate used to estimate fatalities during operations was the NIOSH mortality rate for Washington State for 1980-85 (NIOSH 1989) for all manufacturing occupations (9.7/100,000 person-years). Because occupational fatality rates due to injuries are so low, it was not considered appropriate to generate an annualized risk.

When projections are available for actual staffing of each facility, it will be possible to generate estimates of both lost workday injuries and injury-related fatalities by job code for the operational phase of facilities.

4.7 FATAL LIFETIME LOW-LET CANCER ESTIMATES FOR N/K FUEL PROCESSING OPTIONS

Estimates of numbers of lifetime low-LET (linear energy transfer) fatal cancers were calculated for each facility in the N/K remediation pathway for strategy IX, options 2 and 3. The estimate for each facility was calculated by multiplying a radiation fatal cancer rate factor of 1.5×10^{-5} times person-years of manual labor estimated for each facility. The estimated cancer fatality rate from radiation doses received at DOE facilities is 1.5 per 100,000 (DOE/EH-0171P 1990). This estimate is based on age- and sex-specific risk equations provided in the BEIR V report (NAS 1990). These equations were based primarily on Japanese A-bomb survivor data on risks from acute exposures. The BEIR V committee recognized the need to apply a dose rate effectiveness factor for chronic exposures, which would reduce the risk estimate by a factor of at least two.

Estimated cancer fatalities by facility for options 2 and 3 are listed in Table 4.1. The estimated total numbers of cancer fatalities associated with the 10 years of operations are 0.48 for option 2 and 6.5 for option 3. Therefore, the estimated radiation cancer risk is a factor of 14 higher for

Table 4.1. Fatal lifetime cancers by facility for N/K fuel---strategy IX, options 2 and 3

Option 2		Option 3	
Facility	Fatal Lifetime Cancers	Facility	Fatal Lifetime Cancers
		1	6.2×10^{-3}
2	1.7×10^{-2}	2	1.7×10^{-1}
3	1.7×10^{-5}	3	8.9×10^{-3}
4	1.1×10^{-5}		
5	1.0×10^{-4}	5	3.2×10^{-2}
6	1.0×10^{-5}	6	2.0×10^{-6}
8	1.0×10^{-6}	8	6.0×10^{-6}
10[1]		10	1.0×10^{-6}
		11[2]	
13[1]		13[3]	0.2×10^{-6}
15	1.2×10^{-3}	15	1.0×10^{-2}
Total	1.8×10^{-2}	Total	2.3×10^{-1}

[1] No estimate of N/K fuel feed material
[2] No estimate of total feed material
[3] Existing facility

option 3 than for option 2. Total estimated cancer fatalities for the deactivation phase could be calculated by the same method.

When projections are available for staffing of each facility, it will be possible to estimate radiation doses by facility and occupational category. These radiation doses, along with cancer risk factors for fatal lifetime cancers per person per rem, will be used to estimate the number of fatal lifetime cancers. Use of a risk factor that does not incorporate exposure information is not recommended. However, in the absence of information other than the current annual occupational exposure limit, this was the best approach available for illustrative purposes.

We investigated the alternative of assuming a 500 mrem exposure to each worker, effectively a maximum allowable exposure, in combination with a risk factor that incorporates exposure. The result was inconsistent with other results that instead made use of average risks.

4.8 ACCIDENTS DURING N/K FUEL TRANSPORTATION (NO ACCIDENTAL RELEASES)

This section presents the bases, approach, and results of transportation risk calculations. Two categories of transportation impacts on workers were estimated:

- Routine radiological impacts on workers: routine radiological doses to workers (truck and rail crew members) when shipments of radioactivity reach their destinations without releasing package contents.
- Nonradiological Impacts from Accidents on Workers: nonradiological risks to truck and rail crews from vehicular accidents. These impacts are not related to the radiological nature of the cargo.

These categories estimate health impacts from transport of materials over roadways and rail lines. Impacts associated with loading and handling of shipping containers are excluded. Impacts associated with transport of various materials between facilities by pipeline were quantified above.

4.8.1 Bases and Approach

A unit risk factor approach was developed for this analysis. In this approach, unit risk factors were used to represent the risk per unit distance of travel for each transportation category. For example, radiological risk factors are given in units of radiological fatalities per km. For a given category, the total risk for each waste type is the product of the unit risk factor, the shipping distance, and the total number of shipments. The total risk for a given option is the sum of the risks for each waste type:

$$R_i = \sum_m U_{i,m} * D_m * N_m$$

where:
R_i = risk impact for transportation category i
$U_{i,m}$ = unit risk factor for category i and material m
D_m = shipping distance for material m
N_m = number of shipments of material m.

Data used in these calculations are presented below.

Shipment Data, Option 2: Irradiated fuels were assumed to be shipped by rail from their present locations to an onsite remote material processing facility (RMPF) located in the 200 East Area. After processing, irradiated fuels were assumed to be transported by rail a short distance to a remote handled waste storage/shipping facility, then shipped by rail to an offsite location for disposal. Decontamination solutions generated in the processing facility were assumed to be transported by pipeline to waste storage tanks to await further processing. Low-level solid wastes (LLW) generated at the processing facility were assumed to be shipped by truck to a LLW storage facility in the 200 West Area and then transported by truck to the Hanford Site LLW disposal facility.

Total numbers of shipments of material were estimated by dividing the total quantity of each material by the cargo capacity of vehicles or containers transporting the material. The capacity of rail shipping containers was assumed to be 4.3 metric tons uranium (MTU) per shipment, based on capacities of existing shipping casks for commercial irradiated fuel assemblies. The capacity of packaged fuel shipping containers was also assumed to be 4.3 MTU/shipment. All LLW were assumed to be loaded into Hanford Site general purpose burial boxes having a capacity of about 43 m^3 (1520 ft^3). Each truck shipment was assumed to contain one box. Total numbers of LLW shipments was calculated by dividing the total LLW waste volume by 1520 ft^3/shipment.

Quantities of material to be transported in this option were taken from process flow diagrams and mass balance charts. Quantity information, shipping cask capacities, and numbers of shipments of each material are presented in Table 4.2. As shown, this option involves transport of irradiated fuels and packaged fuels only. LLW generation rates at processing facilities resulting from processing of irradiated fuels were indicated to be negligible (these facilities will generate significant quantities of LLW, but the portion generated during processing of irradiated fuels was indicated to be negligible). Other materials, such as decontamination solutions, evaporator bottoms from water treatment, and grout, were assumed to be transported between facilities by pipeline.

Table 4.2. Shipment data for irradiated fuel---option 2

Material	Quantity	Shipment Capacity	Total Shipments	Shipping Distance, km
N/K Fuel	2000 MTU	4.3 MTU	435	32
PWR Fuel	100 MTU	4.3 MTU	22	11
Packaged Fuel	2100 MTU	4.3 MTU	457	64

Shipping distances for various materials are also presented in Table 4.2. The shipping distance between the Hanford 100 Areas (location of N/K fuels) and the RMPF, assumed to be located in the 200 East Area, was estimated to be 32 km (20 mi). The shipping distance between the 200 West Area (location of PWR fuel) and the RMPF was estimated to be 11 km (7 mi). The shipping distance for offsite rail shipments was assumed to be 4800 km, representative of the distance used in the HDW-EIS (DOE 1987). The analysis stops at the Hanford Site boundary or approximately 64 km (40 mi) from the 200 East Area.

Shipment Data, Option 3: Irradiated fuels were assumed to be shipped by rail from their present locations to an onsite RMPF located in the 200 East Area. Fuels will be reprocessed at this facility to reclaim valuable materials. This facility will generate high-level liquid wastes, LLW, transuranic (TRU) wastes, uranium, and special nuclear materials (SNM) such as plutonium. Transport of these materials is described below:

- HLW and decontamination solutions were assumed to be transported by pipeline to underground storage tanks. These wastes were assumed to be transported ultimately by pipeline to a waste vitrification and packaging facility where they will be incorporated into a glass matrix, packaged in canisters, and transported offsite.
- LLW generated at the fuel reprocessing facility was assumed to be shipped by truck to a LLW storage facility in the 200 West Area and then transported by truck to the Hanford Site LLW disposal facility.
- Cold uranium oxide generated at the RMPF was assumed to be transported by truck to a cold uranium processing facility assumed to be located in the 200 East Area.

- SNM was assumed to be transported by truck from the RMPF to a SNM shipping and storage facility. There, the SNM was assumed to be stored in a secure facility until it is shipped to an offsite location.

Shipping data for option 3 are presented in Table 4.3. As with option 2, numbers of shipments of material types were calculated by dividing the total quantity of each material generated by the estimated shipment capacity for each material. The quantities of each material generated were taken from information provided by WHC.

