BNWL-SA-6007

CONF-770526--5

Decommissioning and Decontamination Planning for Hanford Nuclear Facilities Using Multiattributed Decision Analysis

May 1977

Presented at the ORSA/TIMS Conference
San Francisco, California
May 9-11, 1977

Battelle
Pacific Northwest Laboratories

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DECOMMISSIONING AND DECONTAMINATION PLANNING FOR HANFORD NUCLEAR FACILITIES USING MULTIATTRIBUTED DECISION ANALYSIS

by

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PREPARED FOR THE U.S. DEPARTMENT OF ENERGY
UNDER CONTRACT EY-76-C-06-1830

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ABSTRACT

The 570-square mile Hanford Project contains facilities with varying degrees of radioactive contamination as a result of plutonium production operations. With the evolution of production requirements and technology, many of these have been retired and will be decommissioned and decontaminated (D&D).

Because of the large number of facilities and high cost of decontamination strategies, a multiattributed decision model was used to develop individual facility D&D priorities. Each facility was treated as an alternative and four prioritization criteria were developed. Because this approach required approximately 2400 performance estimates ($\sim$600 facilities on each of four criteria), computerized models were developed to determine these performance estimates utilizing a computer-based information system as the data base.

The relative importance of each criterion was determined by experts from the Energy Research and Development Administration and the major Hanford contractors using a modified Delphi technique. The importance rankings (or weights) were combined with utility functions, also determined by the experts, to give an importance function that responded to the level of each criteria, as well as to its overall intrinsic importance.

The importance functions and the performance estimates of each facility on each criterion were combined in a prioritization model that determined a priority index for each facility. This index is an integral part of the overall decommissioning and decontamination plan.

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BACKGROUND

The Hanford Project was built during 1943 and 1944 by the Manhattan District of the U.S. Army Corps of Engineers to produce plutonium for nuclear weapons. Located on 570 square miles of shrub steppe desert adjacent to the Columbia River in southeastern Washington State (Figure 1), the project originally included facilities for the fabrication of reactor fuel elements, three graphite-moderated plutonium production reactors, and three plants for separation of plutonium. Production reactors were located in self-supporting complexes ("100 Areas") adjacent to the Columbia River where the large volume of water necessary for reactor cooling was readily available. Separations plants were located in two complexes ("200 Areas") on a plateau near the geographical center of the site. Fuel fabrication facilities ("300 Area") were located along the Columbia River near the southern boundary of the site, north of the project headquarters at Richland.

In the ensuing years, production was increased by process and equipment modification, and construction of additional production reactors and separations plants. At maximum production in the early 1960's, eight production reactors, one dual purpose production/power reactor (N-Reactor), and two separations plants were in operation. The three original separations plants had been converted to alternative uses.

In 1964, a Presidential order to curtail plutonium production resulted in the gradual phasing out of Hanford production activities. At present, operation of all separations plants and all but one of the reactors has been terminated. N-Reactor remains in operation, supplying steam to the adjacent Washington Public Power Supply System (WPPSS) 860 MW generating plant. Four reactors are in standby status and four have been declared surplus. One separations plant (Purex) remains in wet standby status, while the remaining plants are either retired or are performing alternative functions. Ongoing activities center on management of the radioactive solid and liquid wastes that are the legacy of 30 years of Hanford Project operation. These wastes take several forms.

