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Planning Guidance for Nuclear Power Plant Decontamination

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Pacific Northwest Laboratory
Operated by
Battelle Memorial Institute

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U.S. Nuclear Regulatory
Commission

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EXECUTIVE SUMMARY

Reduction in collective occupational radiation exposure (man-rem) in light water reactors is in the best interest of power plant workers, reactor owners, and is in full accord with NRC policy. Decontamination has long been recognized as a viable and cost effective occupational radiation exposure method. Recent foreign experience on large reactor systems as well as system decontamination experience in the United States has illustrated the safety of available decontamination processes.

To encourage the use of decontamination for exposure reduction and to promote its safe application, the U.S. Nuclear Regulatory Commission (NRC) requested the Pacific Northwest Laboratory[a] (PNL) to study the use of decontamination prior to plant maintenance and the available criteria for safe application of decontamination technology. This document is the result of that study. It has been prepared to assist in decontamination planning and evaluation. This analysis is generic and is directed at coordinating efforts in planning, implementing, and monitoring restorative decontamination. Because of the different types of reactors, coolant chemistry, and construction materials used, the specific concerns encountered in decontamination will vary with each reactor and each decontamination process. This analysis focuses on those cases where the decontamination is for restorative purposes. Management oversight and risk tree (MORT) charts are used to logically illustrate the key issues in reactor decontamination.

Decontamination methods rely on chemical, electrochemical, and mechanical techniques or combinations thereof. The method selected should be compatible with reactor materials and should produce the most effective decontamination without excessive corrosion, contamination of clean surfaces, or recontamination of those areas treated. This process should be done safely, within regulatory guidelines, at an acceptable cost, with a minimum of down time, and with minimum radiation exposure to those involved in the decontamination.

Direct and indirect costs of decontamination are considered in the benefit-cost analysis in Section 1.0. A generic form of the benefit-cost ratio is evaluated in monetary and nonmonetary terms, and values of dollars per man-rem are cited. The overall dose and dollar savings should be calculated to determine whether the benefit of the decontamination process justifies its cost.

Federal and state agencies that may have jurisdiction over various aspects of decontamination and waste disposal activities are identified in Section 2.0. Most restorative decontaminations will not require either a change in technical specification or involve an unresolved safety concern and can therefore be done without additional regulatory approvals.

(a) The Pacific Northwest Laboratory is operated for the U.S. Department of Energy by Battelle Memorial Institute.

Methods of decontamination, their general effectiveness, and the advantages and disadvantages of each are outlined in Section 3.0. Dilute or concentrated chemical solutions are usually used in-situ to dissolve the contamination layer and a thin layer of the underlying substrate. Electrochemical techniques are generally limited to components but show high decontamination effectiveness with uniform corrosion. Mechanical agents are particularly appropriate for certain out-of-system surfaces and disassembled parts. These processes are catagorized and specific concerns are discussed.

Good management of each phase, from planning the decontamination strategy to returning the reactor to service, is essential for an effective, safe, and efficient project. Section 4.0 stresses the planning that is necessary to manage the project, develop and implement procedures, and perform the decontamination operation.

The treatment, storage, and disposal or discharge of liquid, gaseous, and solid wastes generated during the decontamination process are discussed in Section 5.0. Radioactive and other hazardous chemical wastes are considered.

The environmental effects of decontamination can be minimized by monitoring emissions and instituting appropriate controls and treatment strategies. The monitoring, treatment, and control of radioactive and nonradioactive effluents, from both routine operations and possible accidents, are discussed in Section 6.0.

Protecting the health and safety of personnel onsite during decontamination is of prime importance and should be considered in each facet of the decontamination process. The radiation protection philosophy of reducing exposure to levels as low as reasonably achievable should be stressed. These issues are discussed in Section 7.0. In addition to internal and external radiation exposure control, the traditional concerns for industrial safety and hygiene should be addressed for decontamination. Personnel should be aware of specific hazards during decontamination procedures and they should be trained in emergency measures.

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PLANNING GUIDANCE FOR NUCLEAR POWER PLANT DECONTAMINATION

INTRODUCTION

Although decontamination has been used successfully to reduce occupational radiation exposure in light water reactors, its use has generally been limited to isolated systems and/or to very serious exposure problems where it is a "last resort." To encourage the safe application of available decontamination technologies to maintain occupational radiation exposures as low as reasonably achievable (ALARA), the U.S. Nuclear Regulatory Commission (NRC) has directed the Pacific Northwest Laboratory (PNL) to summarize existing criteria that are applicable to decontamination. This document identifies the issues that are essential to a safe and successful decontamination of a major component or full reactor system and discusses the applicable criteria. To do this, a modified management oversight risk tree (MORT) technique has been employed (Buys 1977). An objective type of analytical tree has been used to define those elements necessary to achieve a successful reactor decontamination. These key elements are shown in Figure I.1.

Prior to considering these key issues, the reader should be aware of the following characteristics of the MORT approach:

1. Not all key issues thus identified are, or should be, of concern for every decontamination. The reactor operator has some concerns that are not of concern to regulatory agencies and these are also addressed.
2. The relative level of importance of the various issues to the success of the decontamination is not indicated.
3. The order in which the issues should be addressed is not established.
4. The interrelationships of the issues are not illustrated, (e.g., waste management concerns depend in large part, if not wholly, on the process selected, but the MORT approach presents them independent of one another).

The major advantage of the MORT approach is that it breaks a complex project down into a series of basic concerns that can be more easily addressed. A MORT approach of this type has proved useful to the NRC in the appraisal of the adequacy of health physics and emergency preparedness programs at operating reactors (Cunningham et al. 1982), in start-up readiness reviews (Nertney et al. 1975), and (in a slightly different form) in failure analysis (Johnson 1975).

The main intent of this document is to provide an overview of reactor decontamination and to highlight the key issues of concern. The charts, with clarification from the text, may be used as a reference checklist in decontamination planning to assure that responsibilities are assigned and important

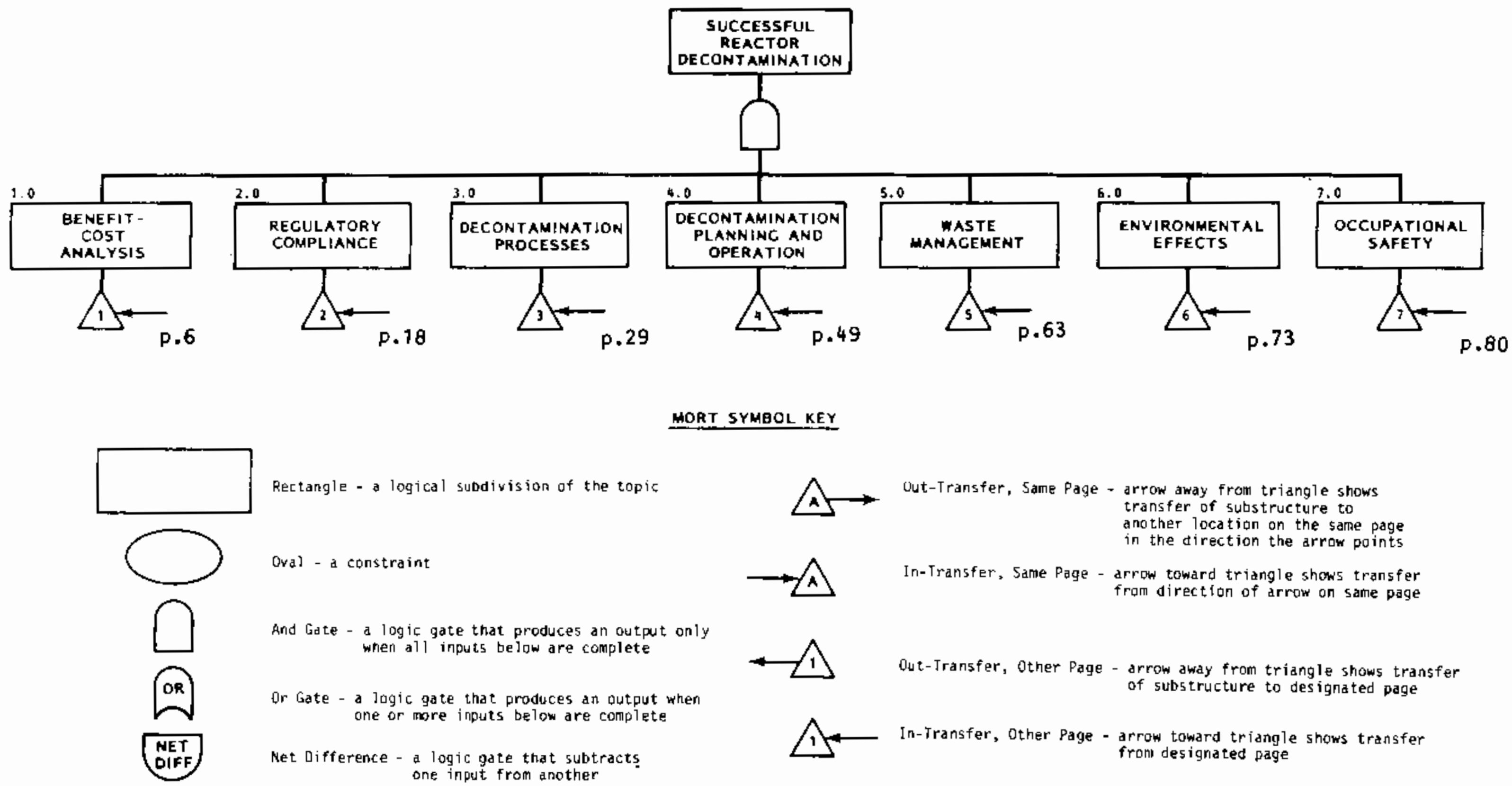

FIGURE I.1. Successful Reactor Decontamination issues planned for so that operations can run smoothly. The actual process of planning and carrying out a decontamination will take a form that is not fully represented on the charts. The planning process is described briefly below to add perspective for the reader who may not be familiar with decontamination processes.

Decontamination planning begins with a perceived present or future need. The decontamination will be less costly and require less exposure if the need is recognized and planned for during the designing of the reactor. In the design stage, physical modifications, such as characterization loops, chemically compatible materials, chemical addition and draining connections, and adequate waste containment capacity, can be more easily incorporated into the system. If these modifications are included in the initial construction, they will be less expensive than retrofits and require no occupational radiation exposure. Decontamination can also be addressed in the safety analysis report and technical specifications at the licensing stage.

In some cases, the need to decontaminate will not be recognized until after reactor operation has begun and dose rates begin to rise. The need may arise from a general concern about cumulative exposures, from an anticipated reduction in allowable occupational radiation exposure limits, or from a predicted shortage of certain radiation workers. These relatively long-range concerns have been the primary incentives for the repeated decontaminations of the CAN-DU reactors in Canada and of the Hanford N reactor, but they have been atypical of the reasons for decontamination at U.S. nuclear power plants. At U.S. power reactors, consideration of decontamination has usually been in response to: the inability to perform required inspections at existing dose rates, the need for major restorative maintenance of a particular component, or accident recovery.

Selection of an appropriate decontamination process or processes will be dependent on the perceived need. Preparations made during the design phase will probably be aimed at a full-system decontamination. Decontamination for maintenance reasons is likely to involve a single component or a subsystem. Decontamination of a major component, such as a steam generator or heat exchanger is likely to be simpler than full-system decontamination because of shorter outage times and lower waste volumes. The simplest major-component decontaminations will be those involving only decontamination materials that are innocuous to the system, such as water, ice, or boric acid crystals. Mechanical decontamination methods, employing potentially harmful materials, and various chemical methods are more expensive and complicated, but can also be more effective.

If a full-system or major-subsystem decontamination is deemed necessary, a dilute process, in which radionuclides and decontamination chemicals are concentrated on ion-exchange resins, is expected to provide the simplest waste management. Such processes have produced a decontamination factor in the range of 1.5 to 5 on full reactor systems in other countries and appears to have a similar effectiveness on corrosion films in U.S. boiling water reactors (BWRs). An oxidation pretreatment step is thought to be required to achieve similar results on U.S. pressurized water reactors (PWRs). It appears that the fuel could be left in place during such a decontamination, although the question of fuel warranties would probably require resolution with the fuel supplier. A more effective decontamination can be achieved using more concentrated reagents; however, their use may require removal of the fuel and evaporation of waste for volume reduction prior to solidification.

A thorough analysis of plant conditions will indicate the viable decontamination alternatives. Analysis of a particular alternative will require study of well-defined parameters including: 1) the portions of the system to be decontaminated, 2) the chemical mixing and waste treatment facilities required, 3) the waste volumes anticipated, 4) the extent of regulatory involvement, 5) the anticipated effectiveness, and 6) the reactor outage time and manpower required. When the available alternatives have been defined, they can be quantitatively analyzed and a selection made.

At this point, detailed planning begins and procedures and schedules are prepared. If no change in technical specifications and no unresolved safety concern is anticipated, the NRC need not be informed or involved. If the decontamination is sufficiently different from others that have been performed in the U.S., either because of chemical composition or reactor condition, it is advisable to inform the NRC of plans. If a process were selected that involved a change in technical specifications or an unreviewed safety concern, a license amendment and safety analysis would be required. There are no technical reasons why preparatory activities could not take place during reactor operation.

After the planning and preparatory activities have been completed, the reactor can be shut down, system modifications can be made, and the decontamination process performed. The sections that follow indicate the key issues and many of the details that should be addressed to ensure the success of a decontamination.

1.0 BENEFIT-COST ANALYSIS

The decision to decontaminate a reactor is dependent upon a number of factors. A very important factor is: Does the benefit justify the cost? This determination can be made through a benefit-cost analysis, in which the present value (present worth) of benefits is compared with the present value of costs. If the benefits exceed the cost, or the benefit-cost ratio is greater than 1, decontamination is justified. A MORT chart for a benefit-cost analysis is shown in Figure 1.1.

Net benefits may be realized either in terms of reduced financial cost or in reduced radiation exposure. In the more traditional case, decontamination may be performed at some cost in order to reduce worker exposures. However, if a reactor becomes inoperable because of severe contamination, it can either be decontaminated or it can be left shutdown. A decontamination will have both a financial and an exposure cost, but the plant will become operable and generate revenue. If the plant is left shutdown, there is no decontamination cost, but the loss of the plant should have to be absorbed or it should need to be replaced.