Shipping distances for various materials and transport segments are shown in Table 4.3. The shipping distance between the 200 East and 200 West Area facilities was estimated to be about 11 km (7 mi); the distance between the 200 West Area LLW storage facility and the disposal facility also located in the 200 West Area is estimated to be less than 1.6 km (1 mi). The SNM storage facility and the waste vitrification and packaging facility are assumed to be located in the 200 East Area. The LLW packaging facility is assumed to be located in the 200 East Area. The remaining LLW management facilities, including storage and disposal facilities, are assumed to be located in the 200 West Area.

Table 4.3. Shipment data for irradiated fuel---option 3

Material	Quantity	Shipment Capacity	Total Shipments	Shipping Distance, km
N/K Fuel	2000 MTU	4.3 MTU	435	32
PWR Fuel	100 MTU	4.3 MTU	22	11
LLW to Pkging Fac.	21.7 m^3	43 m^3	1	1.6
LLW to Storage Fac.	21.7 m^3	43 m^3	1	1.6
LLW to Disposal	21.7 m^3	43 m^3	1	1.6
HLW	53260 m^3	3.1 m^3	17181	64
SNM	12.88 m^3	0.13 m^3	99	1.6
U Oxide	19170 m^3	43 m^3	446	1.6

Unit Risk Factors: Unit risk factors represent the incremental risk for transporting the various material a unit distance. These factors were derived from a number of sources. The basic approach was to divide the total projected impacts (radiological latent health effect [LHE, includes fatal lifetime cancers and genetic effects in all generations], nonradiological injuries, or nonradiological fatalities) given in source documents by the total shipping distance to arrive at the unit risk factors (LHE, injuries, or fatalities per km). Some adjustments were necessary to account for different shipping distances. Unit risk factors are also available for use directly in some documents.

Unit risk factors for irradiated fuel shipments were taken directly from Cashwell, et al. (1986, pp. 165-168). These values are assumed to apply to both bare (unprocessed) fuel assemblies and packaged fuels. Unit risk factors for remaining materials were taken from Wolf (1984, pp. 31-33). It was necessary to convert values given by Wolf from units of person-rem/km to LHE/km. The conversion factor used was 2E-4 LHE/person-rem. Unit risk factors are shown in Table 4.4.

4.8.2 Calculations

Results of transportation impact calculations for irradiated fuels options 2 and 3 are presented in Table 4.5. Impacts in each risk category are shown in the table for each material.

Table 4.4. Worker Unit Risk Factors[1]

	UNIT RISK FACTORS, per km						
Risk Category	N/K Fuel	PWR Fuel	Packaged Fuel	LLW	Vitrified HLW	SNM	Uranium Oxide
Radiological Routine							
LHE/km	2.0E-09	2.0E-09	2.0E-09	6.0E-09	2.0E-09	9.1E-09	1.00E-10
Nonradiological							
Fatalities/km	1.8E-09	1.8E-09	1.8E-09	3.7E-09	1.8E-09	3.7E-09	3.70E-09
Injuries/km	2.5E-07	2.5E-07	2.5E-07	1.3E-08	2.5E-07	1.3E-08	1.30E-08

[1]Sources of unit risk factors include Cashwell, Neuhauser, et al. (1986) and Wolf (1984).

Table 4.5. Results of transportation impact calculations for irradiated fuels---options 2 and 3

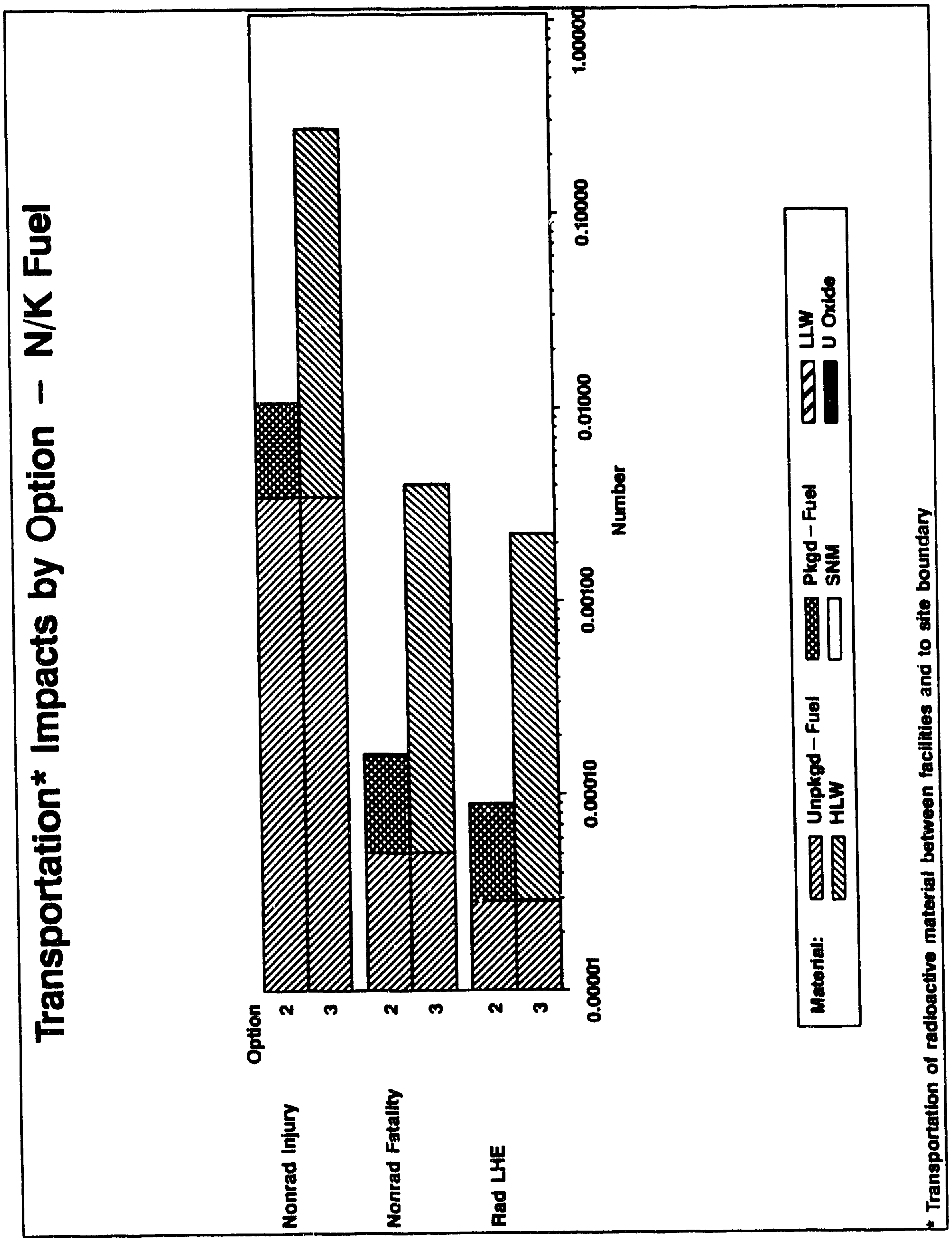
Risk Category	Material					
OPTION 2	Unpackaged Fuel	Packaged Fuel	Total			
Radiological Routine LHEs	2.9E-05	6.0E-05	8.9E-05			
Nonradiological Fatalities Injuries	5.1E-05 3.5E-03	1.1E-04 7.2E-03	1.6E-04 1.1E-02			
OPTION 3	Unpackaged Fuel	LLW	HLW	SNM	Uranium Oxide	Total
Radiological Routine LHEs	2.9E-05	7.8E-08	2.2E-03	1.4E-06	7.1E-08	2.3E-03
Nonradiological Fatalities Injuries	5.1E-05 3.5E-03	9.6E-08 6.3E-08	4.0E-03 2.7E-01	1.2E-06 2.1E-06	5.3E-06 9.3E-06	4.0E-03 2.7E-01

Transportation impacts resulting from implementation of option 2 are dominated by nonradiological accidents. This is also true for option 3. This demonstrates that nonradiological impacts are significantly higher than radiological impacts of transporting materials for the two options.

Transportation impacts calculated for option 2 are dominated by transport of bare N/K fuel and packaged fuel elements. No other materials are transported in significant quantities in this option. The impacts associated with option 3 are dominated by transport of HLW canisters. Transport of bare N/K fuel also forms a significant fraction of the total impacts of option 3.

Figure 4.1 compares transportation impacts associated with the two options. As shown, impacts of option 3 are larger than impacts associated with option 2. This is primarily because HLW canisters are transported in option 3 but not in option 2.