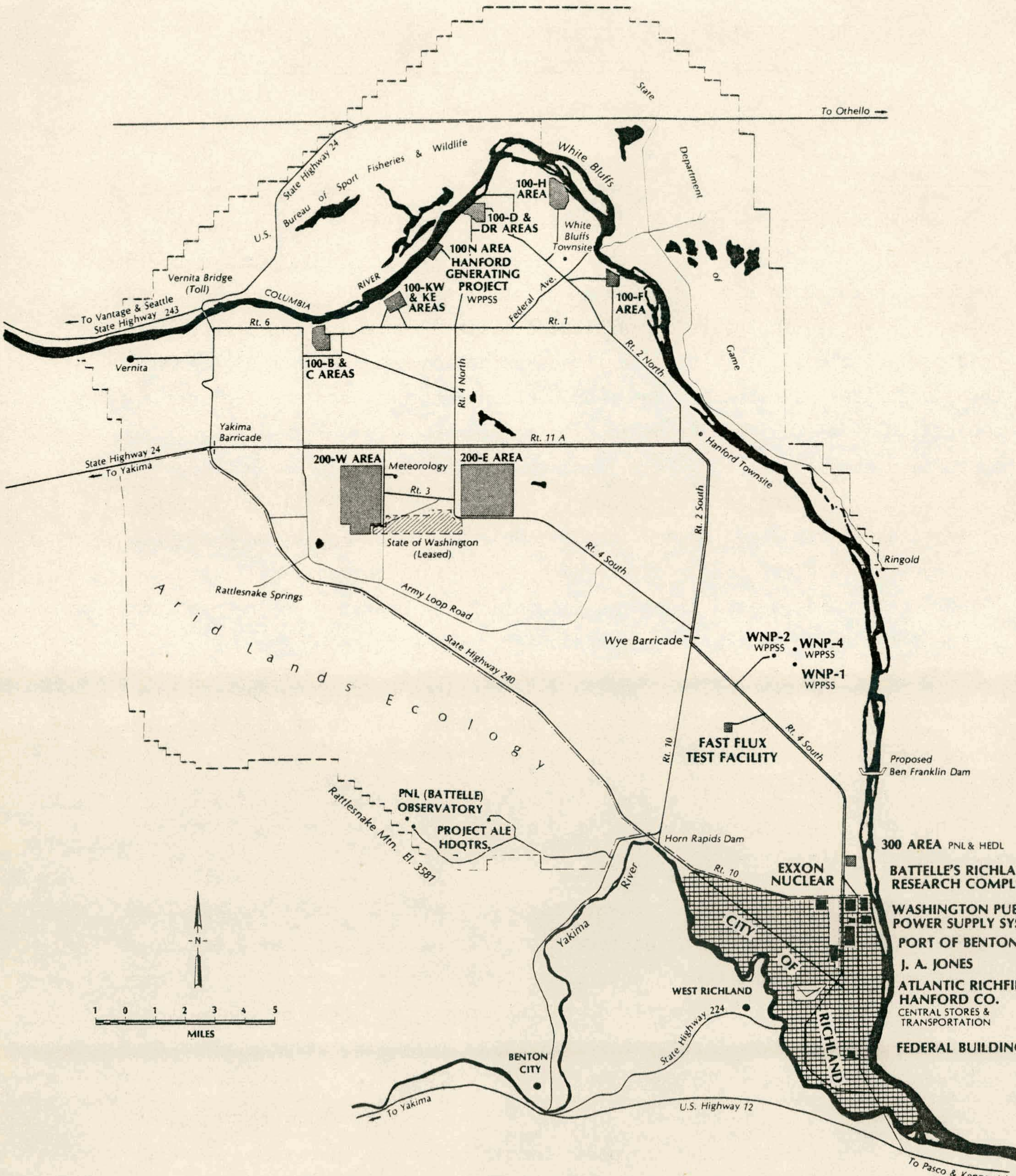

FIGURE 1. Map of Hanford Reservation

High Level Liquid Waste

High level liquid waste from chemical processing of irradiated reactor fuel is stored in underground tanks ranging in capacity from 55,000 to 1,000,000 gallons. Twelve additional 1,000,000 gallon tanks are under construction. Tanks are located in 15 operating tank farms, with 2 more tank farms under construction. Self-boiling liquid wastes are fractionated to remove the long-lived, heat emitting fission products cesium-137 and strontium-90. The fractionated isotopes are converted to cesium chloride and strontium fluoride, doubly encapsulated, and stored under water for continuing surveillance. Following removal of strontium and cesium, the remaining liquid is concentrated by evaporation to form a damp, immobile "salt cake" and a caustic terminal liquid. Non-boiling liquid waste receives similar treatment. Salt cake is formed and stored within the existing high level waste tanks.

Other Liquid Waste

Liquid waste having lower levels of radioactivity has, in the past, been transferred to the soil column underlying the project through various disposal structures. This was considered an acceptable method of waste disposal because of the favorable ion-exchange properties of the soil, the great depth of the ground water table (approximately 400 feet), and the isolated location of the Hanford site. Intermediate level liquid waste streams were discharged to subsurface structures, while low level waste streams were discharged to surface ponds or trenches. Use of the soil column for radionuclide disposal is being terminated wherever feasible.

Solid Waste

Solid radioactive waste, including failed equipment, contaminated structural debris, and trash generated during the normal course of operation is stored in burial grounds currently occupying approximately 475 acres of land at Hanford.[2] Since 1970, solid wastes containing or suspected of containing concentrations of transuranic isotopes in excess of 10 nano-curies per gram have been segregated for retrievable transuranic storage in special facilities designed to allow ready retrieval of intact packages for up to 20 years.

With the curtailment of plutonium production, alternative uses of the Hanford Reservation have been sought. These presently include:

- Construction of three commercial nuclear power plants by WPPSS.
- Lease of 1000 acres to the State of Washington for commercial nuclear waste disposal.
- Development of 86,000 acres lying north of the Columbia River by the U.S. Bureau of Sport Fisheries and Washington State Department of Game as a wildlife refuge and recreation area.
- Designation of a 120 square mile Arid Lands Ecology Reserve.
- Designation of the Hanford Reservation as a National Environmental Research Park.