The benefits and costs of decontamination will be realized at different times, and such differences will affect the determination of cost justification. To allow for the effect of time when evaluating the merit of a project, discount rates should be used to convert the value of future benefits and costs to present values (PV). Present value is determined by multiplying a benefit (b_j) or a cost (c) occurring in any year (j) by a discount factor $1/(1 + i)^j$, where i is the appropriate discount rate. The discounted values of benefits and costs are then determined to yield the net present value (NPV) as follows:

$$NPV = (PV)_b - (PV)_c$$

$$= \sum_{j=0}^{n} \frac{b_j}{(1 + i)^j} - \sum_{j=0}^{n} \frac{c_j}{(1 + i)^j}$$

where the sum of the benefits $(PV)_b$ over a facility life of n years is:

$$(PV)_b = \sum_{j=0}^{n} \frac{b_j}{(1 + i)^j} = \frac{b_o}{(1 + i)^o} + \frac{b_1}{(1 + i)^1} + \frac{b_2}{(1 + i)^2} \cdots + \frac{b_n}{(1 + i)^n}$$

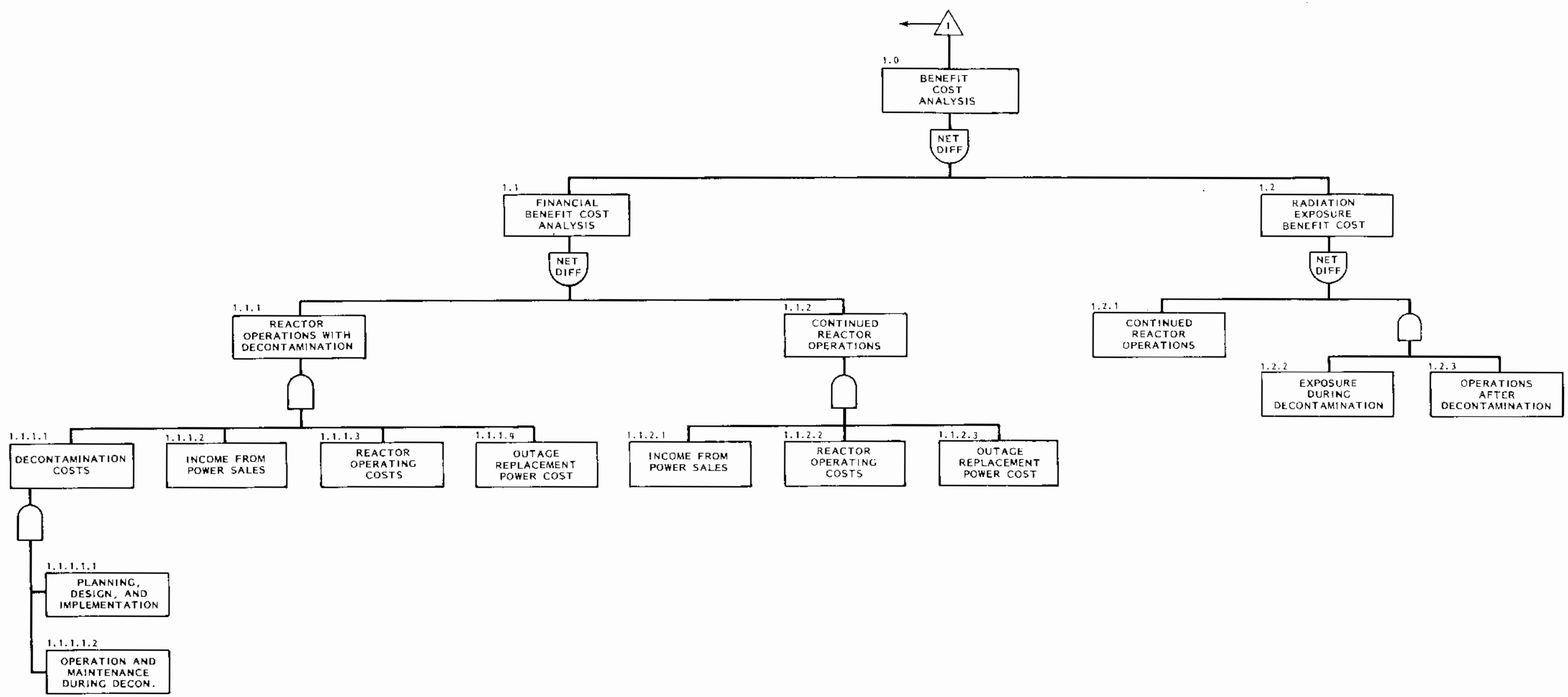

FIGURE 1.1. Benefit-Cost Analysis

The sum of costs $(PV)_c$ is determined similarly. The benefit-cost ratio for the project is:

$$B/C = \frac{(PV)_b}{(PV)_c}$$

A more thorough discussion of present value, benefit-cost ratio, and alternative methods for establishing merits of projects (such as discount cash flow rate of return) is given in general economics and engineering economics literature: Treasury Board-Canada 1976; Grant et al. 1976; Stermole 1980; Smith 1979; and Newman 1980. Each method uses monetary values and the time value of money in its calculations, even to express social values. In this generic benefit-cost analysis approach to evaluating decontamination, a monetary value, expressed as dollars/man-rem, would be used for radiation exposure. Although a wide range of values of dollars/man-rem have been proposed, the most appropriate value is one that specifically applies to the reactor and crafts under consideration.

An alternate method, in which no dollar value is assigned to radiation exposure, is discussed briefly in the appendix to this section. This method, proposed by Hall et al. (1979) and based on extensive experience, involves calculation of an "apparent reduction potential" (ARP) and an "achievability index" (AI). An AI value greater than 1.0 is interpreted to mean that the action under consideration is or may be justified; a value less than 1.0 means that the action is not justified. The larger the AI value, the stronger the justification for the action.

For decontamination benefit-cost analysis, it is important to have the results of both the financial and the radiation exposure benefit-cost evaluations. Monetary values for radiation exposure are also used in making an overall benefit-cost determination. Consequently, these analyses form two branches of the total benefit-cost analysis.

1.1 FINANCIAL BENEFIT-COST ANALYSIS

In a financial benefit-cost analysis, the costs and income of a base case are compared with those of an alternative. In this evaluation, reactor operation that includes a single decontamination or periodic decontaminations is compared with its alternative, the continued operation of a reactor without decontamination. The elements of cost and income are given in the following discussion. However, some of these cost elements will not be included for the more simple decontaminations.

1.1.1 Reactor Operations with Decontamination

The overall costs and income for reactor operation that includes decontamination are determined using these four elements: 1) decontamination costs, 2) income from sale of power and perhaps thermal energy (process heat), 3) the reactor operating costs during power production, and 4) the cost of replacement power during outages for routine or unscheduled maintenance and for decontamination. The present values of these costs and incomes should be used.

1.1.1.1 Decontamination Costs

Decontamination costs are composed of costs for planning, design, implementation (including construction), operating or conducting the decontamination, maintenance of decontamination facilities, waste disposal, post decontamination testing and startup, and any subsequent followup.

1.1.1.1.1 Planning, Design, and Implementation. Costs incurred before decontamination of a reactor system are those for planning, design, and implementation of a process and for construction of permanent or temporary facilities. Knowledge of costs will be required for the categories listed in Table 1.1.

1.1.1.1.2 Operation and Maintenance During Decontamination. After the facilities are built, decontamination solutions selected, and procedures prepared, costs listed in Table 1.2 for operating and maintaining the facility must be considered.

If the decontamination facilities are temporary rather than permanent, they will have to be decontaminated and cleaned so that they can be removed and transported elsewhere. Following removal of these facilities, the site may be returned to the original or an improved condition. These costs must be included with operating costs or with construction costs.

The cost of replacement power required to meet commitments during the decontamination is an operating cost, provided the reactor would otherwise be operating. In this analysis, however, it is handled along with other replacement power costs due to outages, which are discussed in Section 1.1.1.4.

1.1.1.2 Income from Power Sales

Reducing the radiation fields around a reactor will increase the accessibility and maintainability and may increase reliability, efficiency, and availability of the facility, allowing more power to be produced. The gross income that would be realized over the life of a decontaminated facility is used as its present value in the benefit-cost calculation.

1.1.1.3 Reactor Operating Costs with Decontamination

These are the variable and fixed operating costs that normally would accrue for power production. These costs are discussed in more detail in Section 1.1.2.2. Operating costs, including maintenance costs, may decrease over the long term where decontamination is performed, primarily because lower radiation exposures will permit reduced labor requirements and more efficient use of labor. A near-term benefit of decontamination may be the replacement of

TABLE 1.1. Planning, Design, and Implementation Costs of Decontamination

A. Project Management and Administration
B. Planning and Process Development
   1. Establishing organization - plant personnel, consultants, contractors
   2. Information collection
      - Determination of need for decontamination
      - Assessment of initial situation
      - Identification of cleaning objectives
   3. Inventory of reactor materials to come in contact with decontamination fluids
   4. Selection of decontamination methods
   5. Criteria development for solvents, procedures, facilities, equipment, personnel
   6. Solvent selection
   7. Crud deposit analysis
      - Pretesting of decontamination solvent for concentration, effectiveness, efficiency, corrosivity, redeposition, temperature, pressure, etc.
        - Laboratory work
        - Pilot work
        - Reactor loop study
        - Full reactor
      - Determination of relationship between chemical reagents added and system responses so that system capacity can be designed to effectively handle released material
   8. Procedures (normal and emergency), administrative controls, environmental protection measures, and specification for task completion
   9. Specifications for decontamination system - facilities, equipment
   10. Waste management - high-, medium-, low-level wastes
   11. Health physics procedures
       - Personnel
       - Reactor and decontamination systems
       - Criticality and accountability considerations
C. Design and Implementation (construction and other pre-decontamination work)
   1. Indoctrination and training
      - Worker certification - skill, security, medical
      - Training - job objectives and procedures, safety, health physics
      - Work orientation and mockup training
   2. Development of site for decontamination facility
      - Clearing, grading, fencing, work and parking areas, storage, fire prevention
      - Returning of site to original state after work completion or developing site for other operation alternatives if decontamination facilities are temporary/mobile
   3. Process equipment (including placement, bulk materials, labor, subcontract)
      - Storage tanks, mix tanks, pumps, ion-exchange units, filters, heat exchangers, remote handlers
   4. Shielding (work enclosures)
   5. Waste-handling facilities
   6. Process building (temporary/mobile or permanent)
   7. Auxiliary buildings
      - Administration offices, change house, solid chemical storage (warehouse), chemical control laboratory
   8. Building and facility services
      - Electrical, lighting, dust collection, HEPA filtration, HVAC, plumbing, communications, etc.
   9. Process piping, insulation, instrumentation, electrical
   10. Utilities (yard services): electrical generation, plant air, water treatment-demineralization, water cooling
   11. Nonprocess equipment: transportation, office furnishings, shop equipment, laboratory equipment
   12. Freight charges
   13. Construction costs (engineering and construction company)
       - Project management, scheduling, cost control, procurement
       - Engineering, design and drafting
       - Home office: procurement, administration, overhead
       - Field office: construction supervision, support, travel, living expenses, overheads, tools, equipment rental
       - Temporary facilities
       - Legal: licenses, permits, fees, other charges
       - Taxes, insurance
       - Contractor fee
   14. Safety and security
   15. Inspection, quality assurance
   16. Inflation cost allowance
   17. Construction contingency allowance
   18. Interest expense during construction

TABLE 1.2. Operating and Maintenance Costs During Decontamination

A. Labor
    - Operating labor
    - Maintenance and repair labor
    - Operating and maintenance supervision and support
    - Payroll burden

B. Overhead: travel, indirect labor, technical services, procurement, communications, administration, etc.

C. Training: decontamination operators, supervision, and support staff

D. Health Physics
    - Radiation monitoring (personnel and equipment surveys): personnel external and internal dosimetry, protective clothing and equipment, laundry, radiation monitoring equipment, metrology, medical, record keeping, administration

E. Safety: general work conditions, chemical toxicity, industrial hygiene, fire prevention, training

F. Security

G. Quality Assurance
    - Inspection
    - Laboratory
    - Corrosion testing: coupons, probes, test rigs, testing

H. Materials
    - Decontamination and other processing chemicals
    - Ion-exchange resins
    - Filter elements: liquids, HEPA, etc.
    - Operating supplies
    - Maintenance and repair supplies

I. Utilities
    - Electricity
    - Steam
    - Water: cooling and demineralized
    - Air, inerting gases, and other gases

J. Equipment Rental

K. Contractor Services (nuclear facilities chemical cleaning contractor)
    - Contractor labor
    - Contractor overhead, fees, profit, etc.
    - Travel and living expenses

L. Waste Management
    - Collection
    - Temporary storage
    - Processing: concentration, solidification, compaction, incineration, chemical treatment
    - Packaging, containers
    - Shipping
    - Permanent storage and disposal

M. Fuel Handling (concentrated decontamination)
    - Removal, reinstallation, fuel element accountability

N. Recommissioning of Reactor System
    - Passivation of reactor system surfaces
    - Restoration of system chemistry
    - Hydrostatic testing, dynamic testing
    - Startup
    - Followup monitoring during reactor operation

O. Cleanup of Decontamination Facilities; preparation of permanent decontamination facilities for idle period, removal of temporary equipment

P. Regulatory Permits, Licenses, Fees

Q. General
    - Administration
    - Legal
    - Insurance, taxes
    - Facility security
    - Public relations
    - Financial: depreciation, debt service, including maintenance of working capital

R. Contingency
    - Leak handling and cleanup
    - Longer-than-planned operation
    - Other

obsolete equipment. If a permanent decontamination facility is built, additional operating costs to be considered are those for its continued maintenance, overhead, administration, financing or debt service, depreciation, insurance, taxes, and licenses.

1.1.1.4 Outage Replacement Power Costs

A major cost during decontamination of a nuclear reactor system can be the net cost for replacement power, either from the utility's own generators or from other utilities. This downtime cost is the difference between meeting the same demand with replacement power and meeting it with the electricity that would be generated if no downtime occurred. Zima et al. (1981) discuss the complex factors involved in this downtime cost. Briefly, the factors are the mix, type, and number of power plants that any one utility system has; whether the utility has more base-load power available than intermediate or peaking power; whether "wheeled" power from another utility to replace the lost power is less expensive than the utility's own power; daily, weekly, and seasonal variations in power demand; and the amount of power needed (interruptible power may be stopped).

Replacement power costs must be considered for the downtime during decontamination and for other downtimes for planned and unscheduled reactor maintenance and repair. These latter downtimes should be for shorter durations following reactor decontaminations.

1.1.2 Continued Reactor Operations

The overall costs and income from a reactor that is not decontaminated are determined using these three elements: 1) income from the sale of power (and perhaps process heat), 2) reactor operating costs, and 3) cost for replacement power during outages for routine or unscheduled maintenance. As in Section 1.1.1, the present values of these costs and incomes should be used. The income and cost elements and an economic evaluation of a nuclear reactor design are discussed by NUS Corp. (1969).

1.1.2.1 Income from Power Sales

The primary income for a nuclear reactor facility is from the sale of electric power. Secondary sources of income may be from the sale of thermal energy as process heat, if a user is nearby. The latter source of income would be very minor, if any.

1.1.2.2 Reactor Operating Costs Without Decontamination

Reactor operating costs consist of the following: staff payroll, fringe benefits, consumable supplies and equipment, outside support services, miscellaneous, general administration, waste disposal, nuclear liability insurance, and fuel. These costs include those for maintenance. Principal elements of these costs are given in Table 1.3.

TABLE 1.3. Reactor Operating Costs

A. Staff Payroll
   - Operations
   - Maintenance
   - Technical support
   - Supervision
   - Clerical and services

B. Fringe Benefits
   - Pension plans
   - Group insurance
   - FICA contributions
   - Other

C. Consumble Supplies
   - Ion-exchange resins and regeneration chemicals
   - Boric acid, etc. for PWR control
   - Fouling prevention chemicals
   - Water treatment chemicals
   - Gases (nitrogen for inerting, helium, etc.)
   - Water
   - Other utilities
   - Oil and lubricants
   - Maintenance materials
   - Other

D. Consumable Equipment
   - Filters
   - Control rods
   - Neutron detectors
   - Fuel channels
   - Other

E. Outside Support Services
   - (all services obtained other than from normal plant staff)
   - Dosimetry/film badge processing
   - Laundering of contaminated clothing
   - Bioassays
   - Major equipment overhauls
   - Consultants
   - Personnel for special tasks such as equipment maintenance and repair, refueling
   - Other

F. Miscellaneous
   - Training new staff
   - Requalification of licensed operators
   - Annual operating fees
   - Property and equipment rental
   - Travel
   - Licenses and fees
   - Public relations
   - Fuel and upkeep of station vehicles
   - Office supplies
   - Other

G. General and Administration
   - Financing and working capital maintenance
   - Taxes and miscellaneous insurance
   - Depreciation

H. Waste Disposal

I. Nuclear Liability Insurance

J. Other Overheads

K. Fuel

The costs in Table 1.3 usually recur annually and are nearly the same from year to year. Nuclear fuel costs, however, are not evenly distributed. Calculation of this cost is complicated (NUS Corp. 1969). In any power plant, the fuel costs can be considered to fall into three broad categories: 1) net fuel material consumption cost, 2) service and process costs, and 3) indirect costs, which include interest on borrowed money, taxes, and costs associated with the time value of money. Fuel costs will probably be unaffected by a reactor system decontamination and, therefore, may not be needed in a benefit-cost calculation.

For further information on fuel cost calculations and more detail on other nuclear reactor power generation costs, refer to the report by NUS Corp. (1969).

1.1.2.3 Outage Replacement Power Costs

The duration of outages for planned and unscheduled maintenance and repairs at reactors that are not decontaminated is likely to be greater than that at reactors that are decontaminated. See Section 1.1.1.4 for a discussion of replacement power costs.