Figure 4.1. Transportation impacts for option 2



4.9 COMBINING RESULTS FOR VARIOUS HEALTH ENDPOINTS

Estimates of worker risk for the N/K fuel stream were added across construction and operation phases for each facility within an option and then totaled. Injury fatalities during construction and operation were added to operational fatal lifetime cancers and transportation LHEs. Although LHEs and fatal lifetime cancers are not exactly equivalent, the LHEs were added to fatal lifetime cancers because the major proportion of the LHE is due to fatal lifetime cancer. Construction, operation, and transportation lost-workday injuries were added together. These worker risks (expressed in terms of numbers of fatalities and lost workday injuries) are presented in Tables 4.6 and 4.7, respectively.

Risks for option 3 are significantly higher than for option 2; that is, reprocessing has greater risks than does repackaging. The total number of fatalities for option 3 is 3.7 compared with 0.25 for option 2, about a 15:1 ratio. The total number of lost workday injuries for option 3 is 1025 compared with 69 for option 2, also about a 15:1 ratio.

The magnitude of these ratios is driven by the assumption that costs for facility 2 in option 3 are a factor of 10 greater than costs for facility 2 in option 2. Nevertheless, these results demonstrate important aspects of the risk assessment process. These aspects are more easily seen when the data are presented in a bar chart.

Figures 4.2 and 4.3 show the comparison between options 2 and 3 by major facilities and transportation of material between facilities for fatalities and lost workday injuries, respectively. These figures indicate the facilities with the greatest worker risks. Clearly, if option 3 is chosen for remediating N/K fuels, facility 2 needs to be designed with the most emphasis on occupational health and safety. The figures also show the contribution of each phase (e.g., construction) to total worker risks. Risks from construction and from operation are similar. Another important conclusion is that risks of death from occupationally induced cancer are small compared with risks of fatality from accidents.

Table 4.6. Fatalities for N/K fuel---strategy IX, options 2 and 3

		Construction	Operation		Transportation		
Option	Fac	Injury Fatalities	Injury Fatalities	Fatal Lifetime Cancers	Injury Fatalities	LHEs	Total
2	2	1.1×10^{-1}	1.1×10^{-1}	1.7×10^{-2}			2.3×10^{-1}
	3	2.9×10^{-4}	1.1×10^{-4}	1.7×10^{-5}			4.2×10^{-4}
	4	2.0×10^{-4}	7.2×10^{-5}	1.1×10^{-5}			2.8×10^{-4}
	5	2.2×10^{-3}	6.5×10^{-4}	1.0×10^{-4}			3.0×10^{3}
	6	6.5×10^{-5}	6.4×10^{-5}	1.0×10^{-5}			1.4×10^{4}
	8	8.0×10^{-6}	5.0×10^{-6}	1.0×10^{-6}			1.4×10^{-5}
	10[a]						
	13[a]						
	15	8.2×10^{-3}	8.0×10^{-3}	1.2×10^{-3}			1.7×10^{2}
	Total	1.2×10^{-1}	1.2×10^{-1}	1.8×10^{-2}	1.6×10^{-4}	8.9×10^{-5}	2.5×10^{-1}
3	1	4.3×10^{-2}	4.0×10^{-2}	6.2×10^{3}			9.0×10^{-2}
	2	1.1	1.1	1.7×10^{-1}			2.3
	3	1.5×10^{1}	5.7×10^{-2}	8.9×10^{3}			2.2×10^{1}
	5	6.9×10^{-1}	2.1×10^{-1}	3.2×10^{-2}			9.3×10^{-1}
	6	1.5×10^{-5}	1.5×10^{-5}	2.0×10^{-6}			3.2×10^{-5}
	8	6.9×10^{-5}	4.2×10^{-5}	6.0×10^{-6}			1.2×10^{4}
	10	3.0×10^{-6}	6.0×10^{-6}	1.0×10^{6}			1.0×10^{5}
	11[b]						
	13[c]		2.0×10^{-6}	0.2×10^{-6}			2.2×10^{6}
	15	6.7×10^{-2}	6.5×10^{2}	1.0×10^{-2}			1.4×10^{1}
	Total	2.0	1.5	2.3×10^{1}	4.0×10^{3}	2.3×10^{3}	3.7

[a] No estimate of N/K fuel feed material
[b] No estimate of total feed material
[c] Existing facility

Table 4.7. Lost workday injuries for N/K fuel---strategy IX, options 2 and 3

Option	Fac.	Construction	Operation	Transportation	Total
2	2	30.9	32.7		63.5
	3	8.5×10^{-2}	3.2×10^{-2}		1.2×10^{-1}
	4	5.9×10^{-2}	2.1×10^{-2}		8.0×10^{-1}
	5	6.4×10^{-1}	1.9×10^{-1}		8.4×10^{-1}
	6	1.9×10^{-2}	1.9×10^{-2}		3.8×10^{-2}
	8	2.3×10^{-3}	1.4×10^{-3}		3.7×10^{-3}
	10[a]				
	13[a]				
	15	2.4	2.4		4.8
	Total	34.1	35.3	1.1×10^{-2}	69.4
3	1	12.5	12.0		24.6
	2	308.7	326.5		635.3
	3	45.0	17.1		62.1
	5	202.1	61.5		263.6
	6	4.5×10^{-3}	4.5×10^{-3}		8.9×10^{-3}
	8	2.0×10^{-2}	1.3×10^{-2}		3.3×10^{-2}
	10	8.0×10^{-4}	1.8×10^{-3}		2.6×10^{-3}
	11[b]				
	13[c]		4.6×10^{-4}		4.6×10^{-4}
	15	19.4	19.5		38.8
	Total	587.7	436.7	2.7×10^{-1}	1024.7

[a] No estimate of N/K fuel feed material
[b] No estimate of total feed material
[c] Existing facility

In addition, while the factor of 10 that was assumed for facility 2 in option 3 drives occupational health risk results, there are other differences indicated by the above ratios. That is, discrimination between the two options is possible over and above the differences created by assumptions. To evaluate the impact of these differences, public and ecological risks would have to be considered, since it is likely that the public and ecological risks will be much lower in the longer term, and that short-term worker risks will have to be weighed against long-term public and ecological risks.

Another approach to demonstrating the differences in worker risks between the two options is to look at the annual ratios of worker risk for option 3 compared to those for option 2. Figure 4.4 shows the ratio of worker fatalities and lost workday injuries for the 10 years of processing N/K fuel. In this demonstration case, the ratio is constant over time at approximately 12.5 because the person-years were assumed to be distributed equally over the 10 years. However, when staffing projections and estimated radiation doses are available by year, this approach will show changes in worker risk between the two options from year to year. These differences will provide information on how to manage the feed of materials from various missions to ultimately manage worker exposure and thus risks.