Originally operated by the Atomic Energy Commission, administration of the Hanford Project was transferred to the Energy Research and Development Administration (ERDA) when the latter agency was created.

RETIRED CONTAMINATED FACILITIES AT HANFORD

Approximately 600 radioactively contaminated facilities are found on the Hanford Reservation. These have been divided into eleven classes based on radiological, structural, and functional characteristics.

Contaminated Liquid Disposal Sites

These facilites were for the disposal of low and intermediate level contaminated liquids to the soil column, including ponds, open and covered trenches, french drains, reverse wells and cribs (hollow or rock filled subsurface structures). Included in this facility class are more than 200 underground structures, 34 surface ponds, ditches and trenches, and 50 sites of accidental releases.[2]

Contaminated Solids Storage and Burial Sites

The facilities are for disposal or intermediate-term storage of contaminated solid wastes. A variety of structures are in use, including burial trenches, vaults, caissons, railroad tunnels, and surface storage. Approximately 70 contaminated solids storage and burial sites are present at Hanford.[2]

Fuel Reprocessing Facilities

These plants are for chemical separation of plutonium, uranium, and other products from irradiated reactor fuel. Each main-line reprocessing plant includes a heavily shielded process building ("canyon" building) and numerous ancillary facilities. Five main-line reprocessing plants and one pilot plant were built at Hanford.[2]

Fuel Storage Basins

These water-filled basins are used to store and age irradiated fuel elements before reprocessing. Twelve fuel storage basins were constructed at Hanford.

Reactors

Eight graphite-moderated direct once-through cooling production reactors were built at Hanford to produce weapons-grade plutonium by exposure to ^{238}U to a neutron flux. In addition, the dual purpose N-Reactor, which produces steam as well as plutonium, was commissioned in 1963 and is still in operation. Five low-power test reactors were also constructed at Hanford.[2]

Reactor Gas and Exhaust Air Systems

These facilities were used to maintain an inert gas atmosphere in the graphite piles of the production reactors. Also included are the ductwork, filters, stacks, and monitoring facilities of the reactor ventilation systems. There are about 40 structures in the class.[2]

Retention Basin Systems

Systems for returning reactor cooling water to the Columbia River include basins for temporary retention of water prior to discharge, river outfall structures and many thousands of feet of large diameter effluent piping. Also included in this class are basins for temporary retention of reprocessing plant cooling water prior to discharge to ponds. Approximately 40 facilities are in this class.

Transuranic Facilities

These facilities were used to process purified transuranic materials and hence are contaminated only with transuranic isotopes. Included are plutonium nitrate concentration and loadout facilities and plutonium finishing facilities. Fewer than ten such structures are found at Hanford.[2]

Uranium Facilities

These facilities are used to process material contaminated with uranium or thorium only. Included are reactor fuel manufacturing and storage buildings and facilities for production of uranium trioxide from reprocessing plant uranyl nitrate product.

Laboratories

These are various process monitoring and research facilities contaminated with all types of radioactive materials. Over 25 contaminated laboratories are located at Hanford.[2]

Waste Management Facilities

These facilities are for processing and storage of high level radioactive wastes generated during fuel reprocessing operations. Included are 15 tank farms (plus 2 under construction) for storage of liquid and salt cake high level wastes, 5 evaporator systems for waste concentration, and a waste transfer system consisting of vaults and diversion boxes interconnected with many thousands of feet of encased underground transfer piping.[1]

NEED AND OBJECTIVES

A large number of Hanford facilities are currently in standby or surplus status due to obsolescence of older facilities and curtailment of plutonium production. Many contain large inventories of radionuclides, presenting potential hazards both on and off the Hanford Reservation. Some structures present potential physical hazards to persons with authorized access and especially to trespassers. Maintaining these facilities in a safe condition requires expensive ongoing maintenance and surveillance.

Because of the potential hazards and costs associated with retired contaminated facilities and interest in alternative uses of the Hanford site, the U.S. Energy Research and Development Administration has commissioned the development of long range plans for decontamination and decommissioning (D&D) of surplus contaminated Hanford facilities. These plans shall include methods, budget requirements, and schedules required to achieve specific goals (scenarios) for future use of the Hanford Reservation. Because future scenarios for Hanford have not been firmly established, a major product of this study will be a set of alternative future scenarios for the Hanford Reservation. A second product will be alternative plans for achieving the goals established by each scenario. Assessments of the major effects of proposed plans will also be provided. The sponsor can then select a preferred scenario and a comprehensive D&D plan for achieving that scenario.