1.2 RADIATION EXPOSURE BENEFIT-COST ANALYSIS

For a normal decontamination project to be beneficial, the objectives of reducing radiation exposures and the overall cost of generating power must be satisfied. In this benefit-cost analysis, dollar values expressed as dollars/man-rem are assigned to radiation exposure. However, the values to assign are difficult to select. Kathren and Selby (1980), in their discussion on the risk, cost, and benefit of reducing exposure, relate the difficulties of putting monetary values on the effects of radiation exposure to personnel and of comparing the values obtained with the cost of reducing exposure. They cite literature-reported values that range from tens of dollars to a few tens of thousands of dollars per man rem. LeSurf and Tilbe (1980) note that the many attempts to evaluate the cost of a man-rem have used different ground rules and reached different values, some quite arbitrary. They also cite the 1975 NRC recommendation of a budgetary value of $1000 for 1 man-rem of environmental exposure. As LeSurf and Weyman (1981) point out, a key consideration is the availability of skilled radiation workers to perform the tasks required. They further state that the most common values used for radiation workers are in the range of $5000 to $7000. Demmitt et al.(1981) also note the complexity of occupational radiation dose assessment, but recommend a "guideline estimate" of $3000 to $5000 as reasonable for the value of a man-rem saved through application of decontamination procedures. A utility considering decontamination of a nuclear reactor system should select a range of values for dollars/man-rem that are appropriate for their particular situation.

Before dollar costs can be calculated, exposure reductions must be estimated. LeSurf and Weyman (1981) give the following equation for a specific task, which can be used in this determination:

$$S_t = (D_r \times DF) - (D_r)$$

where S_t is the radiation dose for a task, t, saved by decontamination; D_r is the actual dose received in performing the task after decontamination (assuming the task would be performed in the same way); and DF is the decontamination factor, or the ratio of activity present before decontamination to activity afterwards. The overall dose saving (ODS) is:

$$ODS = \sum_{t=1}^{t=n} S_t - (D_d + D_w)$$

where D_d is the dose expended in performing the decontamination and D_w is the dose received in disposing of the waste arising from decontamination.

After determination of whether a savings in occupational dose can be accomplished by performing a decontamination, radiation exposure benefit-cost for decontamination can be determined by comparing the radiation exposure costs of reactor operations with those obtained for the decontamination and for operations following decontamination.

1.2.1 Continued Reactor Operations

Radiation exposure for continued reactor operations with no decontamination can be projected from exposure records.

1.2.2 Exposure During Decontamination

This exposure can be predicted before decontamination from the existing conditions and the conditions expected for tasks during the decontamination operation. All decontamination operations, including waste handling and disposal, would be included.

1.2.3 Reactor Operations After Decontamination

This exposure can be predicted using the expected decontamination factors for each equipment item or area, the number of personnel expected to be used in each area, and the duration of the work performed in each area. An estimate of the rate of radiation buildup during reactor operation following decontamination will also be needed.

APPENDIX

ALTERNATE METHOD OF BENEFIT-COST ANALYSIS

An alternate method of benefit-cost analysis for nuclear power plants developed by Hall et al. (1979), which is based on extensive experience, can be used to determine the merits of a potential system decontamination. The method, discussed briefly by Demmitt et al. (1981), employs two indices: 1) an apparent reduction potential (ARP), and 2) an achievability index (AI).

The ARP can be used to calculate the relative potential for reducing the occupational radiation exposure associated with various tasks within radiation zones by decontaminating the work area before performing the tasks. The ARP is derived by:

$$ARP = \alpha \cdot E \cdot D^n$$

where α = an experience factor from 0.8 to 1.2
E = accumulated exposure for task
D = dose rate at work site, rem/h
n = an experience factor from 0.2 to 0.4.

The coefficients α and n are calculated from plotted historical data, with total accumulated occupational radiation exposure as the ordinate and work area radiation level (rem/h) as the abscissa. A linear regression analysis is performed to establish the best-fitting curve for the data. The experience factors α and n are somewhat variable from plant to plant, but are estimated to be about 1.0 and 0.33, respectively. The equation was defined such that an ARP value greater than 1.0 indicates a good potential for exposure reduction; a value less than 1.0 indicates little or no potential.

The ARP is used to indicate where to look for improvements. The AI, on the other hand, indicates which alternative to use from an ALARA viewpoint.

The AI is a measure of the socioeconomic desirability of a proposed action and uses the net cost, C, of an action along with average individual radiation exposure and exposure limits. The equation for AI determination is:

$$AI = \left[\frac{k\ R\ G\ E_{ai}\ E_{ag}\ E_{qi}\ E_{qg}}{C\ L_a^2\ L_q^2}\right]^B \times P\ F_d$$

where B = +1 if exposure is decreased and cost increased by the action
B = -1 if exposure is increased and cost decreased by the action
k = a dimensionless constant = 1.0
R = net exposure difference, rem
G = annual salary and overhead of employees, dollars

C = net cost of action, dollars

E_{ai} = maximum annual individual exposure, rem

E_{ag} = average annual individual exposure, rem

E_{qi} = maximum quarterly individual exposure, rem

E_{qg} = average quarterly individual exposure, rem

L_a = annual exposure limit, rem

L_q = quarterly exposure limit, rem

P = planning and coordination factor (ranges from 0.75 to 1.33)

F_d = dose rate factor.

As with a benefit-cost (B/C) ratio, an AI of 1.0 is a break-even point. A B/C or an AI greater than 1.0 indicates that benefits from an action outweigh its costs and that the action may be undertaken. An action with B/C or AI less than 1.0 should not be undertaken. The larger the AI value of an action, the more strongly the action is justified by ALARA criteria.

The NRC Research Information Letter 6.RIL80 (Nuclear Safety 1980) states that with proper data inputs, ARP-AI methodology can be used to assess quantitatively the usefulness and effectiveness of the guidance in the Facility and Equipment Design Section of Regulatory Guide B.8 as well as nearly all the other sections in Regulatory Guide 8.8.

For further details on the derivation of ARP and A1, refer to Hall et al. 1979.

2.0 REGULATORY COMPLIANCE

A reactor decontamination must comply with numerous federal, state and local requirements. The primary federal agencies with regulations that apply are the Nuclear Regulatory Commission (NRC), Environmental Protection Agency (EPA), Occupational Safety and Health Administration (OSHA), and Department of Transportation (DOT). Their involvement will vary depending upon site specific requirements, the decontamination process and reagents used, the magnitude of effluents, the relative safety of the project, and the nature of wastes to be removed from the site. After a plant site is selected for a decontamination project, the concerned state(s), counties, and municipalities in the vicinity of the plant can be identified. Their respective departments of health, labor, environmental protection, transportation, and emergency services may also be involved. Once a plant site and a decontamination process are selected, the need for regulatory interfaces and applicable regulations can be more clearly identified. A MORT chart that illustrates the elements of regulatory compliance is shown in Figure 2.1. Approval of planned actions prior to decontamination is required only in unusual cases as discussed below.

2.1 NUCLEAR REGULATORY COMMISSION

The NRC has the primary responsibility for regulation of nuclear reactors. Specifically, 10 CFR 50.59 provides for changes, tests, and experiments, including decontaminations. (Because of its importance to the subject, 10 CFR 50.59 is reproduced as an appendix to this section.) If decontaminations are adequately addressed in the safety analysis report or are so designed that do not require changes in the technical specifications, and do not involve unresolved safety questions, the NRC requires only that a safety evaluation be prepared and an annual (or more frequent) report on the decontamination be filed.

Collection and analysis of the data called out in Table 2.1 should assist the licensee in determining whether NRC notification will be required.

2.1.1 Permitted Under 10 CFR 50.59

Decontaminations that involve only a change in the facility as described in the Safety Analysis Report (SAR) or a change in the procedures as described in the SAR, but do not involve a change in technical specifications or an unreviewed safety question may be performed without NRC approval persuant to 10 CFR 50.59. Such decontaminations are documented in the licensees periodic safety evaluation report required by 10 CFR 50.59.

2.1.2 NRC Approval Required

For those unusual cases where the licensee's safety analysis of a specific decontamination indicates an unreviewed safety question is involved or changes to the technical specifications are required, the NRC should be informed through the normal licensing process.

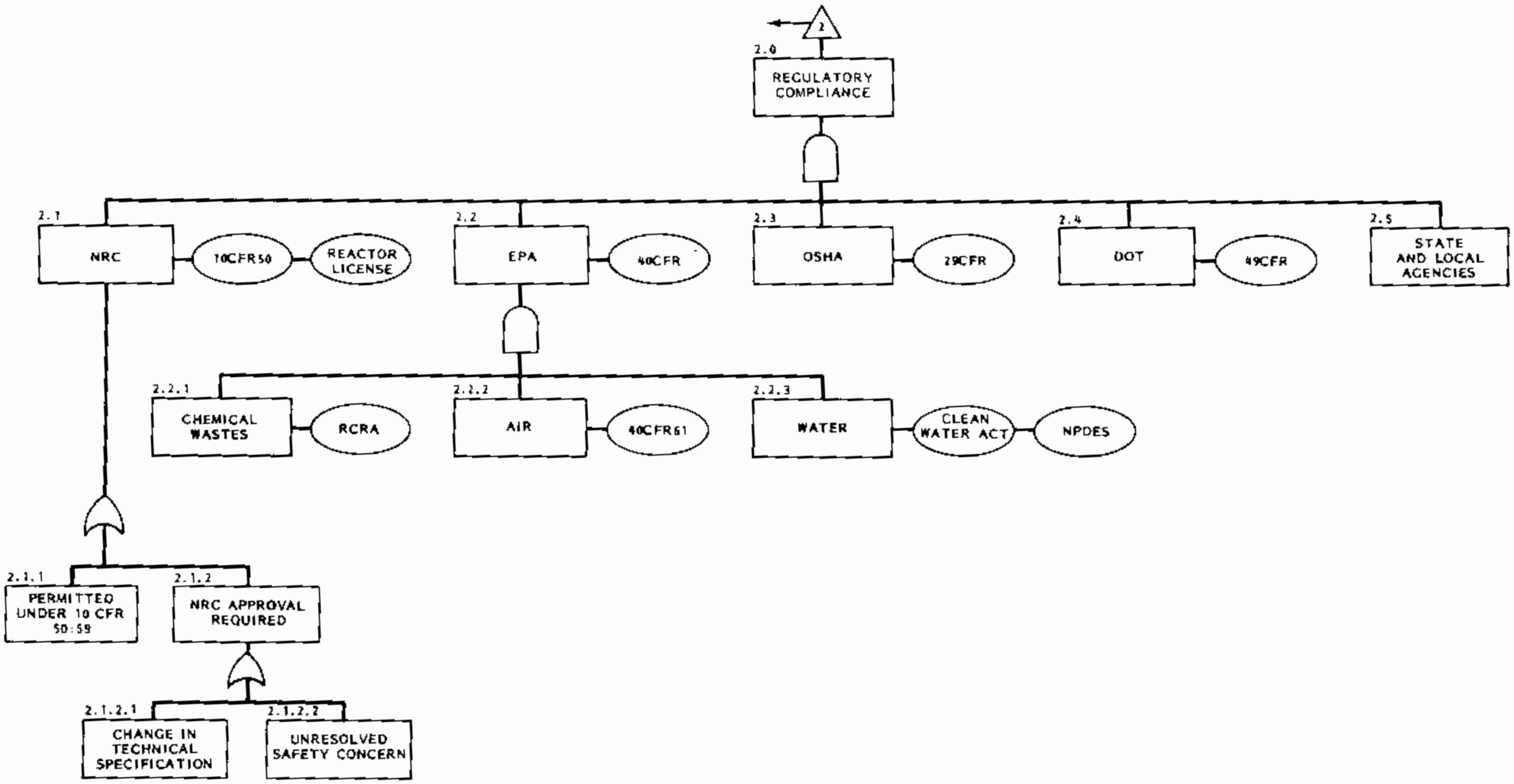

FIGURE 2.1. Regulatory Compliance

TABLE 2.1. Preliminary Decontamination Evaluation (for file)

1. Name of facility.

2. Scheduled date for decontamination.

3. Scheduled date for restart following decontamination.

4. The specific equipment or system to be decontaminated.

5. Will decontamination or resumption of operation thereafter require a technical specification change or other license amendment?
   If answer is yes, what, in general, will these be? What are the scheduled date(s) for submitting proposed licensing action and supporting information?
   If answer is no, has the proposed decontamination been reviewed by your Plant Safety Review Committee to determine whether any unreviewed safety questions are associated with the decontamination (reference 10 CFR 50.59)?

6. Important decontamination considerations, e.g., the decontamination method proposed, the basis for selecting the proposed method, compatibility of system materials and decontamination solutions, etc.

7. The reason(s) that the decontamination is necessary.

8. A description of the management system that will be applied to the decontamination, including qualifications of the decontamination staff, training programs, quality assurance programs, mechanism of approval of staff decisions, public relations, etc.

9. A description of the waste management system for radioactive and hazardous chemical wastes in solid, liquid, and gaseous forms.

10. A draft assessment of the environmental impact of the proposed decontamination.

11. A list and description of emergency procedures for the decontamination operation.

12. A description of the health and safety program for the decontamination including fire protection.

13. Plans for tests, inspections, and recertification of reactor systems prior to startup.

14. A description of proposed documentation and reports.

2.1.2.1 Changes in Technical Specifications

Technical specifications are reactor specific but are not expected to preclude decontamination. Chloride and oxygen water chemistry limits normally apply only when the system exceeds 250°F. The reactor technical specifications should be reviewed with respect to the planned decontamination.

2.1.2.2 Unresolved Safety Concerns

Normally it will be possible to perform a decontamination without encountering an unresolved safety concern. Such concerns are possible, however, and Table 2.2 (based on 10 CFR 50, Appendix A) addresses those situations. The sections below are categorized and numbered to correspond with the safety criteria of 10 CFR 50, Appendix A. While an attempt has been made to include all foreseeable decontamination situations, the list should be regarded as incomplete and the licensee should determine if an unreviewed safety question is involved in the planned decontamination.

2.2 ENVIRONMENTAL PROTECTION AGENCY

The EPA has responsibilities for the protection of the offsite environment. The designated EPA functions may be performed by the state if the state has procedures and regulations equivalent to those of the federal agency and an agreement has been made between the state and the EPA.

2.2.1 Chemical Wastes

Disposal of waste chemicals is currently regulated according to the life cycle of the chemical. Anyone who manufactures, uses, or disposes of a regulated chemical must do so in compliance with the Resource Conservation and Recovery Act (RCRA) (40 CFR 260-265). The criteria are well established, and this should not be an impediment to decontamination.

2.2.2 Air

Air quality is regulated by the EPA through the Clean Air Act (40 CFR 50, 60, and 61). A designated "air pollutant source" is not likely to result from a reactor decontamination. Airborne releases are expected to be very small, and in any case, well within EPA limits.

2.2.3 Water

Liquid effluents are regulated under the National Pollutant Discharge Elimination System (NPDES) (40 CFR 122-125) and the Clean Water Act. An NPDES permit must be obtained and complied with if any liquids are to be discharged to navigable waters.

TABLE 2.2. Unresolved Safety Concerns That May Be Encountered in Decontamination

I. OVERALL REQUIREMENTS

1. Protection Against Natural Phenomena

If decontamination or decontamination waste management activities could substantially increase the severity of the effect of an anticipated natural phenomena (earthquake, tornado, flood, etc.) this safety aspect requires additional review.

2. Fire Protection

If decontamination requires the construction of new or temporary facilities that are important to safety (i.e., barriers to the dispersion of radioactive materials) and these facilities will not meet the fire protection standards of other station structures that are important to safety (noncombustible and heat resistant material, fire detection, and fire fighting systems, etc.) then an unreviewed safety question exists.

II. PROTECTION BY MULTIPLE FISSION PRODUCT BARRIERS

3. Reactor Coolant Pressure Boundary

If chemicals used in decontamination, or chemicals that may remain in crevices or dead legs in the reactor system could increase the probability of abnormal leakage, of rapidly propagating failure or of gross rupture of the reactor coolant pressure boundary then an unreviewed safety question may be involved. (A combination of purity control of decontamination reagents, corrosion testing and inspection of representative pressure boundary materials following decontamination can be used to assure that the probability of a reactor coolant pressure boundary failure is not increased over that evaluated in the SAR.)

4. Containment

If temporary piping, utilities, etc. (As might be installed to facilitate decontamination) interferes with the ability to maintain a leak tight containment for as long as postulated accident conditions require, and provisions are not made to immediately eliminate interference, then an unreviewed safety question may exist.