Figure 4.2. Fatalities by option

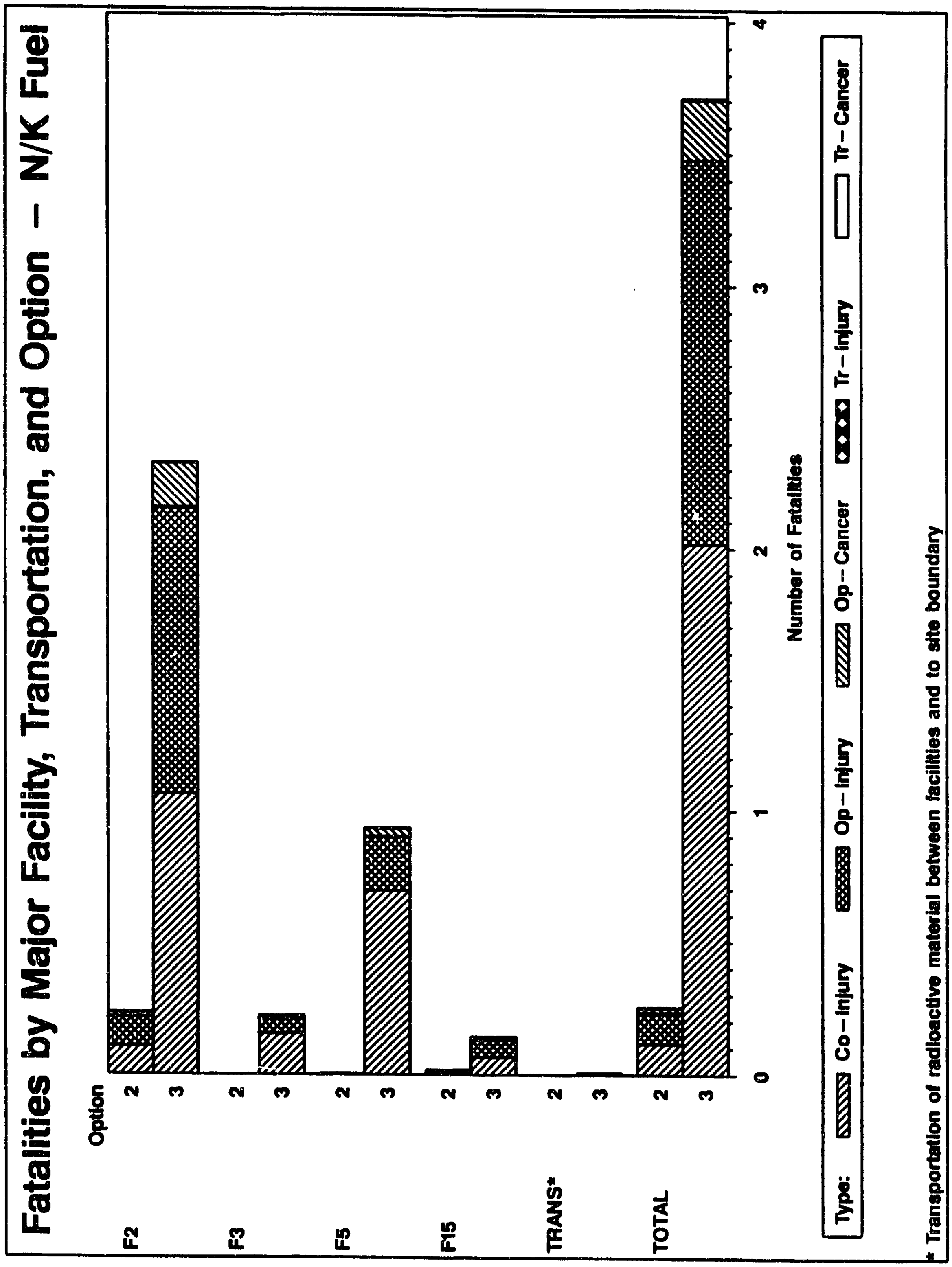


Figure 4.3. Lost workday injuries by option

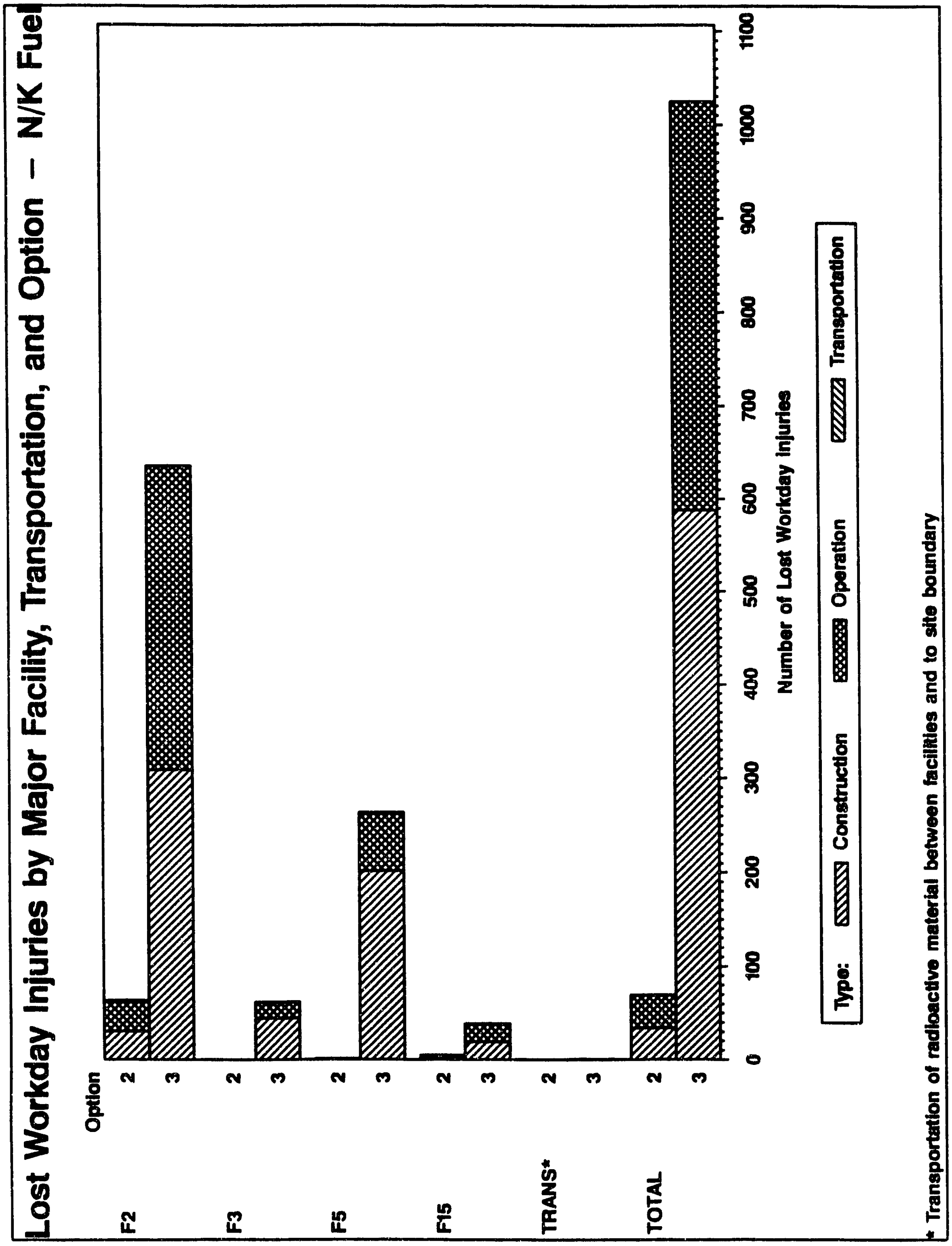
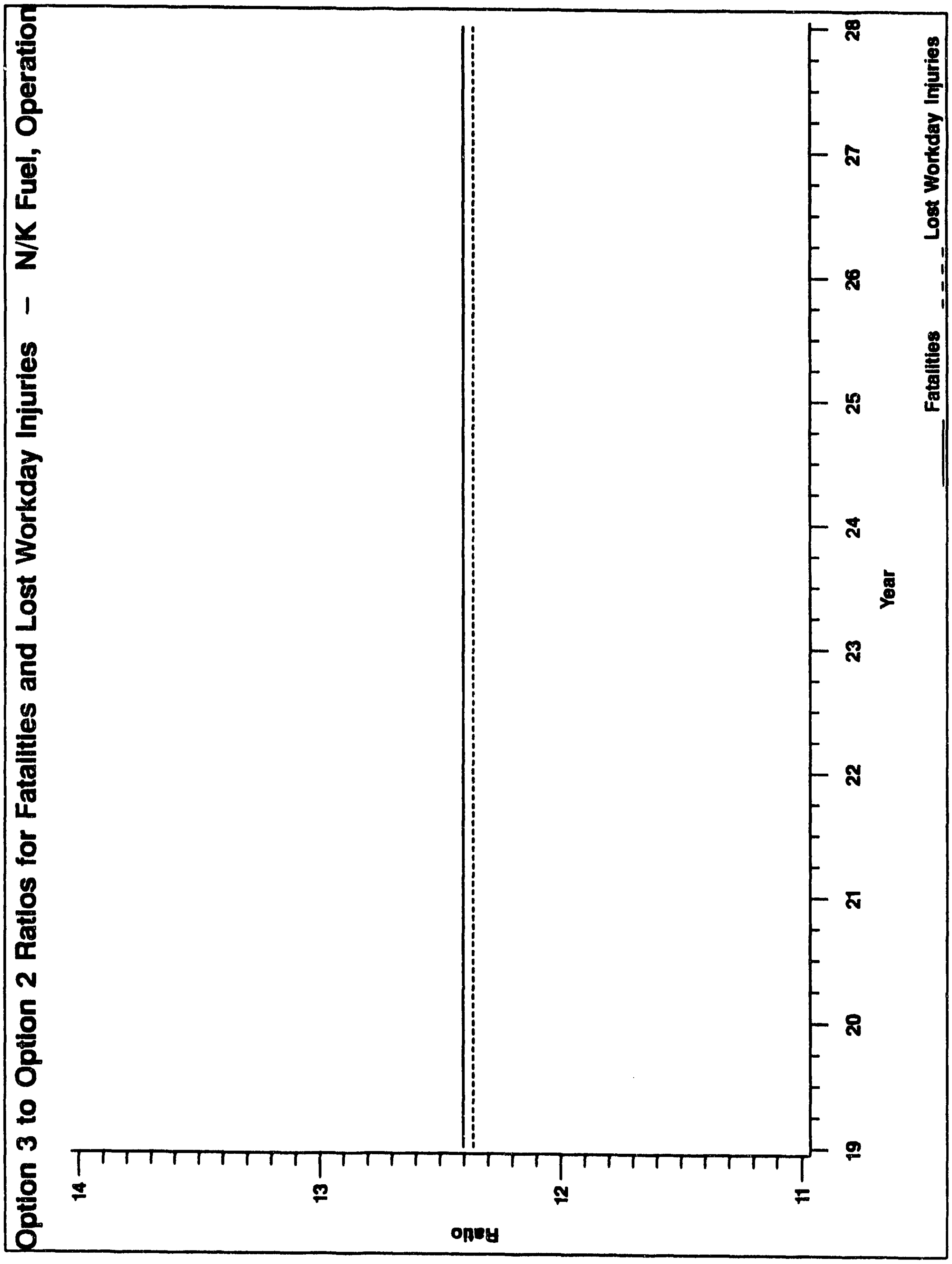


Figure 4.4. Option 3 to option 2 ratios



5.0 CONCLUSIONS AND RECOMMENDATIONS

In this report, a method is described and illustrated for assessing occupational health risk. The method is based on resources provided by the Hanford Strategic Analysis Study. The illustration is for N/K fuels in the irradiated fuels mission area.