Scenarios

Feasible alternative scenarios for the future of the Hanford Reservation will be identified, each with an explicit statement of goals. Goals will include future land use objectives for the Hanford Reservation and dates by which the land use objectives are to be achieved. Because of the size of the Hanford Reservation and the wide scattering of contaminated facilities, it is likely that land use objectives will differ for various areas within the Reservation. Other goals specified in a scenario may include acceptable levels of potential onsite or offsite hazard following completion of D&D activities, acceptable expenditures for post-D&D surveillance and maintenance of decommissioned facilities, waste management assumptions, and future uses for specific facilities.

Plans

One or more alternative plans for achieving each scenario will be developed. The elements of a plan will include:

- A schedule of D&D activities including each surplus contaminated facility
- Identified D&D modes[a] for each surplus contaminated facility
- Budget requirements to support decommissioning activities.

Sequential D&D modes may be specified for certain facilities. For example, a reactor might be placed in layaway for five years, followed by fifty years of protective storage to allow decay of ^{60}Co, after which the facility may be dismantled.[a]

Effects

In addition to achieving the goals of the associated scenario, each plan will have numerous effects (in addition to cost) which are important in evaluating the merits of alternative plans. Important effects of each plan will be assessed as part of the Hanford D&D planning program. Potentially significant effects include: volumes of contaminated and uncontaminated wastes generated by D&D activities; manpower requirements; occupational dose resulting from plan implementation; changes in levels of potential offsite and onsite hazards; and potential environmental effects.

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[a] Decommissioning methods are reviewed in the Appendix.

PLANNING APPROACH

The planning problem outlined above is being solved through a seven phase planning approach. The phses in approximate order of completion are:

- Facility Characterization
- Data Collection and Information Management
- Facility Prioritization
- D&D Mode Selection
- D&D Activity Characterization
- Scenario Definition
- Integrated Planning

Facility Characterization

Facility characterization information was compiled in the initial phase of the Hanford D&D planning program. Surplus contaminated facilities were identified; locational, historical, physical, and radiological characteristics of each facility were documented.

Information Management

Both computerized and written data management systems are being used for Hanford D&D planning. The computer-based information system utilizes the Computer Sciences Corporation Data Management Language (DML). Currently over 90 data elements are maintained on each of 537 Hanford facilities. Additional facilities will be added as characterization information becomes available. A computer-based information system facilitates use of models for predicting costs, manpower requirements, project duration, and other facility-specific information.

Information is also maintained in the Hanford D&D "Resource Book".[2] The Resource Book contains a description of the Hanford Reservation, generic descriptions of each of the facility classes, and a discussion of D&D techniques and plans. Also provided are information sheets for each facility containing administrative, historical, and locational information in addition to the physical and radiological characteristics.

Facility Prioritization

The development of D&D schedule requires assigning priorities for disposition to individual retired contaminated facilities. The prioritization process is discussed in greater detail in the next section.

D&D Mode Selection

Mode selection requires first that feasible D&D modes applicable to classes of facilities be identified and then that specific modes for individual facilities be selected. The objective of the first task is to eliminate nonfeasible D&D modes from consideration wherever possible, simplifying development of cost and manpower estimates, and other information. Feasible modes were identified by experts familiar with Hanford facilities and experienced in the management of radioactive materials. At present, a structured methodology has not been developed to facilitate selection of specific modes for individual facilities; however, we plan to develop a decision model to assist in this selection.

D&D Activity Characterization

Characteristics of D&D activites required for development and assessment of D&D plans at Hanford include:

- Cost
- Project Duration
- Manpower Requirements
- Occupational Exposure
- Waste Volumes

These items must be estimated for the set of D&D modes applicable to each facility. The combination of multiple D&D modes for a large number of facilities results in a massive amount of needed information. Because of fortuitous similarities among facilities, it has been possible in many cases to utilize models for predicting D&D activity characteristics. The general approach to activity characterization has been to: 1) identify a set of similar facilities; 2) select a representative facility; 3) prepare conceptual procedures for the D&D of the representative facility, for each of the feasible D&D modes; 4) estimate costs, project durations, etc. wherever possible; and 5) construct models to scale costs, durations, etc. to similar facilities.

Scenario Definition and Integrated Planning

These activities, currently underway, are discussed in the conclusion of this paper.

PRIORITIZATION

The development and analysis of alternative D&D plans and schedules requires ranking the approximately 600 Hanford facilities by priority for D&D. In addition, demonstration projects to establish and validate cost and occupational exposure data require a list of Hanford facilities by priority for D&D.