III. PROTECTION AND REACTIVITY CONTROL SYSTEMS

5. Protection System Functions

The compatibility of the decontamination chemicals and the post decontamination testing program should serve to assure that functioning of the control rod drive mechanisms has not been degraded. Degradation of this system would result in an unreviewed safety concern.

IV. FLUIDS SYSTEMS

6. Quality of Reactor Coolant Pressure Boundary

All reactor coolant pressure boundary materials including packing and gasket materials, should either be tested and shown to be unaffected by the decontamination process or be inspected and replaced as necessary following decontamination. Failure to do this could result in an unreviewed safety question regarding the quality of the reactor coolant pressure boundary.

TABLE 2.2. (continued)

7. Fracture Prevention of Reactor Coolant Pressure Boundary

   Decontamination should not decrease the margin of safety provided by the reactor coolant pressure boundary under operating, maintenance, testing and postulated accidents conditions with respect to non-brittle behavior and fracture propagation. Any decrease in the safety margin specified in the SAR represents an unreviewed safety question. The effect of decontamination on the steam generator tubes that have experienced denting may pose special concerns.

V. REACTOR CONTAINMENT

8. Piping Systems Penetrating Containment

   If decontamination piping systems which penetrate containment are to remain in place during the next operating period they shall be provided with leak detection, isolation, and containment capabilities having redunancy, reliability, and performance capability equivalent to similar reactor systems that penetrate containment. Failure to meet this criterion would constitute an unreviewed safety question.

VI. FUEL AND RADIOACTIVITY CONTROL

9. Control of Releases of Radioactive Materials to the Environment

   The decontamination preparation shall include means to control the releases of radioactive materials in gaseous and liquid effluents and to handle radioactive solid wastes produced from decontamination in a manner equivalent or superior to that described in the SAR. Likewise sufficient holdup capacity shall be provided for the retention of gaseous and liquid decontamination waste in a manner equal or superior to that provided for effluents containing similar levels of radioactivity generated during operation. Inability to limit effluents to the concentrations predicted in the SAR, insufficient holdup capacity, or failure to provide equivalent integrity of the hold up system to similar systems covered in the SAR may constituent an unreviewed safety question.

10. Radioactivity Control

    Systems that contain decontamination solution that have radioactive materials present, or that process decontamination waste shall be designed: 1) to permit appropriate inspection and testing of components important to safety before use (and periodically if reuse is anticipated); 2) with suitable shielding for radiation protection; and 3) with appropriate containment, confinement, and fitting systems. Failure to provide a margin of safety equivalent to that described in the SAR for the radioactive waste treatment system may constitute an unreviewed safety question.

11. Prevention of Criticality

    Where criticality in decontamination solution is not prevented by the small quantity of fissile material in the reactor system outside the fuel assemblies, as may be the case following a serious fuel rupture accident, an unreviewed safety question should be considered to exist.

12. Monitoring Waste Storage

    Systems provided in decontamination waste storage and handling areas to detect excess radiation levels and initiate appropriate safety action shall be equivalent to those described in the SAR in waste handling areas. Failure to provide equivalent systems may constitute an unreviewed safety question.

2.3 OCCUPATIONAL SAFETY AND HEALTH ADMINISTRATION

This agency has regulatory authority over aspects of decontamination involving worker health and safety. A memorandum of understanding between OSHA and NRC makes it unlikely that OSHA will become involved unless there is a request by NRC or an employee complaint. The OSHA regulations are prescribed in Part 29 of the Code of Federal Regulations (29 CFR).

2.4 DEPARTMENT OF TRANSPORTATION

Compliance with DOT regulations is necessary for the shipment of decontamination chemicals to the site and the shipment of solidified decontamination waste offsite. The criteria and procedures are well established in Part 49 of the Code of Federal Regulations (49 CFR).

2.5 STATE AND LOCAL AGENCIES

States may have some regulatory authority over decontamination if there is an agreement with the federal government to administer the EPA or OSHA acts within the state. Since state and local governments are prohibited from regulating interstate commerce, they are not expected to have other regulatory roles.

APPENDIX

10 CFR PART 50.59

§50.59 Changes, tests and experiments

(a)(1) The holder of a license authorizing operating of a production or utilization facility may (i) make changes in the facility as described in the safety analysis report, (ii) make changes in the procedures as described in the safety analysis report, and (iii) conduct tests or experiments not described in the safety analysis report, without prior Commission approval, unless the proposed change, test or experiment involves a change in the technical specifications incorporated in the license or an unreviewed safety question.

(2) A proposed change, test, or experiment shall be deemed to involve an unreviewed safety question (i) if the probability of occurrence or the consequences of an accident or malfunction of equipment important to safety previously evaluated in the safety analysis report may be increased; or (ii) if a possibility for an accident or malfunction of a different type than any evaluated previously in the safety analysis report may be created; or (iii) if the margin of safety as defined in the basis for any technical specification is reduced.

(b) The licensee shall maintain records of changes in the facility and of changes in procedures made pursuant to this section, to the extent that such changes constitute changes in the facility as described in the safety analysis report or constitute changes in procedures as described in the safety analysis report. The licensee shall also maintain records of tests and experiments carried out pursuant to paragraph (a) of this section. These records shall include a written safety evaluation which provides the bases for the determination that the change, test or experiment does not involve an unreviewed safety question. The licensee shall furnish to the appropriate NRC Regional Office shown in Appendix A of Part 20 of this chapter with a copy to the Director of Inspection and Enforcement, U.S. Nuclear Regulatory Commission, Washington, D.C. 20555, annually or at such shorter intervals as may be specified in the license, a report containing a brief description of such changes, tests, and experiments, including a summary of the safety evaluation of each. Any report submitted by a licensee pursuant to this paragraph will be made a part of the public record of the licensing proceeding. In addition to a signed original, 39 copies of each report of changes in a facility of the type described in §50.21(b) or §50.22 or a testing facility, and 12 copies of each report of changes in any other facility, shall be filed. The records of changes in the facility shall be maintained until the date of termination of the license, and records of changes in procedures and records of tests and experiments shall be maintained for a period of five years.

3.0 DECONTAMINATION PROCESSES

In the broadest terms, decontamination is defined as the removal of superficial dirt and oxides from surfaces. Decontamination of a nuclear reactor implies the removal of radioactive species from system components. Decontamination may be required as a result of contamination from activated corrosion products or fuel element failures. The type of decontamination undertaken will depend upon which of these conditions predominates and upon why the decontamination is needed. The primary process specific considerations are outlined in the MORI chart shown in Figure 3.1.

In general, a licensee contemplating a primary system or major component decontamination will be selecting from among demonstrated processes whose safety and effectiveness is known. However, to aid the licensee in judging the degree of development of novel processes and to assist in the development of new processes, the typical development/testing program is discussed in an Appendix to this section.

The selection of a restorative decontamination process presupposes that the plant will be capable of operating for an extended period after the decontamination. Because processes used for decontamination as a precursor to decommissioning do not have the same goal, they can be more aggressive, with significantly higher decontamination factors (DFs).

Selection of a decontamination process requires considerable understanding of the corrosion product layers and crud deposits that form on coolant system surfaces. In general, these deposits differ in BWRs and PWRs because of differences in coolant chemistry and construction materials. Because of an oxidizing chemistry, BWR coolants favor the formation of the higher iron oxidation state (hematite) in an outer crud layer and ferrite in an inner crud layer. Corrosion products in PWRs are composed of a loose crud layer on top of a magnetite tightly adherent spinel that incorporates chromium in the +3 oxidation state, which is insoluble without further oxidation. Table 3.1 lists some of the operating conditions for BWRs and PWRs.

When decontamination is contemplated because of fuel element failure, different processes may be used. Debris from ruptured fuel elements is most often sorbed onto low-temperature films or maintained in suspension in the coolant. Filtration and ion-exchange resins are used to purify coolant water. Chemical removal of $UO_2 \cdot PuO_2$ residues and fission products usually involves the use of high-concentration oxidizing reagents, although some success has been reported in mobilizing fuel debris by undercutting, that is, by dissolving the oxide layer to which it adheres.

The ideal goal of any decontamination process is to completely remove all traces of foreign material from a system or component. In practice, decontamination of nuclear facilities is considered complete when maximum effectiveness or a preset objective has been attained.

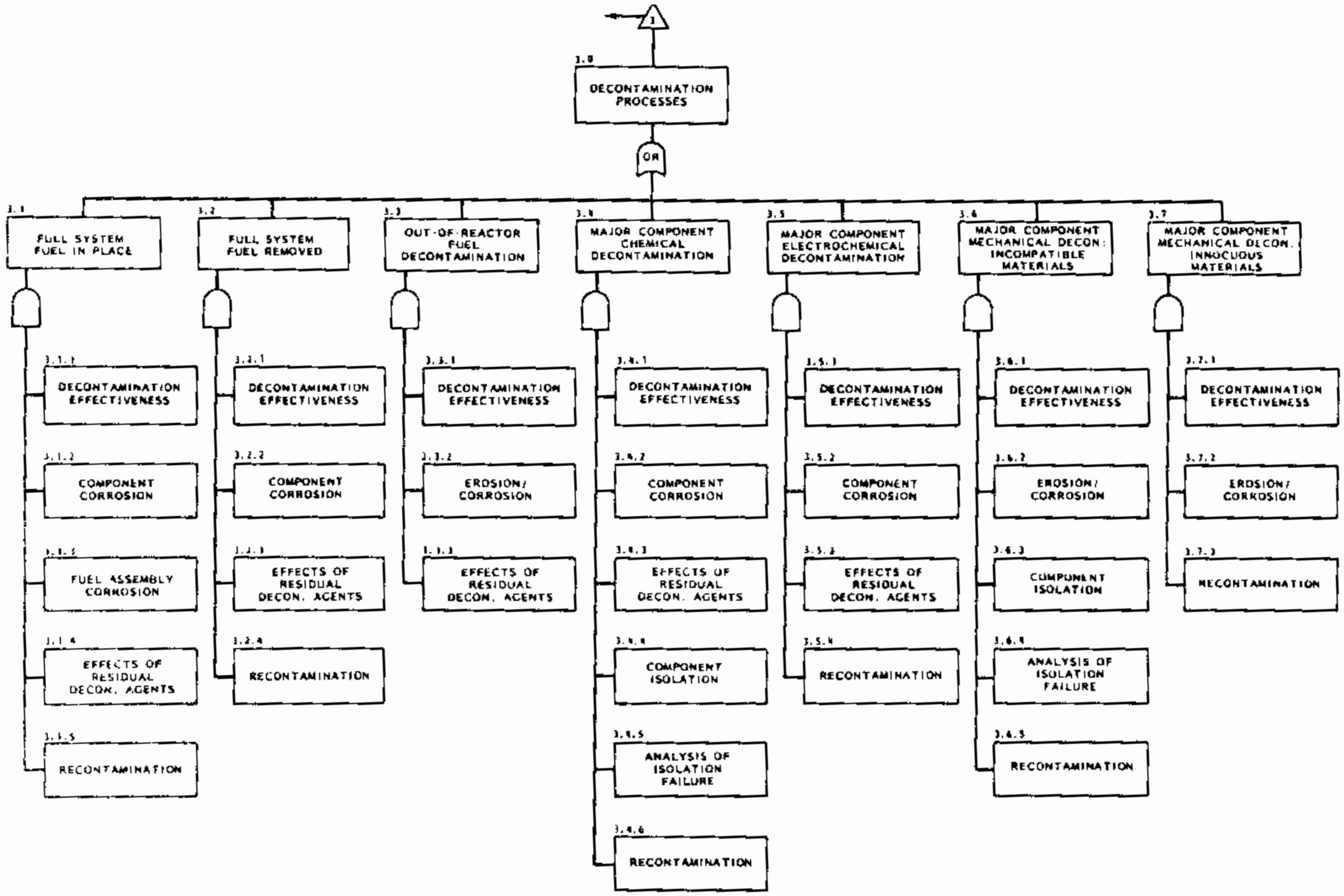

FIGURE 3.1. Decontamination Processes

TABLE 3.1. Typical Operating Conditions for BWRs and PWRs[a]

	BWR	PWR
Chemistry		
Boric acid, ppm B	no additive	0 - 3000
LiOH, ppm Li	no additive	0.2 - 2.2
H_2, cc/kg H_2O at STP	no additive	15 - 60
O_2, ppm	0.2 - 0.3	0.005
pH	5.6 - 8.6	4.5 - 10.2
Cl^-, ppm	0.2	0.15 max
Temperature, °C		
Core inlet	278	292
Core outlet	287	325
Coolant Volumes (1000 MWe)		
Primary coolant volume, ℓ	4×10^5	3.5×10^5
Core flow rate, ℓ/min	8×10^5	1×10^6
Feed flow, ℓ/min	10^5	
By-pass cleanup, ℓ/min	10^3	3×10^2
Materials, area in m^2		
Inconel		1.77×10^4
Zircaloy	1.1×10^4	6.07×10^3
Stainless steel	4.0×10^4	2.17×10^3
Cobalt alloys		1×10^3

(a) Choppin et al. 1979.

If the motivation for system decontamination is to permit inspection or repair of major components at reduced exposure rates, a "campaign" approach yielding DFs up to 20 might be necessary. These major campaigns are expensive, and may require an extended reactor outage while auxiliary equipment for liquid handling is installed. Relatively concentrated reagents are used that are more corrosive to components of the system but are well within safety limitations. More frequent decontamination using relatively mild, dilute reagents may reduce average primary system radiation levels sufficiently to allow routine maintenance with an overall saving in personnel exposure. Acceptable decontamination factors for these processes may be as low as 2 and still be beneficial.

Decontamination factors for some processes may be relatively high, but because of continued contact of contaminated solutions with the newly cleaned surfaces, redeposition of the contamination may occur, resulting in little net gain. Additionally, areas that were previously clean may become contaminated and constitute an even larger radiation exposure problem than before. Recontamination is sometimes minimized by decreasing the contact time of the solutions with the surfaces, but this also decreases the initial decontamination effectiveness. For adequate decontamination, it is necessary to select processes and procedures that balance an acceptable DF with minimal recontamination.

Whichever decontamination process is performed, it will fall into one of the categories shown in Figure 3.1. Full-system decontamination is chemical in nature and may be performed with the fuel in place or removed. The types of processes and chemicals available vary according to the fuel location. If the fuel is removed for the decontamination, there are incentives for cleaning it prior to returning it to the reactor. However, any decontamination process applied to the fuel should be discussed with the fuel vendor because of warranty considerations. When only a major component is decontaminated (not the entire reactor system), not only a wide range of chemical methods, but also electrochemical and mechanical methods are available. The methods and concerns of fuel decontamination and of major-component decontamination are discussed in this section.

3.1 FULL-SYSTEM DECONTAMINATION: FUEL IN PLACE

Large-scale restorative decontaminations are usually chemical in nature and involve physical modifications of the plant, such as connective piping and valving for introducing and removing decontamination reagents (Perrigo et al. 1979). Leaving the fuel in place during decontamination may shorten the outage time and provide some cleaning of the fuel. Clean fuel is thought to contribute to lower radiation buildup rates during the next operating period. In practice, leaving the fuel in place limits the use of concentrated chemicals and precludes a "fill-and-drain" procedure.

Chemical methods are broadly divided into processes using concentrated (5% to 10%) and dilute (0.1% to 1.0%) solutions. Concentrated processes are typically of the "campaign" type in which the reactor may be out of service for an extended period, depending on its readiness for decontamination, and overall DFs may run up to 20 or higher. Because of the greater corrosiveness of concentrated decontaminations and the extended shutdown involved, campaign decontaminations might be performed only once or twice during the service life of the reactor. Conversely, dilute decontaminations may be performed more frequently, depending on need, yielding overall DFs of 2 to 4 each time. In such cases, the loss of material by corrosion should not exceed some nominal amount (in the range of 10%) of the designed corrosion allowance for fuel, components, and systems that are in contact with the solution (FitzPatrick et al. 1981). Dilute decontaminations minimize waste volumes (Perrigo and Divine 1979) and do not require fuel removal or isolation of reactor components. Full-system decontaminations with the fuel in place use relatively dilute solutions because of possible heat transfer and corrosion concerns. A more complete description of chemical decontamination processes is given in Section 3.4.1.