5.1 ADEQUACY OF USING THE HANFORD STRATEGIC ANALYSIS STUDY AS A BASIS FOR RISK ASSESSMENT

The Hanford Strategic Analysis Study provides a general comparison analysis tool to guide selection and future modification of an integrated plan for Hanford Site cleanup. The Hanford Strategic Analysis Study provides a structure and much of the information that serves as a basis for health risk assessment. The key to using study resources to assess risk is twofold: 1) being able to deal with the information systematically and globally, and 2) using the information for "exposure" assessment. The information is the basis for defining how many individuals are exposed or put at risk in other ways and also what and when each individual or group of individuals is subjected to risks. Information on health risks per unit of "exposure" are obtained from other nationally available sources. The health risk assessment is conducted in a traditional manner using steps prescribed by NAS (1990).

Information in the Hanford Strategic Analysis Study is evolving, and as its accuracy and level of detail improves, parallel improvement will occur in the quality of risk assessments. In particular, when waste processing facilities and pathways are better defined, exposure assessment activities can be greatly improved. In addition, more accurate costs and schedules will allow similar improvements in risk assessments. Finally, the risk assessments provide feedback to the Hanford Strategic Analysis Study as to what additional wastes need to be tracked. For instance, in assessing exposures that are likely to occur in N/K fuels processing, ^{85}Kr was noted as important to include.

5.2 ADEQUACY OF OTHER DATA/METHODS TO SUPPORT RISK ASSESSMENTS

As noted above, the primary data used, in addition to data from the Hanford Strategic Analysis study, were risk coefficients. Whereas the numbers used are those generally accepted in the scientific community, there are a number of issues associated with estimates of risk related to cancer and other diseases or conditions. These issues also affect levels of cleanup. Issues include

- how to assess risk for exposure to mixed agents and how to assess total exposure and risk by multiple routes of exposure in a protective yet less conservative way than is currently accepted, so that related cleanup standards are not prohibitively expensive to attain
- how to take mechanistic data, data from short-term or in vitro studies, and pharmacokinetic data into account in developing risk estimates, so that if there is a threshold it can be used in managing cleanup activities
- how to use biomarkers or other methods of determining exposure/dose to biological targets in developing risk estimates and in monitoring exposure limits.

5.3 CONCLUSIONS FROM THE N/K FUELS EXAMPLE

For N/K fuels, strategy IX, option 2 oxidizes and repackages fuel then disposes of wastes, whereas option 3 separates uranium and plutonium, repackages, and disposes of wastes. Associated risks considered included lost workdays from injuries and fatal accidents during construction of reprocessing facilities, during operations, and during decommissioning and decontamination, including transportation accidents. In addition, latent fatal cancers from radiological exposure were considered; chemical exposures associated with N/K fuels are minimal.

Our assessment showed that risks for option 3 are significantly higher than for option 2; that is, reprocessing has greater risks than repackaging. Estimated numbers of fatalities and estimated number of lost workday injuries were about 15 times greater for option 3 than for option 2. The magnitude of these ratios is driven by the assumption that costs for facility 2 in option 3 were a factor of 10 greater than costs for facility 2 in option 2. In addition, risks from construction and from operation are similar, and risks of death from occupationally induced cancer are overwhelmed by risks from accidents.

This example led to the following conclusions:

- Differences in risks between strategies and options can be discriminated and thus evaluated.
- Sources (e.g., waste sites, waste streams, mission areas) of greatest risk can be identified.
- Differences in risks from different cleanup activities (e.g., construction, operation, transportation) can be understood and compared.
- Cancer fatalities and fatalities from accidents can be compared and put in perspective, as can lost workday injuries.

Future efforts will develop uncertainty information to evaluate if differences found are meaningful. Differences in risks also need to be put in perspective with baseline and end-state risks, and the tradeoffs with associated public health and ecological risks need to be understood.

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APPENDIX A

EXAMPLES OF DATA AVAILABLE ON FACILITIES SPECIFIED IN THE HANFORD STRATEGIC ANALYSIS STUDY

FACILITY SPECIFICATION SHEET
Strategy:____IX___, Option:_____2____
Facility: #2, Name: Remote Materials Processing Facility (RMPF)

FACILITY REQUIREMENTS & ATTRIBUTES	
GENERAL FACILITY DESCRIPTION	
Physical Description	
Facility Type (1)	SHC
Facility Size	
Length (Ft) / Width (Ft) / Height (Ft)	
Total Floor Space (Sq Ft)	
Total Volume (Cu Ft)	
Number of Floors	
Volume Below Ground (%)	
Major Facility Functions	
cesium & strontium recovery & dissolution	
N & K fuel decladding	
N & K fuel oxidation & packaging	
PWR Core II repackaging	
FFTF fuel repackaging	
N & K oxide powder briqueting	
N 7 K fuel container decontamination	
cesium & strontium container decontamination	
Feed Processing Rates & Operating Lifetimes	
Assumed Annual Feed Processing Rate (Mt/Yr)	
Required Operating Lifetime (Yrs)	10
Assumed Operating Lifetime (Yrs)	
Required Annual Feed Processing Rate (Mt/Yr)	
Annual Operating Requirements	
Materials (Mt)	
Staffing	
Engineering	
Operating	
Program	
Administrative	
Engineering Support	
Total Staff	

FIGURE A.1. Facility specification sheets for the Remote Materials Processing Facility in strategy IX, option 2.

01-29 92

FACILITY SPECIFICATION SHEET
Strategy: IX , Option: 2
Facility: #2, Name: Remote Materials Processing Facility (RMPF)

FACILITY REQUIREMENTS & ATTRIBUTES MATERIAL FLOWS	Lifetime Total (Mt)	Annual Average (Mt)
Feed Materials (Mt)		
Cs & Sr capsules	14.6	
N & K fuel	2,600	
PWR Core II fuel	27.8	
FFTF fuel	50	
Product Materials (Mt)		
recovered Cs & Sr solution	4.54 (#85)	
oxidized N & K fuel, repackaged FFTF, PWR Core II fuel	2,810 (#72)	
Chemical Additions (Mt)		
process additions	478 (#123)	
water	25.2 (#125)	
Utilities (Mt)		
Water		
Steam		
Electricity (MW)		
Waste Generation (Mt)		
Liquids		
Non-Hazardous Non-Radioactive Liquid Waste		
High Level Mixed & Non-Mixed Waste Liquids		
Low Level Non-Mixed Waste Liquids		
Low Level Mixed Waste Liquids (decontamination solutions)	177 (#135)	
Condensate		
Other Liquid Waste		
Solids		
Non-Hazardous Non-Radioactive Solid Waste		
Non-Radioactive Hazardous Solid Waste		
High Level Solid Waste		
Low Level Non-Mixed Solid Waste		
Low Level Mixed Solid Waste (decontaminated containers)	170 (#30)	
TRU Non-Mixed Solid Waste		
TRU Mixed Solid Waste		
Other Solid Waste		

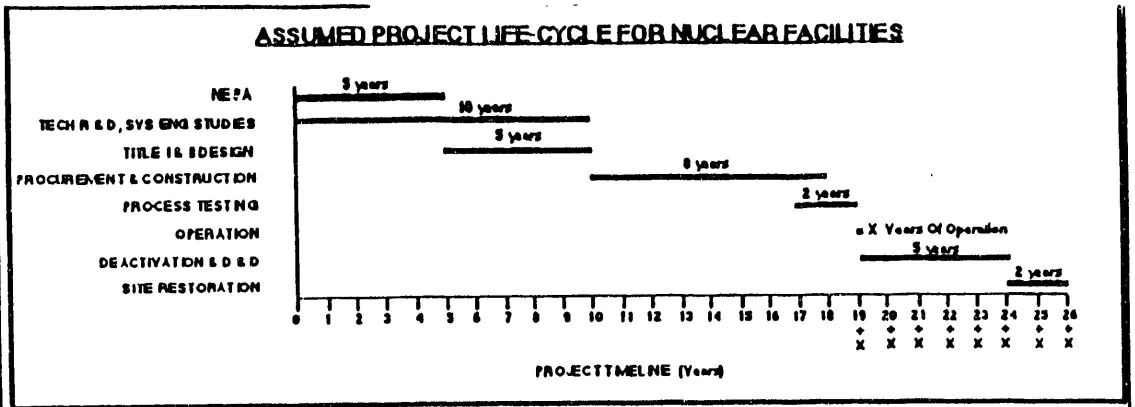
FIGURE A.1. Cont.