Because there are many facilities, it was necessary to adopt a structured decision analysis methodology to establish a reasonably consistent priority index. A multiattribute methodology was chosen to integrate several distinct impacts of a facility into this priority index. Structuring the prioritization methodology helped to identify specific data requirements necessary to establish priorities, and to document the decision making process used to establish priorities. Because of limited and imperfect information, it is unrealistic to assume that a prioritization methodology such as ours could comprehensively examine all factors impacting on an ultimate D&D priority. The intent of the prioritization efforts is to guide future D&D planning but not to make decisions. The ultimate decision-making responsibility rests with ERDA.

Development of a consistent priority list first requires definition of relevant criteria for judging priority of further D&D action. Second, it is necessary to establish relative importance weights on each of the prioritization criteria. Third, each facility must be compared to each of the criteria to determine the relative level of performance of the facility on the criteria. Finally, criteria performance data and relative importance weights must be integrated to determine the priority for further D&D action.

Basic Prioritization Assumptions

Three assumptions were required to develop a consistent set of priorities for all facilities at Hanford. First, we assumed that a priority would be established for additional D&D action beyond the existing ongoing maintenance and surveillance activities. Secondly, all facilities were assumed to be in their current condition except for active ponds which were assumed to be drained, backfilled, and, where necessary, fenced. Finally, we assumed that this prioritization is independent of the selection of specific D&D modes.

Prioritization Methodology

The prioritization methodology operates using multiple judgment criteria. Each facility is evaluated with respect to the selected criteria to determine the level of performance of the facility on each criterion. The methodology that we selected can be described as a multiattribute, non-linear weighted composite. This method is similar to the standard weighted linear composite of the form:

$$\text{Total Priority}_J = \sum_{i=1}^{n} W_i P_{iJ}.$$

In this model, shown in Figure 2, the relative importance weights (W_i) are constant for all levels of performance (P_{ij}) of alternative j on each criterion (i). Constant relative importance weights represent constant marginal utility over the expected range of performance. For narrow ranges of performance this assumption may be acceptable; however, over wide ranges of performance the validity of assuming constant importance weights and therefore linear utility functions is questionable.[5,6] Because wide ranges in performance were observed, a methodology allowing for non-linear utility functions was selected. This method takes the form:

$$\text{Total Priority}_J = \sum_{i} W_i * U_i(P_{iJ})$$

where U_i is the utility function for criterion (i), determining the relative utility of the performance level of the j^{th} alternative on the i^{th} criterion, and W_i is the relative importance of criterion i. The total priority is then the sum over all criteria of the relative utilities of the performance values multiplied by the relative importance weights (W_i).

CRITERIA	REL IMPT WEIGHTS	FACILITY PERFORMANCE	PRIORITY INDEX
OFFSITE	W_1	P_1	W_1P_1
ONSITE	W_2	P_2	W_2P_2
COST	W_3	P_3	W_3P_3
COMPATIBILITY	W_4	P_4	W_4P_4

PRIORITY INDEX = ΣW_iP_i

FIGURE 2. Priority Model

Criteria Definition

A comprehensive set of mutually independent criteria are used to estimate the priority for further D&D action. It was of major importance that these criteria be relevant to the Hanford D&D decision making process and that the criteria selected could be quantified. To assure "relevance", knowledgeable individuals representing the Energy Research and Development Administration plus four Hanford contractors[b] were assembled to develop these criteria.

As a result of several iterations with this group, four criteria were developed as a basis for determining the priority for further D&D of each facility:

- Potential offsite radiological hazard.
- Potential onsite radiological, physical, and chemical hazard.
- Cost of continued maintenance and surveillance.
- Compatability with projected furture uses of the site.

The first two of these criteria relate to the potential physical, chemical, and radiological hazards within Hanford boundaries and to individuals

[b]Contractors involved included Atlantic Richfield Hanford Company (ARHCO) (Fuel Separations and Waste Management Operations); United Nuclear Industries (UNI) (Fuel Fabrication and Reactor Operations); Hanford Engineering Development Laboratory (HEDL); and Battelle, Pacific Northwest Laboratories (PNL).

offsite. These two criteria are intended to identify facilities potentially posing physical health and radiological safety problems and establish them as high priority.

The third criterion is an economic one. Significant economic saving can accrue to ERDA if facilities requiring high-cost maintenance and surveillance can be placed in a condition requiring reduced maintenance and surveillance. For this reason a "high cost" facility would be higher priority than a facility with relatively low maintenance and surveillance costs.

The fourth criterion is designed to identify facilities which are incompatable with existing or projected future uses of the site. Facilities that are incompatible with existing or projected future uses will be of higher priority for D&D action than if the same facility was compatable with those uses.