3.1.1 Decontamination Effectiveness

One of the key factors of any decontamination method is its effectiveness in reducing radiation exposure rates in work areas. The effectiveness is a function of the DF (the ratio of the original amount of radioactivity to the final amount) and the recontamination or redistribution of radioactive species during and following the decontamination process. In general, high DFs are associated with relatively high uniform corrosion rates. Recontamination or redeposition is likely under three conditions: 1) when there is pH, thermal, or radiolytic degradation of the decontamination chemicals, 2) in areas such as dead legs where decontamination solutions cannot be removed prior to degradation, or 3) when the corrosion layer becomes so thick that it can mechanically separate from the substrate.

Cohen (1969) lists the following factors to which the effectiveness and corrosiveness of a decontamination process are most sensitive:

- alloy composition
- physical metallurgy, heat treatment
- surface treatment (roughness, cold work)
- temperature of coolant, and hot-to-cold leg temperature difference
- velocity of coolant
- fluid pH
- accumulation of corrosion products
- concentration of coolant solutes
- dissolved gases
- hydrogen release (steam-generator tubes).

Components of the reactor coolant system will have operated under differing conditions. This will cause differences in the manner in which corrosion products and radionuclides have collected. Decontamination reagents should be chosen with these conditions in mind. There is presently no known dilute decontamination process capable of dissolving the debris of ruptured fuel elements from a system.

Choppin et al. (1979) list the following criteria for dilute decontamination:

- A dilute, mild, single-solution process should achieve a DF of at least 2.

- The decontamination process should operate effectively, without extending the shutdown unduly, at temperatures attainable with a combination of available pump and decay heat.

- The thermal and radiation stability of additives must be consistent with the use of dilute chemicals at the process temperature (possibly up to 200°C) over two or three days of operation. Continuous makeup and feed of additional reagents is acceptable. It is recognized that the thermal stabilities of many chelating agents in aqueous solutions (e.g., EDTA, EDTP, HEDTA, DTPA) deteriorate substantially at the upper end of this temperature range.

- The process must not promote plate-out of solubilized or suspended metals and oxides over a reasonable range of pH, oxidation potential, temperature, time, and radiation field conditions.

The effectiveness of a decontamination is ultimately determined by comparing radiation levels before and after the decontamination operation. A full survey of radiological conditions, taken after the reactor is shut down but prior to the decontamination, will provide the baseline data. Comparison of an identical survey, made after the decontamination but prior to restart, to the baseline survey data will permit the calculation of DFs and an assessment of the effectiveness. It is important that the surveys include measurements at locations where repairs and inspections are frequent. Exposure reductions at these locations will likely be the primary motive for the decontamination.

Average DFs of less than 2 may be acceptable if the DF of a subsystem or component of particular concern is sufficiently high. The measurement system and acceptance criteria should be established as part of the decontamination planning.

3.1.2 Component Corrosion

Extensive work has been undertaken to determine the corrosion rates of reactor materials exposed to dilute decontamination chemicals. The results of these efforts are not reported here. When the corrosiveness of a reagent is in doubt, the reagent should be evaluated in a test loop under relevant conditions to assure that corrosion rates are acceptable.

Effective decontamination processes have the potential to remove some of the base material. In establishing acceptable corrosion rates, the primary consideration is to assure that system components will not be damaged. FitzPatrick et al. (1981) recommend that for dilute decontamination, no single operation should use more than 10% of the designed corrosion allowance. Obviously, permissible corrosion rates will not be the same for all components, and certain types of corrosion should not be permitted. These include pitting, crevice corrosion, stress corrosion cracking, and caustic embrittlement. Particular concern should be given to 1) residual decontamination chemicals remaining in dead legs or crevice areas, which may cause excessive corrosion after restart, and 2) decomposition products from the decontamination concentrates that are incompatible with primary system materials.

3.1.3 Fuel Assembly Corrosion

There are generally three major construction materials in a fuel assembly: the zircaloy cladding of the fuel rods, the stainless steel support structure, and Inconel springs in the fuel spacers. Each material is in intimate contact with one or both of the others. Under normal operating conditions, each material is quite corrosion resistant, and little interaction is observed. During decontamination, consideration must be given to possible galvanic effects between the various alloys. Further, because components such as the springs are very thin, a uniform, low corrosion rate must be assured. This will prevent adverse mechanical effects by maintaining a smooth surface on the fuel and springs. Use of decontamination chemicals that leave no reactive residues is also required because of the many crevices in the fuel assemblies.

3.1.4 Effects of Residual Decontamination Agents

Historically, the dilute reagents of choice have been chelating agents, especially those containing carbon, hydrogen, nitrogen, and oxygen. Reagents of this type decompose under heat and radiation to relatively harmless products that are compatible with primary system materials. Not all reagents behave in this manner. Some have decomposition products with poor materials compatibility, while others decompose very little and consequently remain in the system for longer than recommended times.

3.1.5 Recontamination

In addition to effectively decontaminating the coolant system, the process and reagents used should not promote rapid recontamination upon startup. The following considerations should be addressed:

- The process should leave metal surfaces passive so that new corrosion films do not rapidly form and incorporate activated corrosion products upon restart.
- Solubilization or suspension of deposited metal oxides should be controllable so that existing or modified reactor coolant purification systems can remove the suspended activated species from the primary system.
- Any residual chemicals left in the system are compatible with subsequent reactor operation.

3.2 FULL-SYSTEM DECONTAMINATION: FUEL REMOVED

Removal of the fuel assemblies prior to system decontamination allows the use of concentrated reagents and the subsequent draining of the coolant loop to remove them. These solutions are more corrosive than dilute reagents and are generally more difficult to dispose of. Because of the more concentrated and costly waste, reactor systems are generally drained to remove concentrated solutions. This process is unacceptable for reactors with fuel in the core because draining would uncover the fuel and remove the necessary cooling.

Concentrated reagents could be used with the fuel in place if they were removed by a "feed and bleed" process. This is generally not an attractive option because it increases waste volumes. A more complete description of concentrated chemical decontamination is given in Section 3.4.1. Other concerns peculiar to concentrated decontamination processes are also discussed.

3.2.1 Decontamination Effectiveness

Concentrated solutions may be capable of effectively removing contamination in a single step, or may be used in a multistep process. Separate processes exist for the removal of activated corrosion products and fuel debris. These processes rely on various combinations of acids, complexants, and oxidizing agents for the removal of contamination.

Two-step processes for corrosion product removal have been most widely used for films generated in PWRs. The first step generally is an oxidizing procedure designed to convert chromium in the +3 oxidization state, and other reduced species, to a more soluble oxidized state. A typical example of a two-step process is the use of alkaline permanganate (AP) followed by a complexing and/or acid solution (i.e., an oxidizing step followed by a dissolution step).

Factors limiting effectiveness are generally the same as those discussed in Section 3.1.1. The more aggressive chemicals used in concentrated processes often yield overall DFs of up to 20 or higher. A quantitative measure of the effectiveness should be determined from a comparison of shutdown radiation survey data, as described in Section 3.1.1.

3.2.2 Component Corrosion

The higher DFs resulting from the use of concentrated reagents are obtained at the expense of significantly increased corrosion rates on virtually all components of the coolant system. These component corrosion rates can vary considerably in both magnitude and uniformity.

Considerable effort has been expended to establish the corrosion rates of potential decontamination solutions on reactor materials (see, for example, Ayres 1970 and Nelson and Divine 1981). Early in the process selection stage, candidate processes should be evaluated in terms of their established corrosion rates (when available) and the materials of construction. This evaluation will permit the elimination of obviously nonviable alternatives and/or permit early analysis of how best to isolate incompatible components from the concentrated solutions. There are few criteria for judging the acceptability of corrosion rates. Since decontaminations with concentrated solutions are done less frequently than dilute processes, a corrosion allowance of more than 10% (as recommended by FitzPatrick et al. 1981) may be acceptable.

3.2.3 Effects of Residual Decontamination Agents

Unlike typical dilute reagents, the concentrated solutions often do not decompose to harmless by-products after extended exposure to heat and radiation. As a consequence, greater care must be taken to assure that as little residual reagent as possible remains in the system upon startup. This usually requires multistep procedures for filling and flushing the coolant system and special connections to permit the flushing of dead legs. A consequence of these filling and flushing procedures is the generation of large volumes of liquid waste. The treatment and disposal of these wastes adds to the time and cost of the decontamination effort.

3.2.4 Recontamination

The considerations for post-decontamination radiation buildup in systems decontaminated with concentrated reagents are essentially the same as those outlined in Section 3.1.5 for dilute decontamination. Many concentrated decontamination reagents require a separate passivation step to minimize recontamination.

3.3 OUT-OF-REACTOR FUEL DECONTAMINATION

During a decontamination for which the core is removed, the discharged fuel is stored in the spent fuel pool and returned to the reactor after the chemical treatment of the primary system is completed. Consequently, core deposits with over 70% of the original surface radioactive material inventory is available for reintroduction into the primary system. When reactor operation resumes, buildup rates will be substantially higher (even with preconditioning of the cleaned system) than they would be if the fuel element surfaces were cleaned. No specific data is available to confirm this, but there is a general belief that there will be a significant reduction in the radiation buildup rate if the fuel is also cleaned. Significant reduction in the rate of radiation build up may also be obtained by cleaning fuel that is removed for reasons other than primary system decontamination, i.e., steam generator replacement.

Fuel cleaning processes may be mechanical or chemical in nature. There is little incentive to use harsh chemicals in an effort to affect tightly adherent corrosion products, but there are significant incentives to remove less adherent material. Disassembly of fuel bundles for cleaning is possible but is likely to be prohibitively expensive because all operations must be remote.

Viable methods are most likely to include mechanical agitation, ultrasonic cleaning, scraping or brushing, and the use of either dilute or concentrated chemicals. The principal concerns are discussed below.

3.3.1 Decontamination Effectiveness

Consideration of decontamination effectiveness includes principally those concerns discussed in Section 3.1.1. However, in the case of fuel decontamination, effectiveness will only become apparent when trends in shutdown radiation measurements are analyzed.

3.3.2 Erosion/Corrosion

In addition to the chemical corrosion discussed in Section 3.1.3, fuel assemblies cleaned by nonchemical methods could be subject to surface damage by mechanical erosion during the decontamination process. As tolerances are very close significant erosion or corrosion would not be considered acceptable. More detailed analyses of electrochemical and mechanical decontamination methods and their associated erosion and corrosion rates are given in Sections 3.5, 3.6, and 3.7.

3.3.3 Effects of Residual Decontamination Agents

Proper choice of chemicals and rinsing procedures for fuel decontamination should ensure that residual chemicals are not likely to adversely affect the fuel after it is returned to the reactor. However, mechanical methods such as brushing have a potential for returning extraneous solids to the reactor and this should be guarded against. Solid material caught on the fuel bundles could result in fuel damage from poor heat transfer at fouling points, or cause mechanical erosion from residual solids abrading fuel surfaces (fretting failure). The consequences of solid residues on fuel should be avoided.

3.4 MAJOR-COMPONENT CHEMICAL DECONTAMINATION

Contamination circumstances may require the cleaning of only part of a reactor system, or a dilute decontamination may be planned with concentrated processes applied to only certain components. The chemical decontamination of such isolated components or subsystems is addressed in this section.

Chemical decontamination involves the use of either concentrated or dilute reagents, as discussed in Sections 3.1 and 3.2. In general, both the concentrated and dilute processes fall into one of six chemical classifications:

- high-pH oxidation and dissolution
- high-pH oxidation followed by low-pH dissolution
- low-pH oxidation and dissolution
- low-pH oxidation followed by low-pH dissolution
- low-pH dissolution
- low-pH reduction and dissolution.

An example of the high-pH oxidation and dissolution chemistry is the use of alkaline permanganate (AP), which dissolves chromium oxide and attacks various hard-surface alloys, organics, and (to some extent) copper. The use of AP followed by Citrox or any other acid is an example of high-pH oxidation followed by a low-pH dissolution. In this case there is some dissolution in the first step, but the major purpose of the AP is conditioning the corrosion product film; most of the decontamination occurs with the dilute acid step. These processes are generally applied to PWR systems, which operate under reducing conditions.

A similar use is made of low-pH oxidation and dissolution. For example, nitric acid can be used as both oxidant and acid, particularly in the removal of uranium oxide fuel debris. Since nitric acid is not a sufficiently strong oxidant, it cannot oxidize Cr^{3+}. Because the composition of Dow NS-1 is proprietary, its effectiveness as an oxidant is uncertain (Dow 1977). It is a low-pH solvent that is thought to be mildly oxidizing because it can remove copper from BWR systems. On the other hand, it is not thought to be strongly oxidizing since it is unsuitable for use in a PWR.

A procedure that is similar to the high-pH oxidation and low-pH dissolution process uses nitric acid as a low-pH oxidant followed by Citrox or another acid for a low-pH dissolution step. This process is suitable for the removal of fuel and fission product debris and can be used for corrosion product removal if little or no chromium is present.

Several solutions are available for low-pH dissolution. The best known of these are phosphoric acid and CAN-DECON. Inhibited phosphoric acid has been used successfully for many years in the Hanford N-Reactor, a primarially carbon steel system. CAN-DECON, a dilute solution used on reactor-scale operations in Canada, has also been successful on BWR components and on PWR components with an oxidizing pre-treatment. Phosphoric acid vaporized with steam has been used for vapor-phase cleaning of isolated components. Variations of this process are being examined for use in PWRs.

Low-pH solutions that are strongly reducing are not common because reactions with water tend to make them unstable. One process developed for high-temperature stainless steel is RDS (reducing decontamination solution), which uses hydrazine. For systems that can accept chloride, a solution of hydroxylamine hydrochloride has proven useful for dissolving magnetite. All of the above solutions, and the only solutions that have been tested in a reactor, are aqueous.

3.4.1 Decontamination Effectiveness

Sections 3.1.1 and 3.2.1 listed the general parameters of concern for both dilute and concentrated chemical decontaminations of full reactor systems. The concerns are the same for a single component as for the entire system, although the choice of available reagents may be greater.

3.4.2 Component Corrosion

The factors that influence corrosion rates of isolated components that undergo chemical decontamination are similar to those described in Sections 3.1.2 and 3.2.2.

3.4.3 Effects of Residual Decontamination Agents

The effects of reagents remaining on a component that is returned to service are influenced by the amount of reagent present, the thermal and radiolytic stability of the reagent, and the materials present in the rest of the system. These concerns were discussed in Sections 3.1.4 and 3.2.3.

3.4.4 Component Isolation

Components may be isolated in a number of ways during a full-system decontamination process. Discrete sections of the system can be valved off in many cases. Blind flanges can be installed at piping connections. Water dams and freeze plugs have been used successfully in some instances. Complete physical removal is an option in certain cases and may be required when there is no other access to the component or when failure of the isolation would be intolerable.

3.4.5 Analysis of Isolation Failure

Failure of an isolation technique to prevent the transport of decontamination reagents to other parts of the system may manifest itself as corrosive attack on components by incompatible chemicals. This general topic has been discussed in Sections 3.1 and 3.2. The extent of damage incurred by an isolation failure would depend upon the quantity of chemical introduced, the type of chemicals in use, the duration of contact, and the component materials. Precautions and contingency procedures are advisable if an isolation failure could result in serious damage under credible conditions.

3.4.6 Recontamination

The considerations for post-decontamination radiation buildup for isolated component decontaminations are similar to those described in Sections 3.1.5 and 3.2.4. In general, major components are decontaminated prior to a particular outage job requiring extensive modification or inspection. The components may return to an equal or greater exposure rate during the next operating period without seriously affecting the success of the decontamination.

3.5 MAJOR-COMPONENT ELECTROCHEMICAL DECONTAMINATION

Electrochemical decontamination is not yet an option for a full-system decontamination, but it may be performed on components in-situ or removed from the system. Two similar processes are available: electropolishing and electrobrushing. These processes are generally fast and easy to control, and give very high DFs.

Electropolishing is typically performed by immersing the object to be cleaned in an electrolyte solution and passing a current through the object so that a small amount of the surface is removed, along with the contamination, in an anodic reaction. In-situ electropolishing techniques are currently being developed that will not require that the contaminated object be immersed in an electropolishing cell, but may require that it be filled with electrolyte (Allen et al. 1978).