FACILITY SPECIFICATION SHEET
Strategy: IX , Option: 2
Facility: #2, Name: Remote Materials Processing Facility (RMPF)

FACILITY REQUIREMENTS & ATTRIBUTES	
COSTS	
Capital Cost	
Cost Basis	112,000 sq ft
Facility Of Similar Type	PFM Preconceptual
Capital Cost Of Similar Facility	$416M
Costing Attribute Of Similar Facility	45,000 sq ft
Scaling Factor	40%
Estimated Capital cost	$170M
Annual Operating Cost	
Rough Estimate	
Facility Of Similar Type	Facilities in SST Study (WHC-EP-0405)
Operating Cost Of Similar Facility	$60-130M/yr
Operating Cost Adjustment	used low end of operating cost range
Additional Scaling Factor	-
Estimated Operating cost	$60M/yr
Materials	
Personnel	
Engineering	
Program	
Operations	
General Support	
Total Staffing Cost	
Total Annual Operating cost ($M/yr)	$60
Project Annual Expense cost ($M/yr)	$10 (assumed)
Life Cycle Expense Cost	
Facility Operating Time (years)	10
Project Pre-Production Time (years)	18
Lifetime Operating Cost ($M)	$600
Project Expense & Training Costs ($M)	$300
Total Life-Cycle Expense Cost	$900

Notes:
(1) GloveBox (GB), Shielded Canyon (SC), Shielded Hot Cell (SHC), Concrete Low Hazardous Facility (CLHF), Steel Buttler Building (SBB)

FIGURE A.1. Cont.

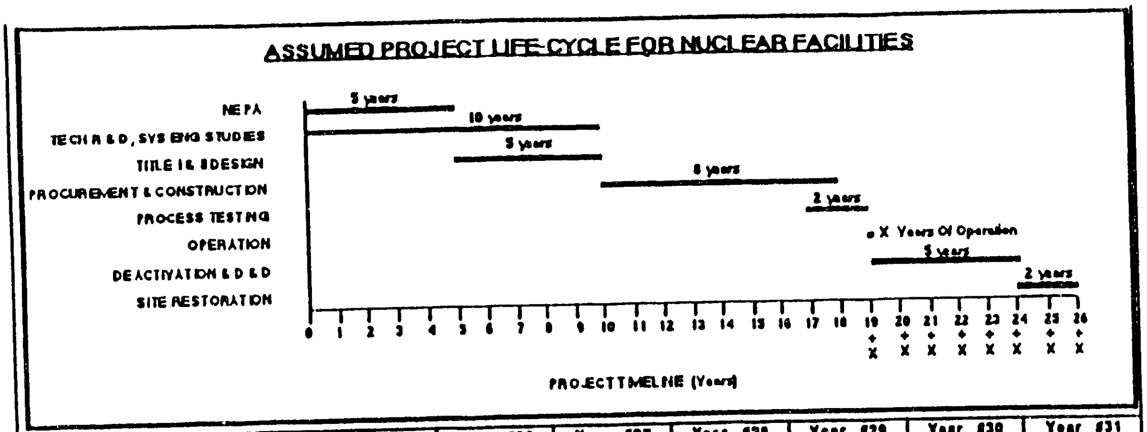


	Year #1	Year #2	Year #3	Year #4	Year #5	Year #6	Year #7	Year #8
Capital Cost								
CNRTC Cost								
Operating Cost								
Waste Storage Cost								
Waste Disposal Cost								
Total Cost								
Material Processed								
Cs & Sr								
Irradiated Fuel								
Waste To Disposal								
Glass								
Grout								
Solid Waste								
Soil Discharge								
Water Discharge								

	Year #9	Year #10	Year #11	Year #12	Year #13	Year #14	Year #15	Year #16
Capital Cost								
CNRTC Cost								
Operating Cost								
Waste Storage Cost								
Waste Disposal Cost								
Total Cost								
Material Processed								
Cs & Sr								
Irradiated Fuel								
Waste To Disposal								
Glass								
Grout								
Solid Waste								
Soil Discharge								
Water Discharge								

	Year #17	Year #18	Year #19	Year #20	Year #21	Year #22	Year #23	
Capital Cost								
CNRTC Cost								
Operating Cost								
Waste Storage Cost								
Waste Disposal Cost								
Total Cost								
Material Processed			Cs & Sr/Ir Fuel	Cs & Sr/Ir Fuel	Cs & Sr/Ir Fuel	Cs & Sr/Ir Fuel	Cs & Sr/Ir Fuel	
Cs & Sr								
Irradiated Fuel								
Waste To Disposal								
Glass								
Grout								
Solid Waste								
Soil Discharge								
Water Discharge								

FIGURE A.2. Project life-cycle worksheets for the Remote Materials Processing Facility in strategy IX, option 2.



	Year #24	Year #25	Year #26	Year #27	Year #28	Year #29	Year #30	Year #31
Capital Cost								
CNRTC Cost								
Operating Cost								
Waste Storage Cost								
Waste Disposal Cost								
Total Cost								
Material Processed	Cs & Sr/Ir Fuel	Ir Fuel	Ir Fuel	Ir Fuel	Ir Fuel			
Cs & Sr								
Irradiated Fuel								
Waste To Disposal								
Glass								
Grout								
Solid Waste								
Soil Discharge								
Water Discharge								

	Year #32	Year #33	Year #34	Year #35	Year #36	Year #37	Year #38	Year #39
Capital Cost								
CNRTC Cost								
Operating Cost								
Waste Storage Cost								
Waste Disposal Cost								
Total Cost								
Material Processed								
Cs & Sr								
Irradiated Fuel								
Waste To Disposal								
Glass								
Grout								
Solid Waste								
Soil Discharge								
Water Discharge								

	Year #40	Year #41	Year #42	Year #43	Year #44	Year #45	Year #46	Life Total
Capital Cost								
CNRTC Cost								
Operating Cost								
Waste Storage Cost								
Waste Disposal Cost								
Total Cost								
Material Processed								
Cs & Sr								
Irradiated Fuel								
Waste To Disposal								
Glass								
Grout								
Solid Waste								
Soil Discharge								
Water Discharge								

FIGURE A.2. Cont.

APPENDIX B

TABLES USED TO ASSESS RISKS FOR N/K FUELS, OPTIONS 2 AND 3

Table B.1. Summary of data used to calculate person-years for N/K fuel. strategy IX. option 2

Facility

	2	3	4	5	6	8	10	12	15
Pre-construction (years)	10 (0-9)	4 (0-3)	10 (0-9)	10 (0-9)	6 (0-5)	6 (0-5)	6 (0-5)		4 (0-3)
Construction (years)	8 (10-17)	4 (4-7)	8 (10-17)	8 (10-17)	6 (6-11)	6 (6-11)	6 (6-11)		4 (4-7)
Testing (years)	2 (17-18)	1.5 (7.5-8)	2 (17-18)	2 (17-18)	2 (11-12)	2 (11-12)	2 (11-12)		1.5 (7.5-8)
Operation (years)	10 (19-28)	30 (9-38)	20 (19-30)	20 (19-38)	23 (13-36)	30 (13-42)	30 (13-42)		26 (9-34)
Deactivation (years)	5	2	5	5	3	3	3		2
Site restoration (years)	2	0.3	2	2	1	1	1		0.3
Capital construction cost ($M)	170	1560	1800	1970	1640	1310	585		124
Construction (years)	8	4	8	8	6	6	6		4
% of capital cost is labor	46.4	35.5	46.4	46.4	35.5	35.5	35.5		46.4
% of labor is manual	70.4	60.5	70.4	70.4	60.5	60.5	60.5		70.4
Manual person-years to construct (Assuming $120K/person-year)	463	2792	4900	5363	2935	2345	1047		338
Operating costs ($M/year)	60	40	110	100	145	55	90	18	16
Operation (years)	10	30	20	20	23	30	30	46	26
% of operating cost is labor	41.3	31.0	41.3	41.3	31.0	31.0	31.0	31.0	41.3
% of labor is manual	56.4	81.6	56.4	56.4	81.6	81.6	81.6	81.6	56.4
Manual person-years to operate (Assuming $120K/person-year)	1165	2530	4270	3882	7030	3478	5692	1745	807
Deactivation ($M/year)	2.43	67.83	25.71	28.14	41.00	32.75	14.63		5.39
Deactivation (years)	5	2	5	5	3	3	3		2
% of deactivation cost is labor	46.4	35.5	46.4	46.4	35.5	35.5	35.5		46.4
% of labor is manual	70.4	60.5	56.4	72.4	60.5	60.5	60.5		70.4
Manual person-years to deactivate (Assuming $120K/person-year)	33	243	280	383	220	176	79		29
Site restoration cost ($M/year)	2.43	67.83	25.71	28.14	41.00	32.75	14.63		5.39
Site restoration (years)	2	0.3	2	2	1	1	1		0.3
% of restoration cost is labor	46.4	35.5	46.4	46.4	35.5	35.5	35.5		46.4
% of labor is manual	70.4	60.5	70.4	70.4	60.5	60.5	60.5		70.4
Manual person-years to restore (Assuming $120K/person-year)	13	36	140	153	73	59	26		4
% of total feed is N/K fuel feed	96.6795	0.0439	0.0173	0.1732	0.0094	0.0014	0	0	10.2007