Performance Estimates

Following identification of the four prioritization criteria it was necessary to develop estimates of performance of each facility on each criterion. Because of the large number of estimates (600x4=2400 estimates), it was necessary to develop computer models to aid estimating criteria performance. The computerized data base was used to provide basic information for the criteria performance models and to store the completed estimates. In cases where insufficient data exists for the models to estimate performance, we have made comparisons with similar facilities to estimate criteria performance.

Potential Offsite Radiological Hazard: The estimates for potential offsite radiological hazards are made by a relative hazard index model developed by David Waite of the PNL Occupational and Environmental Safety Department. This model is a weighted, linear composite of each of the radionuclides within a facility. The quantity of each radionuclide present is weighted by a relative hazard index; the weighted sum represents an estimate of potential offiste radiological hazard. This potential hazard is scaled by a release fraction and a locational factor to estimate the resulting potential for offsite radiological hazard.

Potential Onsite Hazard: The criterion for potential onsite physical, chemical, and radiological hazard is more subjective because it includes estimates of physical and chemical hazards that resist quantification. Subjective field estimates were made on several of the facilities within each class and a regression analysis was performed on the potential relative hazard index found from the offsite hazard model. Based on this regression a forecast of the potential onsite radiological hazards for each facility was developed. This forecast was then taken into the field on a second round of onsite inspections and subjectively adjusted to establish the final estimate for potential onsite hazard.

Continued Maintenance and Surveillance: Cost of continued maintenance and surveillance were estimated by an interactive model which allows the user to perform any or all of the following four maintenance activities.

- Installation of fencing
- Earthfill of variable thickness
- Removal of unwanted plant life by clearing or sterilization
- Installations of cordons and monuments.

Based on these user-specified alternatives, a present value estimate of the continued maintenance and surveillance costs for the next 20 years is developed for each facility.

Future Compatability: The future compatability model is based on assumptions of projected future use for each of the areas of the Hanford Project. This model estimates compatibility based on proximity to areas of existing or potential future uses.

Development of Utility Functions

An example of a typical prioritization methodology is shown in Figure 2. For this application the constant relative importance weights were replaced with utility functions. These utility functions were composites of importance functions (relating importance to level of criteria performance) and relative importance weights (estimates of the value of each criterion when compared to the other criteria).

A three-stage modified Delphi approach was used to estimate importance functions and relative importance weights. The first stage involved establishing the expected range of performance of each of the four criteria. Next, a hypothetical facility was constructed to demonstrate the maximum level of performance on each of the four criteria. For this hypothetical facility, the relative importance of each criteria was established by use of paired comparisons.[7,8] Respondents were first asked to order the four criteria in an ordinal ranking from most to least important. A value of 100 was assumed for the most important criterion. The respondent was then requested to assign a number (between 0 and 100) representing the relative importance of the second criterion as compared to the first. The respondent then fixed the value of the second criterion at 100 and compared the third criterion to the second. This process continued until each criterion had been compared to the preceeding criterion. An on-line interactive computer system was used to develop normalized estimates of the relative importance weights for each of the respondents and to feed back the expected values of the group's criteria weights. The resulting relative importance weights of each of the four criteria are shown in Figure 3.