Electrobrushing is similar to electropolishing, but in this process the electrolyte is continuously fed to a sponge-like material that is used as a scrubber in place of a solution-filled cell. The object being cleaned acts as the anode and the electrobrush as the cathode in the electrical circuit. Electrobrushing generally requires more time than electropolishing, but produces less waste volume when used on larger components.

Electrochemical decontamination provides high DFs with uniform corrosion rates that can be easily controlled. The processes do, however, produce large volumes of liquid radioactive waste, and the electrolytes used can attack surfaces excessively if uncontrolled.

3.5.1 Decontamination Effectiveness

Research has shown that electrochemical decontamination can reduce radiation levels on a variety of tools and other hardware by a factor of 10,000 in less than 10 minutes (Allen et al. 1978). Its effectiveness and overall benefit for particular reactor components will depend on accessibility and component configuration.

3.5.2 Component Corrosion

The amount of metal removed from components during typical electrochemical decontamination processes is usually less than 0.002 inch. In addition, the metal is uniformly removed, with no preferential attack on grain boundaries or other microstructural features. The surface produced typically has better corrosion resistance than the original surface (Allen et al. 1978). The acceptability of this amount of corrosion should be reviewed.

3.5.3 Effects of Residual Decontamination Agents

Phosphoric acid is the most commonly used electrolyte in the electrocleaning process. The effects of small quantities of this acid or other electrolytes on various materials should be assessed either by a review of the literature or by actual compatibility tests.

3.5.4 Recontamination

Components decontaminated using electropolishing generally have greater resistance to recontamination because of the progressive smoothing of the metal surface. Thus, electropolishing may be a useful pretreatment technique in place of, or in addition to, a passivation step. This applies to either new materials or materials decontaminated by alternate methods. The advisability of an additional passivation step has not been established.

3.6 MAJOR-COMPONENT MECHANICAL DECONTAMINATION: INCOMPATIBLE MATERIALS

Mechanical decontamination methods use energy as the primary means of removing activated corrosion products. This energy may be in the form of high-pressure water sprays (hydrolazing), scrubbing, grit blasting, ultrasonics, etc. For the purpose of this study, these processes are divided into two groups based on the effect of the decontamination medium in the reactor system. If the decontamination agent would result in damage if it entered the primary coolant system (as sandblasting would), the concerns are discussed in Section 3.4.4. If the decontamination agents would not result in significant damage in the primary system (as hydrolazing would not), the concerns are discussed in Section 3.7.

Mechanical decontamination methods are restricted to situations where the contaminated surfaces are accessible from the component exterior. Because of the numerous valves, pumps, elbows, tanks, and miscellaneous projections in a reactor system, mechanical methods are not well suited for in-situ decontamination of most systems. However, they are well suited to out-of-system decontamination of parts and certain major components such as steam generators where the contaminated parts are readily accessible.

Mechanical decontamination is generally performed in water or with water for two reasons. The first is to reduce the amount of airborne contamination. The second is that water is a good carrier for abrasives and a ready means of transferring kinetic energy into a film removal action. The composition of the waste from mechanical decontamination is particulate corrosion products, grit, water, and nonreusable equipment (Perrigo et al. 1979).

3.6.1 Decontamination Effectiveness

Where abrasive particles are used, high DFs can be achieved and recontamination of the component during cleaning is rarely a problem because of the particulate nature of the removed activity. However, as described in Section 3.6.5, rapid recontamination after restart can occur.

3.6.2 Erosion/Corrosion

Mechanical decontamination methods are, by design, erosion processes. Controls must be in place to balance effectiveness and acceptable erosion rates.

3.6.3 Component Isolation

The process must be designed to ensure that harmful materials do not enter the primary system. The available isolation techniques were discussed in Section 3.4.4.

3.6.4 Analysis of Isolation Failure

See Section 3.4.5.

3.6.5 Recontamination

Since mechanical decontamination methods may abrade the oxide coating, a new oxide layer can form. If it forms in contact with contaminated primary coolant, considerable radioactivity may be incorporated. Although major-component decontaminations are not generally performed with the idea that dose rates will be lower over a prolonged period (see also Section 3.4.6), some passivation step may be justified following a harsh mechanical decontamination to limit recontamination.

3.7 MAJOR-COMPONENT MECHANICAL DECONTAMINATION: INNOCUOUS MATERIALS

Considerable development work has been directed toward finding mechanical decontamination techniques that are fully compatible with reactor materials. These include the experimental techniques of grit blasting with ice crystals, dry ice crystals, and boric acid crystals, and various types of water spraying such as hydrolazing. The advantages of these techniques are apparent in that component isolation and analysis of isolation failure are less critical. However, in one case of hydrolazing, enough water entered a reactor system to cause a low boron concentration alarm, so isolation cannot be ignored.

3.7.1 Decontamination Effectiveness

The principal drawback of the presently available methods of this type is in the area of decontamination effectiveness. The available methods generally remove loosely adherent crud and so result in reduced protective clothing requirements for later work. These methods seldom attack tightly adherent corrosion films and, therefore, reduce working exposure rates only slightly.

3.7.2 Erosion/Corrosion

The magnitude of the erosion expected from most mechanical decontamination methods employing innocuous material is less than that previously discussed in Section 3.6.2. In the case of dry ice blasting, however, there could be an additional deleterious effect on the component from thermal shock. The effect of this shock on future performance of the component should be well understood before this method is used.

3.7.3 Recontamination

The concerns are similar to those discussed in Section 3.6.5.

APPENDIX

DECONTAMINATION PROCESS DEVELOPMENT

The development of decontamination processes that are economical, effective, and safe takes a substantial amount of time. This is the case because of a large number of variables which must be carefully evaluated to fully determine what the process may do under anticipated operating conditions. The variables to be studied include: 1) chemical and/or mechanical efficiency in removing the contaminants, 2) the effects of engineering scale (size) factors on efficiency, 3) immediate and long term effects on decontamination effectiveness, 4) immediate and long term corrosion effects, 5) waste handling, transportation and disposal options, 6) safety as related to the formulation of chemical solutions and the application of processes for their intended purposes, and 7) health physics considerations as they relate to or are influenced by application of the decontamination process and the subsequent restorative operations.

The examination of these variables involves consideration of: 1) laboratory investigations, 2) small loop studies, 3) loop investigations to examine corrosion effects and related phenomena, 4) in-reactor loop proof of process trials and 5) full reactor decontamination. This hierarchial series of tests has been found to be the best method of anticipating the performance of a process under the many different conditions that are often found in operating reactors. Although the most desirable and conservative approach would involve an examination of candidate processes using the above-mentioned hierarchy, the development effort can be shortened particularly if the process is closely related to tested processes. However, it should be recognized that because the processes are not adequately understood shortening or avoiding steps increases the risks substantially of using processes that may produce less than optimum performance, corrosion behavior or other operational characteristics.

The role for each of the evaluation steps in the suggested hierarchy is given below:

1. Laboratory Investigations

Laboratory testing under quiescent and stirred conditions is used to identify a few promising formulations from a large number of candidates. Investigations are generally conducted in glass or stainless steel beakers at different temperatures, chemical concentrations and exposure times. (Container material, volume and agitation can influence results.) Before and after treatment radioactivity measurements are used to calculate decontamination factors (DFs) while weight loss data are generally used to determine the corrosivity of the candidate formulations. Autoclaves can be used in the same manner if the chemical composition requires elevated temperatures to be effective.

Although static and dynamic laboratory testing are useful tools, the results from these preliminary screening studies should be used with caution to predict reactor cleanup efficiencies or corrosion rates. Frequently, reactor DFs are 2 to 3 orders of magnitude lower than laboratory values and corrosion rates can be several times greater than those found in beaker studies.

2. Bench Scale Dynamic Tests

The next step in the testing hierarchy involves the use of bench scale equipment for dynamic evaluations of candidate processes. Normally very simple systems comprised of stainless steel, fiberglass, or plastic piping, a pump, a temperature sensor, a flow meter and a heater are sufficient for this type of work. Generally decontamination operations are at atmospheric pressure or only slightly above so no ASTM code requirement must be met. Contaminated specimens and corrosion compounds that may be of the same of different size and shape to those employed in the laboratory investigations are used to acquire efficiency and weight loss data. The loop should be designed so that contaminated specimens and coupons can be subjected to both laminar and turbulent conditions. Variables that are best examined in bench scale tests are the effects of temperature and flow on the efficiency and corrosivity of the process.

Some general information about ease of introduction and removal of decontamination chemicals can be inferred from bench scale tests if there is a reasonable similarity between these operating steps.

Frequently the decontamination factors from bench scale testing are considerably lower than those found in beaker or autoclave investigations.

3. Out-Of-Reactor Loop Testing

Equipment used for this part of the evaluation hierarchy is designed to be as similar as is reasonably possible to the power reactor systems that are to be decontaminated. These similarity requirements result in high-pressure, high-temperature systems and these designs must conform to ASTM codes. Also, the materials of construction should be essentially the same as those that are used in the power reactor systems for which the processes are to be used.

Some investigations use special test sections that can hold various alloys fabricated to have high surface area to volume ratios as a means for skewing the relative abundance of materials in the loop for different types of tests. These high-temperature, high-pressure loops are employed primarily to acquire two types of information about corrosion effects and performance data. The former may involve the cyclic application of decontamination chemicals with subsequent operation at temperature and pressure to uncover latent as well as the more obvious corrosion effects. The loop systems can be designed to study crevice, stress, galvanic and fatigue effects as well as general weight loss effects.

Because the loop should be similar in many respects to power reactor primary systems it can be used also to determine: 1) ease of process application and removal, 2) equipment performance with chemicals in the system, 3) general information about waste characteristics, ratio and volumes, and 4) any special effects such as deposition that may result from pH changes, inhibitor breakdown, etc.

Some out-of-reactor loops are also used for decontamination effectiveness studies. When employed for that purpose, contaminated specimens are charged into the loop. These types of test, however, suffer from deficiencies that can arise from the chemical treatment of a system with only a small contaminated surface area relative to one with a relatively large uncontaminated surface area. Unless special precautions are taken to ballast with high surface area contaminated materials, unusual deposition effects may influence efficiency measurements obscuring the real behavior of the process.

4. In-Reactor Loop Testing

In-reactor loop testing of candidate processes that have successfully passed preceding investigations is undertaken to: 1) acquire protypical decontamination efficiency data, 2) evaluate equipment performance, 3) study system operating characteristics, 4) examine operator responses and needs and special training requirements, 5) investigate the radiation stability of the cleaning solutions, 6) determine in-core cleaning characteristics, and 7) investigate waste generation, handling and disposal factors.

Items 5 and 6 are generally only achieved with a reactor loop which passes through the core. To obtain maximum benefit from an in-reactor loop the loop should have the same materials of construction and operating history as the system to be decontaminated. It should also have a similar surface to volume ratio. The accepted method of evaluating efficiency involves making radiation measurements before and after process application on specific items of equipment. It is extremely important that typical pieces of equipment with a variety of conditions be used for these measurements. Also, these measurements are contact measurements taken in the same position with the same device, preferably one with a shielded detector. General field measurements are useful for health physics purposes but are of limited use in determining specific performance of a decontamination process. Following the decontamination of the system, the loop should be operated for a period of time to not only acquire general system performance data but to monitor radiation buildup. The same sites used for the efficiency measurements should be employed for this purpose.

Investigating equipment performance and special operating characteristics is straightforward. Keeping good records and identifying those abnormalities that result from the decontamination operation are most important. The lack of problems should also be noted.

While an attempt will have been made to anticipate training needs experience gained from loop testing may indicate additional needs. Experience gained in loop testing can help achieve decontamination objectives during reactor decontamination.

High gamma fields affect the stability of many chemical solutions. These effects, decomposition rates and the characteristics of degradation products should be known before a demonstration is undertaken. In-core deposits may differ sufficiently from out-of-reactor deposits and consequently cleanup efficiency may also vary. Knowledge of these relative efficiencies is especially important in light of data that indicates over 70% of the radioactivity in a reactor system is to be found on in-reactor surfaces (structural components and fuel).

Candidate waste processing, handling and disposal techniques will have been tested previously but the processing of waste from loop testing will be an important intermediate prior to full scale waste treatment.

Bypass loop testing on power reactors can provide useful data but it is no substitute for in-reactor loop work. Recontamination in the former occurs rapidly and may or may not be relatable to anticipated conditions after a full reactor decontamination.

Decontamination factors from properly designed in-reactor loops are generally quite close to those resulting from actual decontamination operation.

On occasion substitution of a "demonstration" decontamination of a test reactor or similar system may serve many of the same functions as loop testing. A demonstration may also preceed application of a decontamination reagent to a reactor system. While such tests are not essential, they can provide valuable cost, planning, and waste management data.

4.0 DECONTAMINATION PLANNING AND OPERATION

Ideally, the planning for decontamination begins with the design of a new reactor. However, this ideal is seldom attained because the need for decontamination has not been widely recognized during this early phase. If the need for decontamination is identified at any time prior to reactor startup, modifications (such as connective pipes and valves for introducing and removing decontamination solutions) can be made with no radiation exposure to personnel. Decontamination techniques and procedures can also be planned and developed with no radiation exposure. Realistically, planning for decontamination usually starts either when the reactor has settled into routine operation or when a specific need arises.

Planning for decontamination is certainly not a clear-cut procedure but must be tailored to the reactor in question. The type of decontamination must be selected in light of the need. There are several reasons why decontaminations may be needed:

- Radiation levels at certain locations are unacceptably high from an operational standpoint.
- Radiation levels in areas that have suffered mechanical failures are too high to permit effective maintenance or repairs (i.e., frequent crew changes are required to comply with individual exposure limits, and a sufficient number of properly qualified individuals are either unavailable or too costly).
- An accident has contaminated the system beyond levels acceptable for continued operation.
- Decontamination is needed prior to the decommissioning of a reactor (this case is beyond the scope of this report).

In general, there are four major kinds of decontaminations for reactor systems: 1) dilute decontamination of the primary system with fuel in place, 2) concentrated decontamination of the primary system with fuel removed, 3) concentrated decontamination of the primary system because of fuel failure, with no significant contamination outside the primary system, and 4) decontamination of the primary system and associated systems (Ayres 1970). Dilute decontaminations (1) are expected to be the most common because of their safety and the availability of reliable data on the procedures. Concentrated decontamination with the fuel removed (2) will most likely be restricted to isolated components or reactors where design or operating conditions have resulted in unusual occupational exposure problems. Significant fuel failures (3) are rare in the present generation of LWRs and most of those older reactors that have experienced fuel failure are not being considered for restart. Complete decontamination of the primary system and associated components (4) is required only in the case of a severe fuel damage accident such as occurred at Three Mile Island-Unit 2 (TMI-2). There is a wide variation in the details of the major kinds of decontaminations, but many of the planning requirements are similar, varying only in the extent of the effort. The chronological steps of a decontamination are approximately as follows:

Early Planning

- Determine the need for decontamination and specific requirements.
- Select key decontamination staff.
- Review applicable decontamination processes and select candidate processes.
- Develop basic plans and preliminary cost estimates.
- Reach a decision to decontaminate, with concurrence from regulatory agencies.

Detailed Planning

- Develop detailed procedures and specifications.
- Procure supplies, equipment and services.
- Assign manpower and provide training.
- Shut reactor down and perform radiation surveys.

Operation

- Modify reactor systems for the decontamination.
- Perform the decontamination.
- Recondition decontaminated surfaces.
- Recertify reactor systems and restart the reactor.
- Process and dispose of the decontamination waste (see Section 5.0).

Section 4.0 will follow this chronological outline, which is illustrated in Figure 4.1.

4.1 EARLY PLANNING

The advantages of early planning for a decontamination cannot be overemphasized. Many of the physical modifications to accommodate chemical decontamination can be designed in and constructed at little extra cost, and certainly for less than retrofit cost. Another major advantage is that much of the preparatory work can be done with no radiation exposure to personnel. These advantages should be considered when deciding when to begin planning.