Table B.2. Summary of data used to calculate person-years for N/K fuel, strategy IX, option 3

Facility

	1	2	3	5	6	8	10	11	13	15
Pre-construction (years)	6 (0-5)	10 (0-9)	4 (0-3)	10 (0-9)	6 (0-5)	6 (0-5)	6 (0-5)	4 (0-3)		4 (0-3)
Construction (years)	6 (6-11)	8 (10-17)	4 (4-7)	5 (10-17)	6 (6-11)	6 (6-11)	6 (6-11)	4 (4-7)		4 (4-7)
Testing (years)	2 (11-12)	2 (17-18)	1.5 (7.5-8)	2 (17-18)	2 (11-12)	2 (11-12)	2 (11-12)	1.5 (7.5-8)		1.5 (7.5-8)
Operation (years)	10 (13-22)	10 (19-28)	30 (9-36)	20 (19-38)	23 (13-36)	30 (13-42)	30 (13-42)	18 (9-26)		26 (9-34)
Deactivation (years)	3	5	2	5	3	3	3	2		2
Site Restoration (years)	1	2	0.3	2	1	1	1	0.3		0.3
Capital construction cost ($M)	75	1700	1560	1970	1640	1310	585	100		124
Construction (years)	6	8	4	8	6	6	6	4		4
% of capital cost is labor	46.4	46.4	35.5	46.4	35.5	35.5	35.5	35.5		46.4
% of labor is manual	70.4	70.4	60.5	70.4	60.5	60.5	60.5	60.5		70.4
Manual person-years to construct (Assuming $120K/person-year)	204	4628	2792	5363	2935	2345	1047	179		338
Operating costs ($M/year)	40	600	40	100	145	55	90	21	18	16
Operation (years)	10	10	30	20	23	30	30	18	46	26
% of operating cost is labor	41.3	41.3	31.0	41.3	31.0	31.0	31.0	31.0	31.0	41.3
% of labor is manual	56.4	56.4	81.6	56.4	81.6	81.6	81.6	81.6	81.6	56.4
Manual person-years to operate (Assuming $120K/person-year)	466	11647	2530	3882	7030	3478	5692	797	1745	807
Deactivation ($M/year)	1.88	24.29	67.83	28.14	41.00	32.75	14.63	4.35		5.39
Deactivation (years)	3	5	2	5	3	3	3	2		2
% of deactivation cost is labor	46.4	46.4	35.5	46.4	35.5	35.5	35.5	35.5		46.4
% of labor is manual	70.4	70.4	60.5	56.4	60.5	60.5	60.5	60.5		70.4
Manual person-years to deactivate (Assuming $120K/person-year)	15	331	243	383	220	176	79	16		29
Site restoration cost ($M/year)	1.88	24.29	67.83	28.14	41.00	32.75	14.63	4.35		5.39
Site restoration (years)	1	2	0.3	2	1	1	1	0.3		0.3
% of restoration cost is labor	46.4	46.4	35.5	46.4	35.5	35.5	35.5	35.5		46.4
% of labor is manual	70.4	70.4	60.5	70.4	60.5	60.5	60.5	60.5		70.4
Manual person-years to restore (Assuming $120K/person-year)	5	132	36	153	73	59	26	2		4
% of total feed is N/K fuel feed	89.1577	96.6795	23.3389	54.6083	0.0022	0.0124	0.0011	no total feed	0.0009	83.1204

Table B.3. Person-years/year by facility for N/K fuel, strategy IX, option 2

	Facility							
Year	F2	F3	F4	F5	F15	F6	F8	Total
0								
1								
2								
3								
4		0.31			8.62			8.93
5		0.31			8.62			8.93
6		0.31			8.62	0.05	0.01	8.98
7		0.31			8.62	0.05	0.01	8.98
8		0.04			3.17	0.05	0.01	3.25
9		0.04			3.17	0.05	0.01	3.25
10	55.95	0.04	0.11	1.16	3.17	0.05	0.01	60.48
11	55.95	0.04	0.11	1.16	3.17	0.05	0.01	60.48
12	55.95	0.04	0.11	1.16	3.17	0.03	0.00	60.45
13	55.95	0.04	0.11	1.16	3.17	0.03	0.00	60.45
14	55.95	0.04	0.11	1.16	3.17	0.03	0.00	60.45
15	55.95	0.04	0.11	1.16	3.17	0.03	0.00	60.45
16	55.95	0.04	0.11	1.16	3.17	0.03	0.00	60.45
17	55.95	0.04	0.11	1.16	3.17	0.03	0.00	60.45
18	112.63	0.04	0.04	0.34	3.17	0.03	0.00	116.24
19	112.63	0.04	0.04	0.34	3.17	0.03	0.00	116.24
20	112.63	0.04	0.04	0.34	3.17	0.03	0.00	116.24
21	112.63	0.04	0.04	0.34	3.17	0.03	0.00	116.24
22	112.63	0.04	0.04	0.34	3.17	0.03	0.00	116.24
23	112.63	0.04	0.04	0.34	3.17	0.03	0.00	116.24
24	112.63	0.04	0.04	0.34	3.17	0.03	0.00	116.24
25	112.63	0.04	0.04	0.34	3.17	0.03	0.00	116.24
26	112.63	0.04	0.04	0.34	3.17	0.03	0.00	116.24
27	112.63	0.04	0.04	0.34	3.17	0.03	0.00	116.24
28	112.63	0.04	0.04	0.34	3.17	0.03	0.00	116.24
29	6.39	0.04	0.04	0.34	3.17	0.03	0.00	10.00
30	6.39	0.04	0.04	0.34	3.17	0.03	0.00	10.00
31	6.39	0.04	0.04	0.34	3.17	0.03	0.00	10.00
32	6.39	0.04	0.04	0.34	3.17	0.03	0.00	10.00
33	6.39	0.04	0.04	0.34	3.17	0.03	0.00	10.00
34	6.39	0.04	0.04	0.34	3.17	0.03	0.00	10.00
35	6.39	0.04	0.04	0.34	1.50	0.03	0.00	8.33
36		0.04	0.04	0.34	1.50	0.03	0.00	1.94
37		0.04	0.04	0.34	0.45	0.01	0.00	0.87
38		0.04	0.04	0.34		0.01	0.00	0.42
39		0.05	0.01	0.13		0.01	0.00	0.20
40		0.05	0.01	0.13		0.01	0.00	0.20
41		0.02	0.01	0.13			0.00	0.16
42			0.01	0.13			0.00	0.14
43			0.01	0.13			0.00	0.14
44			0.01	0.13			0.00	0.14
45			0.01	0.13			0.00	0.14
46							0.00	0.00