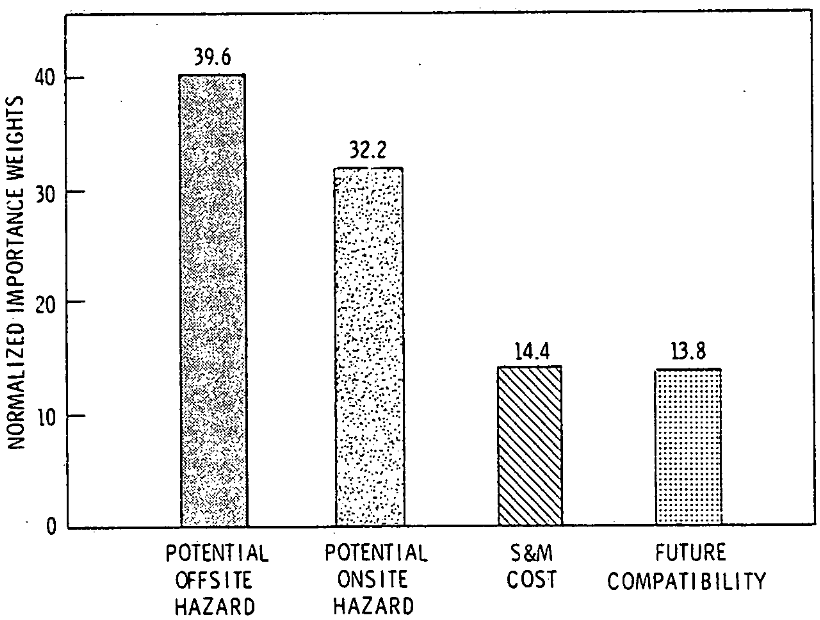

FIGURE 3. Relative Criteria Importance

The third step in developing a utility function for each criterion was to develop functional relationships between importance and the level of performance. The same experts who developed the criteria were given a blank graph of importance versus performance for each of the four criteria. Each expert then estimated the relative level of importance at the performance quartiles, given that the maximum level of performance was arbitrarily assigned an importance score of 10. The group composite importance functions were then displayed to the group and the shape of these importance functions was reestimated. The importance functions obtained for the four criteria are shown in Figure 4.

The relative importance weights of Figure 3 represent the relative importance resulting from paired comparisons of the maximum performance levels of each of the four criteria. The multiplicative combination of these relative importance weights and the importance curves result in the utility functions shown in Figure 5.[9,10,11] Estimates of criteria performance for each facility are transformed through these utility functions to determine utility of each of the four performance levels. The priority index of the facility is determined by summing the estimated utility of each of the four criteria.