4.1.1 Determination of Needs

The decontamination of a reactor should not be undertaken without a demonstrable need because decontamination will require occupational radiation exposure and other resources. It is important to have a program to monitor the buildup of contamination in order to assess the need. Each time the

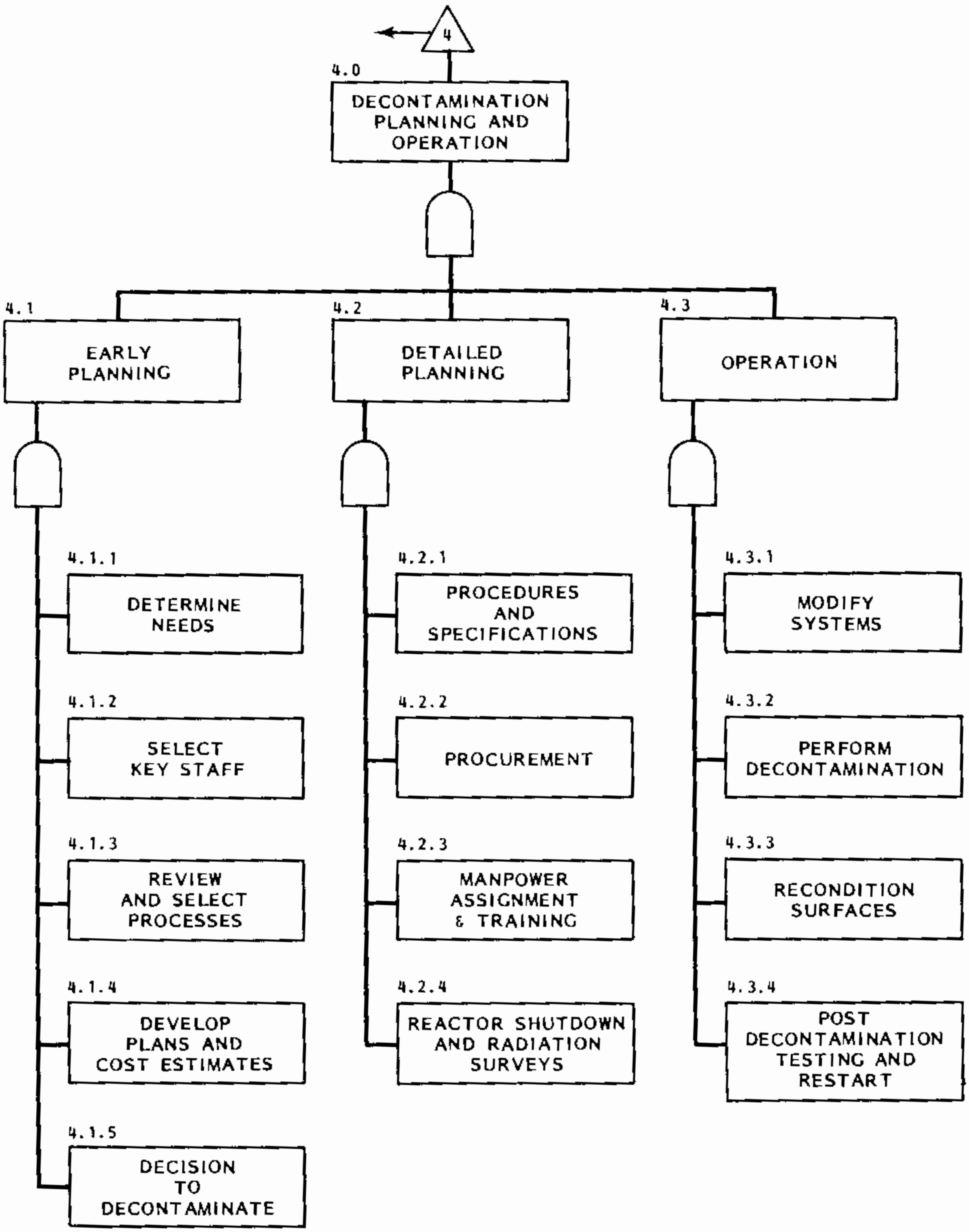

FIGURE 4.1. Decontamination Planning and Operation

reactor is shut down for fueling, maintenance, or repairs, a full radiation survey should be performed and documented. Survey data should be compiled and analyzed for trends and characteristics of the contamination. It is important to distinguish between corrosion product buildup and debris from fuel failure, since different decontamination processes are needed in each case. Any spread of contamination outside of closed systems should also be noted because corrective actions are often less costly than system decontamination and they will be required to achieve dose rate reduction. If the contamination buildup in any location makes maintenance, repairs, or inspections excessively difficult or costly, a decontamination may be a cost effective corrective measure.

Before deciding on a system decontamination, however, alternatives should be considered. For example, radiation exposure rates may be reduced by installing shielding over high-level sources or by removing and replacing contaminated materials such as insulation. Replacement of contaminated components with new or refurbished components may be possible. Components may be decontaminated by the methods described in Sections 3.4, 3.5, 3.6, or 3.7. If none of these alternatives are feasible, or if they fail to adequately correct the problem, then a need for system decontamination may be indicated.

4.1.2 Selection of Key Decontamination Staff

A decontamination specialist should be on the reactor staff well in advance of a specific need. This individual should maintain a thorough knowledge of plant operations. The specialist should be responsible for the program to monitor the buildup of contamination. Data from the monitoring program can be used to determine trends and identify potential problems. The specialist should also keep abreast of developments in decontamination processes and techniques. Some basic decontamination plans can be formulated in advance, which may expedite the work when the need for a decontamination arises.

After the need for a decontamination is clearly established, the utility or corporate management should select an individual who will serve as decontamination director. The decontamination specialist may be a likely candidate for this assignment. This responsibility should not be assigned to a committee or distributed to a group, because a capability for prompt decisions is required on decontamination projects. A deputy director should also be selected to assist the director and to provide a backup; however, all responsibility should rest with the director. The technical background of the director and deputy should include chemical or corrosion engineering experience, and the individuals selected should be thoroughly familiar with the reactor systems to be decontaminated. Previous experience with similar decontamination processes would be invaluable. The decontamination director will have responsibility and authority for performing the decontamination.

Other key personnel should be assigned to the decontamination director when additional expertise is needed. Consultants or subcontractors can provide certain capabilities that may not be available among the permanent reactor staff. Once the initial decontamination staff is assigned, communication channels should be established, including the chain of command for internal approvals and for interactions with regulatory agencies.

4.1.3 Review and Selection of Decontamination Processes

Compatibility between system materials and decontamination reagents is a very important factor in the selection of decontamination processes. Reactor systems are frequently thought to be stainless steel, but closer inspection reveals many different materials in components such as valves, bellows, and instrument interfaces. A detailed study of reactor system materials at TMI-2 has identified several types of stainless steel, inconel, high alloy steel, stellite, corrosion-resistant iron-chromium, silver, asbestos, and ethylene polypropylene (Hicks 1982). An in-depth analysis should be conducted to identify all materials that may be exposed to decontamination solutions. Even different alloys of similar metals can be troublesome. For example, strong electrolytes found in many decontamination solutions can set up electrolytic corrosion couples in inconel (Ayres 1970). A complete list of system materials should be compared to the decontamination solutions under consideration (including impurities) so that any materials compatibility problems can be avoided or solved.

The major decontamination processes are described in Sections 3.1 and 3.2. Only proven decontamination methods should be considered at this stage of planning. The time and other resources required to test an unproven method is not likely to be available during a decontamination.

The technical basis for the selection of the decontamination process must be established by the director. Some of the major points to be considered are:

- process effectiveness
- compatibility of materials and solutions in both the reactor system and waste storage tanks
- system isolation requirements
- sensitivity of solution concentrations (some materials may require protection with a water flush that can dilute solutions slightly)
- solution sensitivity to temperature and pressure (variations that can be tolerated without the solution breaking down or becoming ineffective)
- solution purity requirements (corrosive effects of impurities)
- post-decontamination component repair requirements (replacement of gaskets and valve packing)
- system flushing requirements (number of flushes and volume of wastes)
- process effects on fuel (will warranty be voided)
- requirements for reconditioning decontaminated surfaces (passivation)
- requirements for sampling and surveys to monitor decontamination effectiveness.

The primary consideration, however, is the effectiveness of the process. Based on these considerations, one or more decontamination processes can be selected as the candidate processes.

4.1.4 Development of Plans and Cost Estimates

At this stage of the planning, a proposal should be prepared for each candidate decontamination process. A proposal should describe the process and the evaluation that resulted in its selection as a candidate. It should also include a preliminary cost estimate, expected decontamination factors, and an estimate of the anticipated reduction in radiation exposure levels. Some other management concerns that should be addressed in the proposal are:

- need for a license amendment
- need for an environmental impact statement
- other regulatory requirements
- plant modification requirements
- time requirements and schedule
- manpower requirements and sources
- training requirements
- redundant service requirements (electric power, ventilation, etc.)
- communication and reporting plans
- quality assurance requirements
- system recertification requirements
- waste treatment and disposal requirements
- emergency procedures
- public relations.

4.1.5 Decision to Decontaminate

After assessing the needs for decontamination and the proposals to meet those needs, the utility management can decide whether or not to proceed with a decontamination. If the decision is to proceed, the regulatory approval process should be examined to determine if the decontamination can be performed without regulatory approval. Once this analysis is performed it is well to meet with the cognizant NRC personnel to ensure their agreement in the proposed regulatory interface. Concurrently, utility management must make several important commitments: They must commit the financial resources required to conduct the decontamination; they must provide manpower on a continuing basis; and they must make a commitment to the health and safety of the staff and the public. A public statement of the latter commitment may be advisable for its beneficial effects on public relations.

4.2 DETAILED PLANNING

When the decontamination process has been selected, detailed planning and preparations can begin. Procedures and specifications for the decontamination must be prepared. Supplies, equipment, and special services must be procured. Additional manpower must be assigned to the project and the staff must be trained. The entire decontamination project should be carefully planned, scheduled, staffed, and equipped before the reactor is shutdown.

4.2.1 Procedures and Specifications

Procedures may have been developed by the decontamination specialist, but they will probably require review and modification to be compatible with existing plant conditions. Special procedures may be needed for work that occurs at unique interfaces between the decontamination system and the existing plant. Procedures should be prepared by the person who will be doing the job, for two reasons: 1) any personal risk that may be involved will help ensure that the procedures are well thought out and complete and 2) working through the procedures provides some training. The development of procedures should begin with a job safety analysis, and the procedures should consider emergency conditions. Steps to be taken in case of loss of power, loss of ventilation, spills, etc., should be included. Some of the main procedures that will be needed are:

- handling, mixing, and storing chemicals
- introducing chemicals to the system
- removing chemicals from the system
- the mock decontamination run
- the actual decontamination operations
- monitoring the effectiveness of the decontamination
- waste treatment and disposal
- flushing the system, including dead legs
- surface reconditioning (passivation)
- restoring the system to normal operation
- quality assurance inspections
- preparation of reports and documentation
- emergency procedures.

Specifications for each subsystem and component must be developed in enough detail to facilitate procurement, acceptance testing, and calibration or qualification. System modifications must be engineered and documented through a formal design change to assure that an acceptable system configuration is established after the decontamination. Special test facilities for monitoring the response of plant systems and for requalification of certain plant components may also require engineering attention.

4.2.2 Procurement

Supplies, equipment, and specialized services must be procured in preparation for the decontamination. Specific needs will be defined by the decontamination process selected and the procedures and specifications developed. Procurement of supplies and equipment includes the establishment of firm costs, delivery dates, and shipping requirements. Alternate vendors should be identified in case of delivery problems. Other concerns of procurement include storage capacity for supplies and equipment, and special requirements such as fire protection or security.

Specialized services and consultants may be needed for the decontamination job. Contracts for these services should define specific needs, set schedules, and establish costs.

4.2.3 Manpower Assignments and Training

Manpower requirements can be more accurately determined as procedures for the decontamination are developed. When the types of skills and numbers of people needed are identified, sources of this manpower can be located and costs can be estimated. Some of the manpower will be available from the permanent plant staff. Other manpower may be obtained from vendors who specialize in decontamination services. Contingency plans should be made to guard against the effects of work stoppages, illness, or other disruptions.

Training must be provided as the decontamination staff is assembled. The extent of training required will be based on the complexity of the decontamination being undertaken and the prior experience of the workers. For example, a dilute decontamination may require substantially less training than a concentrated decontamination with fuel removed. Plant workers may require less training than offsite personnel who are not familiar with the plant. In any case, general familiarization with the decontamination project should be provided to all onsite personnel.

Specific technical and safety training must be provided to the utility and contractor personnel involved in the work. The type and extent of training provided to different skill groups should be designed to meet their specific needs. For example, maintenance personnel assigned to system modifications can be given brief but very job-specific training for each task. Decontamination operators need more extensive, in-depth training on procedures and system controls to provide needed versatility and interchangeability of staff members. Training and rehearsals with models or mockups may be useful depending upon the complexity of the work, the intensity of radiation fields, and whether the radiation levels would allow access to work areas. Visual aids, such as videotapes and photographs of plant systems, should be used whenever possible. The final step in training is a full-scale mock run to test personnel and system performance.

Consideration of radiation hazards and chemical toxicity should be an integral part of the technical training. Training should promote the philosophy of maintaining exposures as low as reasonably achievable. Documentation of training should include the names of those trained, the content of training material, dates, instructor, and examination scores. Copies of all training documentation should be placed in individual personnel files.

It is also prudent to provide some training to upper management, to keep them apprised of project developments and to develop confidence in staff capabilities.

4.2.4 Reactor Shutdown and Radiation Surveys

When decontamination is under consideration, the reactor can often continue normal operation. About 90% of the planning and preparation for a decontamination can be completed prior to the shutdown, with the objective of minimizing the outage time. However, additional time must be allowed for system cooldown and drainage if the fuel is to be removed. In any case, the planning and scheduling should be well organized to keep the outage time to a minimum.

Radiation measurements, taken with the plant shut down, are needed before and after the decontamination to assess its effectiveness. Additional monitoring will be needed during the decontamination to assess the dynamics of the process, to characterize the radioactivity of the various waste products, and to assess the environmental impact from effluents. The locations and techniques for the predecontamination radiological monitoring will be determined on the basis of the plant's occupational radiation exposure records and operations and maintenance work history. The same locations and techniques must be used for the post-decontamination measurements in order to obtain comparative data. A plan must be developed for a series of follow-up measurements to obtain data on how radiation that affects occupational exposure builds up with time. These data will be necessary for planning the scope and frequency of subsequent decontaminations.

4.3 OPERATION

The operation phase includes the final preparatory work, the decontamination operation, the reconditioning of decontaminated surfaces, and the recertification and restart of the reactor. The general nature of these tasks is described in this section. More specific planning for the preparatory work and the decontamination will be required when details of the process and plant interfaces are fully defined.

4.3.1 Final Preparatory Work

Modifications must be completed to facilitate the introduction and removal of decontamination reagents and to permit isolation of various parts of the system. Equipment needed to prepare, heat, cool, circulate, purify, and dispose of decontamination solutions must also be installed. This work should be performed in accordance with accepted criteria that specify materials selection, workmanship, quality assurance, acceptance testing, and calibration. "As-built" drawings must be prepared, as part of formal design changes, to fully document the modifications.

If valves are used to isolate systems, care must be taken to ensure that valve components will not fail when subjected to decontamination solutions (Ayres 1970). Blanks or spool pieces should be used as necessary. Some sensitive components may be impossible to isolate, and it may be necessary to install water flush lines to protect them from corrosion, or to simply plan to replace them after the decontamination.

Interconnections required by design changes must be completed where the decontamination systems interface with the plant. These interconnections may include the following:

- utilities - water, sewer, waste systems, electrical power, steam, compressed air, vacuum, lighting
- ventilation - heating, air conditioning, exhaust ventilation with HEPA and charcoal filters
- radiation - area monitors, effluent monitors
- safety systems - fire alarms, sprinklers
- communications - telephones, public address system.

When all of the foregoing preparatory work is completed, an operational readiness review (Nertney et al. 1975) should be conducted by the decontamination director to ensure that personnel, management, plant, and hardware are ready for decontamination startup. Personnel should have been selected, trained and tested, or otherwise qualified. Management controls in place should include appropriate assignments of authority and responsibility, adequate procedures, and an appropriate safety program. Construction and installation of the decontamination system and interfaces should be complete and acceptance tested including a program for maintenance and inspection of the system. The operational readiness review will provide a systematic method for identifying any oversights or omissions in the preparatory work. When deficiencies noted during the review are resolved, the integrity of the decontamination system can be tested by a mock run with water. When this test is successfully completed, the decontamination work can begin.