Table B.4. Person-years/year by facility for N/K fuel, strategy IX, option 3

	Facility									
Year	F1	F2	F3	F5	F15	F6	F8	F10	F13	Total
0									0.00	0.00
1									0.00	0.00
2									0.00	0.00
3									0.00	0.00
4			162.91		70.24				0.00	233.14
5			162.91		70.24				0.00	233.14
6			162.91		70.24	0.01	0.05	0.00	0.00	233.14
7			162.91		70.24	0.01	0.05	0.00	0.00	233.14
8			19.68		25.80	0.01	0.05	0.00	0.00	45.54
9			19.68		25.80	0.01	0.05	0.00	0.00	45.54
10		559.29	19.68	366.08	25.80	0.01	0.05	0.00	0.00	970.91
11		559.29	19.68	366.08	25.80	0.01	0.05	0.00	0.00	970.91
12	30.31	559.29	19.68	366.08	25.80	0.01	0.05	0.00	0.00	1001.22
13	30.31	559.29	19.68	366.08	25.80	0.01	0.01	0.00	0.00	1001.19
14	30.31	559.29	19.68	366.08	25.80	0.01	0.01	0.00	0.00	1001.19
15	30.31	559.29	19.68	366.08	25.80	0.01	0.01	0.00	0.00	1001.19
16	30.31	559.29	19.68	366.08	25.80	0.01	0.01	0.00	0.00	1001.19
17	30.31	559.29	19.68	366.08	25.80	0.01	0.01	0.00	0.00	1001.19
18	41.55	1126.03	19.68	105.99	25.80	0.01	0.01	0.00	0.00	1319.07
19	41.55	1126.03	19.68	105.99	25.80	0.01	0.01	0.00	0.00	1319.07
20	41.55	1126.03	19.68	105.99	25.80	0.01	0.01	0.00	0.00	1319.07
21	41.55	1126.03	19.68	105.99	25.80	0.01	0.01	0.00	0.00	1319.07
22	41.55	1126.03	19.68	105.99	25.80	0.01	0.01	0.00	0.00	1319.07
23	41.55	1126.03	19.68	105.99	25.80	0.01	0.01	0.00	0.00	1319.07
24	41.55	1126.03	19.68	105.99	25.80	0.01	0.01	0.00	0.00	1319.07
25	41.55	1126.03	19.68	105.99	25.80	0.01	0.01	0.00	0.00	1319.07
26	41.55	1126.03	19.68	105.99	25.80	0.01	0.01	0.00	0.00	1319.07
27	41.55	1126.03	19.68	105.99	25.80	0.01	0.01	0.00	0.00	1319.07
28	41.55	1126.03	19.68	105.99	25.80	0.01	0.01	0.00	0.00	1319.07
29	4.55	66.11	19.68	105.99	25.80	0.01	0.01	0.00	0.00	222.16
30	4.55	66.11	19.68	105.99	25.80	0.01	0.01	0.00	0.00	222.16
31	4.55	66.11	19.68	105.99	25.80	0.01	0.01	0.00	0.00	222.16
32	4.55	66.11	19.68	105.99	25.80	0.01	0.01	0.00	0.00	222.16
33		66.11	19.68	105.99	25.80	0.01	0.01	0.00	0.00	217.61
34		66.11	19.68	105.99	25.80	0.01	0.01	0.00	0.00	217.61
35		66.11	19.68	105.99	12.20	0.01	0.01	0.00	0.00	204.01
36			19.68	105.99	12.20	0.01	0.01	0.00	0.00	137.90
37			19.68	105.99	3.66	0.00	0.01	0.00	0.00	129.36
38			19.68	105.99		0.00	0.01	0.00	0.00	125.70
39			28.33	41.83		0.00	0.01	0.00	0.00	70.19
40			28.33	41.83		0.00	0.01	0.00	0.00	70.19
41			8.50	41.83			0.01	0.00	0.00	50.35
42				41.83			0.01	0.00	0.00	41.85
43				41.83			0.01	0.00	0.00	41.84
44				41.83			0.01	0.00	0.00	41.84
45				41.83			0.01	0.00	0.00	41.84
46							0.01	0.00	0.00	0.01

Table B.5. Lost workday injuries by facility for N/R fuels---strategy IX. option 2

Year	Facility 2	Facility 3	Facility 4	Facility 5	Facility 6	Facility 8	Facility 10	Facility 15
0								
1								
2								
3								
4		0.02						0.59
5		0.02						0.59
6		0.02			0.00	0.00		0.59
7		0.02			0.00	0.00		0.59
8					0.00	0.00		
9		0.00			0.00	0.00		0.09
10	3.86	0.00	0.01	0.08	0.00	0.00		0.09
11	3.86	0.00	0.01	0.08	0.00	0.00		0.09
12	3.86	0.00	0.01	0.08				0.09
13	3.86	0.00	0.01	0.08	0.00	0.00		0.09
14	3.86	0.00	0.01	0.08	0.00	0.00		0.09
15	3.86	0.00	0.01	0.08	0.00	0.00		0.09
16	3.86	0.00	0.01	0.08	0.00	0.00		0.09
17	3.86	0.00	0.01	0.08	0.00	0.00		0.09
18		0.00			0.00	0.00		0.09
19	3.27	0.00	0.00	0.01	0.00	0.00		0.09
20	3.27	0.00	0.00	0.01	0.00	0.00		0.09
21	3.27	0.00	0.00	0.01	0.00	0.00		0.09
22	3.27	0.00	0.00	0.01	0.00	0.00		0.09
23	3.27	0.00	0.00	0.01	0.00	0.00		0.09
24	3.27	0.00	0.00	0.01	0.00	0.00		0.09
25	3.27	0.00	0.00	0.01	0.00	0.00		0.09

Lost workday injuries by facility for N/K fuel--strategy IX. option 2 (cont.)

Year	Facility 2	Facility 3	Facility 4	Facility 5	Facility 6	Facility 8	Facility 10	Facility 15
26	3.27	0.00	0.00	0.01	0.00	0.00		0.09
27	3.27	0.00	0.00	0.01	0.00	0.00		0.09
28	3.27	0.00	0.00	0.01	0.00	0.00		0.09
29		0.00	0.00	0.01	0.00	0.00		0.09
30		0.00	0.00	0.01	0.00	0.00		0.09
31		0.00	0.00	0.01	0.00	0.00		0.09
32		0.00	0.00	0.01	0.00	0.00		0.09
33		0.00	0.00	0.01	0.00	0.00		0.09
34		0.00	0.00	0.01	0.00	0.00		0.09
35		0.00	0.00	0.01	0.00	0.00		
36		0.00	0.00	0.01	0.00	0.00		
37		0.00	0.00	0.01		0.00		
38		0.00	0.00	0.01		0.00		
39						0.00		
40						0.00		
41						0.00		
42						0.00		

Table B.6 Lost workday injuries by facility for N/R fuel---strategy IX, option 3

Year	Facility 1	Facility 2	Facility 3	Facility 5	Facility 6	Facility 8	Facility 10	Facility 11	Facility 15
0									
1									
2									
3									
4			11.24						4.85
5			11.24						4.85
6	2.09		11.24		0.00	0.00	0.00		4.85
7	2.09		11.24		0.00	0.00	0.00		4.85
8	2.09				0.00	0.00	0.00		
9	2.09		0.57		0.00	0.00	0.00		0.75
10	2.09	38.61	0.57	25.26	0.00	0.00	0.00		0.75
11	2.09	38.61	0.57	25.26	0.00	0.00	0.00		0.75
12		38.61	0.57	25.26					0.75
13	1.20	38.61	0.57	25.26	0.00	0.00	0.00		0.75
14	1.20	38.61	0.57	25.26	0.00	0.00	0.00		0.75
15	1.20	38.61	0.57	25.26	0.00	0.00	0.00		0.75
16	1.20	38.61	0.57	25.26	0.00	0.00	0.00		0.75
17	1.20	38.61	0.57	25.26	0.00	0.00	0.00		0.75
18	1.20		0.57		0.00	0.00	0.00		0.75
19	1.20	32.65	0.57	3.07	0.00	0.00	0.00		0.75
20	1.20	32.65	0.57	3.07	0.00	0.00	0.00		0.75
21	1.20	32.65	0.57	3.07	0.00	0.00	0.00		0.75
22	1.20	32.65	0.57	3.07	0.00	0.00	0.00		0.75
23	1.20	32.65	0.57	3.07	0.00	0.00	0.00		0.75
24	1.20	32.65	0.57	3.07	0.00	0.00	0.00		0.75
25	1.20	32.65	0.57	3.07	0.00	0.00	0.00		0.75

Lost workday injuries by facility for N/K fuel - strategy IX, option 3 (cont.)

Year	Facility 1	Facility 2	Facility 3	Facility 5	Facility 6	Facility 8	Facility 10	Facility 11	Facility 15
26		32.65	0.57	3.07	0.00	0.00	0.00		0.75
27		32.65	0.57	3.07	0.00	0.00	0.00		0.75
28		32.65	0.57	3.07	0.00	0.00	0.00		0.75
29			0.57	3.07	0.00	0.00	0.00		0.75
30			0.57	3.07	0.00	0.00	0.00		0.75
31			0.57	3.07	0.00	0.00	0.00		0.75
32			0.57	3.07	0.00	0.00	0.00		0.75
33			0.57	3.07	0.00	0.00	0.00		0.75
34			0.57	3.07	0.00	0.00	0.00		0.75
35			0.57	3.07	0.00	0.00	0.00		
36			0.57	3.07	0.00	0.00	0.00		
37			0.57	3.07		0.00	0.00		
38			20.57	3.07		0.00	0.00		
39						0.00	0.00		
40						0.00	0.00		
41						0.00	0.00		
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