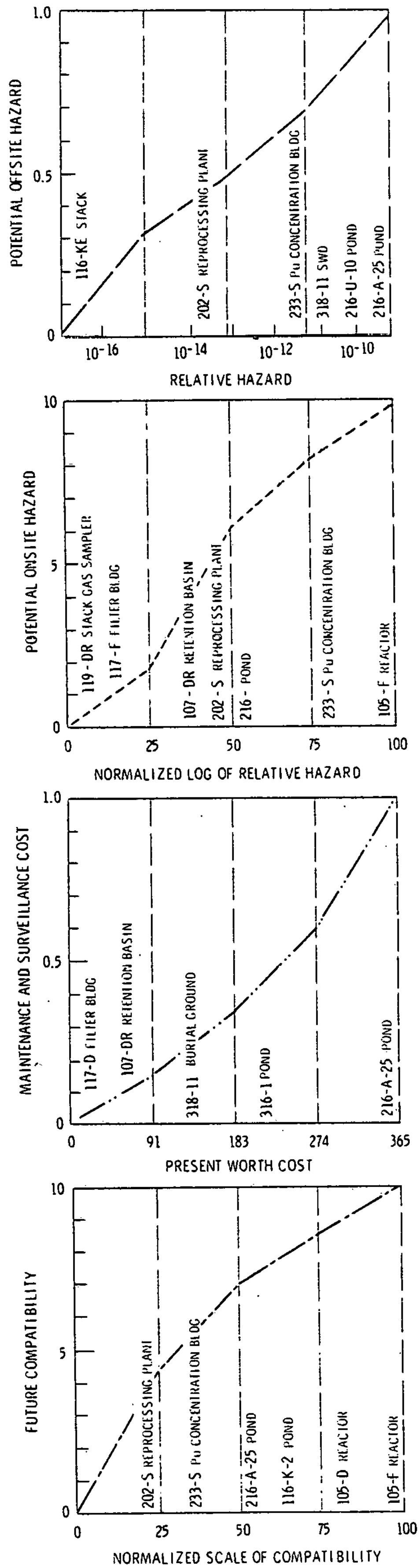

FIGURE 4. Importance Functions

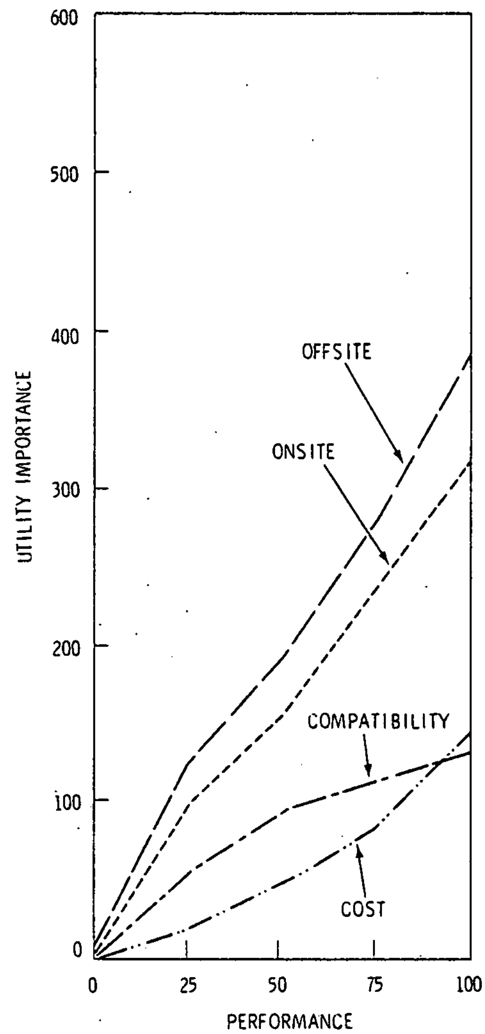

FIGURE 5. Composite Utility Curves

PRIORITIZATION RESULTS

This prioritization methodology has made significant contributions to the Hanford D&D Project. It permits consistent incorporation of additional facilities as information on those facilities becomes available. It provides a basis for discussion and permits revision of the relative importance weights and subjective estimates if necessary. It facilitates incorporation of expert opinion in the prioritization process. The resulting prioritization is a well organized, documented, and replicable system, supporting the development and analysis of alternative, comprehensive D&D plans at Hanford.

SCENARIO DEVELOPMENT AND INTEGRATED PLANNING

Potential future scenarios for the Hanford Reservation are now being identified. Scenarios will be based on objectives cited by the Hanford Waste Management Environmental Impact Statement,[1] the Hanford Master Planning Guide,[3] Hanford Radioactive Waste Management Plans,[4] representatives of the Hanford operating contractors, and ERDA Richland Operations and Headquarters officials. A preliminary scenario involving complete dismantling of all retired facilities within 100 years has been defined; however, final scenario definition is not scheduled until next fiscal year.

Preparation of a single D&D plan for Hanford requires selecting up to 600 individual D&D actions from 2400 alternatives and scheduling these actions over many years (100 years for one preliminary scenario). To reduce this problem to managable proportions and permit rapid assessment of many alternative D&D plans, an interactive computer-based planning system has been developed. Basic planning assumptions are user-specified. These include: 1) specifying facilities to be decommissioned, 2) inflation estimates, 3) land use objectives, 4) time or budget constraints, and 5) D&D mode selection. The system then compiles a schedule of D&D activities for specified facilities over the required time period. Facility ordering is based upon assigned priorities for D&D. Annual budget requirements are computed in both constant and inflated dollars.

When fully developed the system will quickly compile for display major effects of the specified D&D plan including annual costs of maintenance and surveillance, manpower requirements, waste volumes, and estimates of potential hazard. Output information is provided in both tabular and graphic form. This system will facilitate rapid development and assessment of alternative D&D plans once the full set of potential future scenarios for the Hanford Reservation is established.

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APPENDIX

DECOMMISSIONING METHODS

DECOMMISSIONING METHODS

Four decommissioning alternatives have been identified as generally applicable to retired Hanford facilities:

Layaway

The layaway mode is an interim (∿ 20 years) mode in which the facility is maintained in an acceptably safe condition in essentially its current state. Layaway may permit postponement of major D&D activities until acceptable terminal storage is developed. For facilities containing isotopes with short half-lives, radiation levels will be lower, reducing costs and occupational exposures at time of final D&D. Layaway, however, will require continuing expenditures for maintenance and surveillance of the facility and may require initial capital expenditures for structural renovation, containment, housekeeping, and fencing.

Protective Storage

Protective storage is an interim (50-100 year) mode with the objective of placing the facility in an acceptably safe condition long enough to permit substantial decay of the radioactive inventory. Ultimate disposition of the facility may then be accomplished at reduced cost and occupational exposure. Protective storage requires containment barriers designed for 50 to 100 year integrity with minimal maintenance and surveillance.

Entombment

Entombment is a permanent D&D alternative in which the facility is enclosed with a barrier of sufficient integrity to contain the radionuclide inventory until it decays to a safe condition. Approximately 10 half-lives are required to transform a quantity of a given radionuclide to an acceptably safe concentration for general release to the environment. An inventory of ^{60}Co (5.26 y half-life) would require an entombment structure with expected integrity of greater than 50 years; ^{90}Sr (28 y half-life) and ^{137}Cs (30 y half-life) approximately 300 years; and ^{239}Pu (24,000 y half-life) a quarter of million years. It may be reasonable to expect a 300 year lifetime for structures employing current technology; therefore, entombment may be a feasible mode for facilities containing mixed fission products but not for those contaminated with transuranics.

Dismantle

Dismantle mode involves complete removal of radioactivity from the site, usually accompanied by removal of non-contaminated structures as well. A variation of this mode, conversion, would involve decontamination of the facility followed by conversion of the remaining structure to an alternative use. Invoking the dismantling mode will require transfer of the contaminated inventory to a storage facility or to ultimate disposal. Presumably the transfer will result in superior isolation of the inventory.