4.3.2 The Decontamination

The operational aspects of the decontamination include final process scheduling, system control, staff performance, system performance, and record-keeping. Since the duration of the actual decontamination is relatively short, the sequence and timing of each procedural step is critical. The decontamination director should maintain full control over the reactor systems and the effects of the decontamination solutions on them. Observers should be located so as to not obstruct or interrupt the director during these critical operations.

If the decontamination operation takes more than about 12 hours, the director and other key staff should be relieved by their assistants. If they were to work for longer periods, there would be a risk of errors or poor judgment due to fatigue. The performance of the decontamination system should be closely monitored so that any component failures can be detected and prompt corrective action can be taken. Radiation detection instruments should also be monitored closely to determine the effectiveness of the decontamination. The director must attempt to identify the point of maximum effectiveness and decide when to terminate the decontamination process.

Complete records of the decontamination proceedings should be collected, including written logs of all procedural steps. Audio or videotape equipment should be used to record all control room activities, telephone conversations, public address announcements, etc. Data recordings from radiation detection instruments and the post-decontamination radiation surveys should also be included.

4.3.3 Reconditioning of Decontaminated Surfaces

After the decontamination is completed and solutions are removed from the system, the clean surfaces may have to be reconditioned or passivated. Raising the temperature of a water rinse for a specified period of time establishes a protective oxide coating on clean metal surfaces and tends to prevent the rapid buildup of contamination after the reactor resumes operation (Ayres 1970).

Since the passivation process is rather time consuming, it presents an excellent opportunity for debriefing the decontamination crew. A debriefing is essential so that successes, failures, and problems can be evaluated and documented for a final report. The value of such a comprehensive report to the utility who may need to repeat the decontamination and to the industry cannot be overemphasized.

4.3.4 Post Decontamination Testing

The final task of the decontamination project is assurance testing prior to restart of the reactor. This task entails removing decontamination systems and equipment, restoring modified systems to their original state, testing of representative plant components affected by the decontamination, testing of safety systems, and returning the plant to pre-decontamination operational status. The final steps of recertification are a satisfactory operational readiness review, and preparation of a final report on the decontamination.

Decontamination systems and equipment must be disconnected and stored. However, some pipe connections may be left as permanent modifications to facilitate future decontamination, provided they have been appropriately designed, fabricated, and documented in the license. In general, all components that interfaced with plant systems must be properly removed, secured, or returned to their original configuration. Systems that were temporarily modified must be returned to their pre-decontamination status. Gaskets may need to be replaced and valve stems should be inspected and repacked if necessary. Instrument leads that were disconnected or removed must be reinstalled and recalibrated. The decontaminated system should be inspected for excessive corrosion or residual chemicals that could cause problems. Wastes removed by the decontamination must be properly treated, packaged, and shipped (but not necessarily prior to restart).

Plant systems and components that may have been affected by the decontamination should be tested. These tests are similar in intent to the tests described in the applicant's SAR under the title equivalent to "Initial Test Program." The tests considered needed for restart after a decontamination are equivalent to the initial tests prior to fuel loading, described in Regulatory Guide 1.68 as preoperational testing. Other tests dealing with start-up or post-start-up are not expected to be needed unless the decontamination affected pertinent components.

In addition to satisfying the operational test needs, retesting can also provide the opportunity to destroy any residual decontamination chemicals and to repassivate the decontaminated system. The conditions needed to accomplish these two activities should be obtained from the vendor of the decontamination process.

The complexity of the tests listed here, depending on the decontamination operation, may be more or less than that of the initial tests. Furthermore, the tests listed here are recommendations--the presence or absence of a specific test should not be construed as mandating its performance nor as condoning non-performance if good engineering judgement deems otherwise. Among other things, the licensee should determine whether the retesting required after the first decontamination performed on a given system is also required, in toto, on the second decontamination of the same system by the same process.

The pre-restart tests will include tests and inspections of equipment and systems to ensure that new components are properly installed and configured and that old systems have been returned to their proper function; a check that all valve systems are properly configured; that the cleaning and flushing of lines, including instrument lines, to ensure removal of decontamination chemicals was properly completed; that recalibration of instruments used during the decontamination was performed; and that all temporary facilities/equipment used for the decontamination have been completely removed.

After the applicant selects the necessary tests to be performed, each test should be prepared in a written form using the equivalent to the following format:

- Approvals and Title - a cover sheet providing the test title and the appropriate approvals/sign offs;
- Test Objective - a short, precise descriptive amount of what the test is and the expected accomplishments;
- Acceptance Criteria - the objective results with upper and lower limits which will be used to determine the success of failure of the test;
- Conditions Prior to the Test - the original design conditions of the system, the actual start-up conditions, and the conditions at the time of shutdown prior to the decontamination should be provided to permit easy comparison;
- Operating Conditions - all required operating conditions should be called out even if they are stated to be ambient;
- Special Precautions - protective gear or equipment operating limits should be called out keeping in mind the possible presence of residual decontamination solutions;

- Data - the necessary data and collection format, including data sheets, should be tabulated;

- Procedures - a detailed test procedure should be prepared which includes a summary of the test objective, the critical data/limits, and the appropriate responses to the data;

- Equipment List - a list which contains all test equipment needed, together with any needed operating instructions; and the

- Reference List - which provides rationale for the test, the procedures, or any limits stated.

The systems which are candidates for retest are given in Table 4.1. The systems chosen should be selected because:

- The systems were decontaminated and operating conditions may have changed;

- The systems were modified, for example, valved off, recalibrated, or replumbed, for the decontamination;

- The systems were used to process decontamination solutions under conditions different than those for the decontamination, for example, the radwaste evaporator may have been used to process the decontamination solutions;

- An accident or leakage during the decontamination may have exposed the system to corrosive solutions or vapors; or

- The time is opportune for retest.

The tests should include, as needed, electrical, hydrostatic pressurization, functional, and operational tests. Examples of the types of information sought from the tests are given in Table 4.2.

An operational readiness review, similar to the one described in Section 4.3.1.3, should be conducted to ensure that plant personnel, plant management, and all reactor systems are ready for the restart. The items to be considered in the review and the acceptance criteria should be established during the planning phase. The review will provide a systematic way of identifying any residual problems that would impede normal operation.

A summary report to document all aspects of the decontamination project, including successes and failures will serve as a useful reference if the reactor is decontaminated again at a later time or for similar projects at other plants.

TABLE 4.1. Candidate Systems for Retesting

Electrical Systems
Recirculating Cooling Water System
Filtered/Demineralized Water System
Fuel Handling System
Coolant Storage and Treatment Systems
Waste Disposal System
High Pressure Injection System
Low Pressure Injection System
Nuclear Instrumentation
Reactor Protective System
Gas Supply Systems
Chemical Addition and Sampling System
High and Low Pressure Service Water System
Control Rod Drive System
Spent Fuel Cooling System
Reactor Coolant System
Steam Generation System
Feedwater System
Component Cooling System
Reactor Coolant Non-Nuclear Instrumentation
Unit Cooldown System
Emergency Systems
Ventilation Systems
Fire Protection System
Residual Heat Removal System
Recombiner System
Leak Detection Systems
Condensate Systems
Fuel and Fuel Components (vibration flow test)

TABLE 4.2. Partial Test List

- Valves
  - --leakage
  - --operability against pressure
- Pumps
  - --seal or gland leakage
  - --seal cooling
- Motors and Generators
  - --Megger or high potential tests
- Piping and Vessels
  - --leaktightness
  - --cleaning and flushing
  - --clearance of obstructions (blind flanges, etc.)
  - --insulation (if exposed to decontamination solution)
  - --filling and venting
- Electrical, Instrumentation, and Control
  - --verify sensing lines are operable and clean
  - --trip settings
  - --interlocks, prohibits, and permissives
  - --calibration
  - --response time

5.0 WASTE MANAGEMENT

The treatment, storage, transportation, and disposal of wastes from decontamination must be accomplished in an acceptable manner. Standards for solid, gaseous, and liquid radioactive waste processing and treatment systems are specified in ANSI/ANS 55.1-1979, ANSI/ANS 55.4-1979, and ANSI/ANS 55.6-1979, respectively. Standards for measuring, evaluating, and reporting radioactivity in waste media are given in ANSI N13.10-1974 and Regulatory Guide 1.21, Rev. 1. Decontamination wastes are categorized according to physical form, as illustrated in the MORT chart shown in Figure 5.1.

5.1 LIQUID WASTE

All chemical and electrochemical as well as many mechanical decontamination processes will produce contaminated liquid waste. Because decontamination will produce wastes that contain more radioactivity than is typically handled during normal reactor operation, unusual problems or challenges in liquid waste storage, solidification, and disposal will be presented. In this discussion, liquid waste is subdivided into its chemical and radiological constituents. If the liquid contains neither chemical nor radiological constituents (that is, the concentrations of these constituents are at or below the release limits), it is not considered to be waste.

5.1.1 Uncontaminated Chemical Wastes

Decontamination will generate excess chemical decontamination solutions such as makeup tank rinses and uncontaminated chemical solutions from waste treatment processes. However, the volumes of these solutions are expected to be relatively small. The management, storage, transportation, and disposal of these hazardous chemical wastes are governed by DOT and EPA through NPDES and RCRA requirements (40 CFR). Planned disposal methods must assure compliance with all applicable regulations.

The maximum permissible concentrations (MPCs) specified in 10 CFR 20, Appendix B, Table II, Column 2 are used to distinguish contaminated liquid waste from uncontaminated solutions for disposal purposes. Although these limits are not based on dose rates through pathways other than drinking (such as irrigation of crops), they are generally conservative for most real situations.

There is some concern that disposal sites for hazardous chemical waste should be sufficiently far from radioactive waste disposal sites to prevent interaction of the wastes. This is of special concern if the chemical waste contains constituents that would enhance the mobility of radiological waste constituents.

5.1.2 Radioactive Waste That is Free of Hazardous Chemicals

Rinse solutions, reactor coolant, and water from mock runs are the main contaminated solutions that are relatively free of hazardous chemical constituents. The division between this category of wastes and radiologically contaminated chemical waste is not distinct. For the purpose of this analysis, chemical constituents are significant if they affect the assumptions on which the disposal criteria are based. Those assumptions address migration rates in the environment and uptake by biological systems. Radiologically contaminated wastes that are free of chemical hazards are essentially equivalent to normal reactor waste and are therefore regulated by existing criteria.

5.1.2.1 Liquid Storage

During decontamination, the liquid waste treatment process should not be on the critical path. In the event of a waste treatment system failure, the decontamination solutions would have to be retained in the system being cleaned. This might result in excessive corrosion or precipitation of contaminated chemicals. Therefore, capacity for storage of decontamination waste solutions may be a major factor in deciding whether a full-reactor decontamination is feasible. Proper planning for both routine storage and possible emergencies is imperative.

5.1.2.1.1 Routine Storage. In planning safe storage of waste decontamination solutions, the following factors should be considered:

- Materials Compatibility. The concerns of materials compatibility for solution storage are much the same as those for decontamination (see Sections 3.1 and 3.2). However, the contact time, corrosion rates, and materials may be different and must be anticipated. Treatment prior to storage by processes such as neutralization may be used to alter materials compatibility. If such processes are used, the effects must be evaluated.

- Chemical Compatibility. Chemicals that may react violently when mixed or form toxic or otherwise hazardous compounds should be stored in separate locations.

- Isolation. Radioactive waste solutions must be isolated from workers and the public. The degree of isolation and the integrity and redundancy of the isolation barriers should be related to the duration of dependency and the magnitude of the hazard (the amount and type of contamination and the environment potentially affected). There is considerable precedent for isolation, but no definitive criteria have been established for the extent of isolation required.

- Capacity. The volume of waste storage space available must be sufficient to contain all of the decontamination solutions and rinses. This is especially true if these liquids need to be removed from the reactor quickly because of: 1) excessive corrosion, 2) redeposition of contamination, or 3) a greater-than-expected effectiveness of the decontamination (with a consequent rapid increase of radioactivity in the solution). Criteria have not been established defining the required margin of safety in excess waste storage capacity. This can be evaluated either from mathematical models that maximize all uncertainties, or from

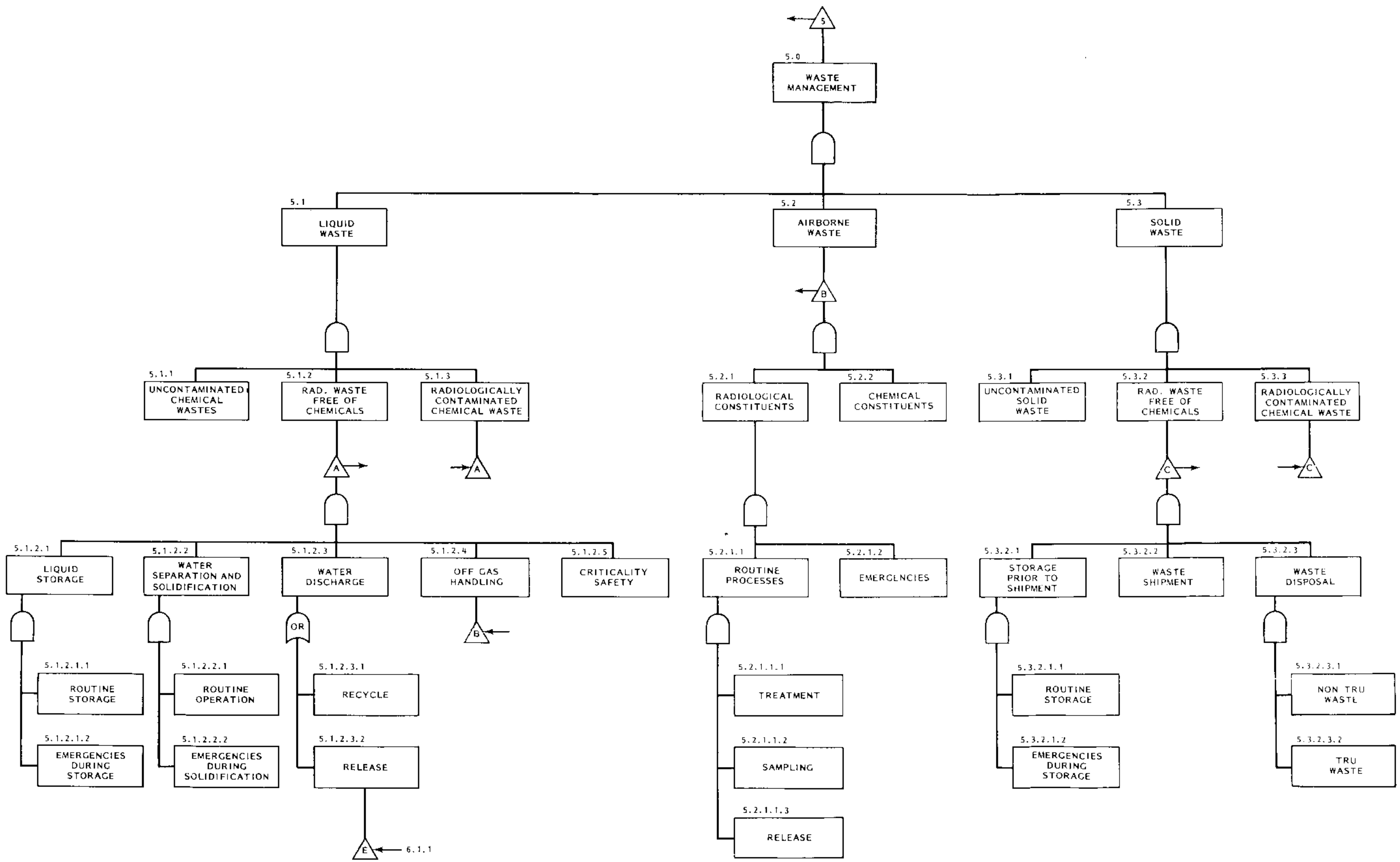

FIGURE 5.1. Waste Management

actual experience. An additional low-cost safety factor may be built in by designing the system so that decontamination solutions would overflow to rinse tanks or chemical mix tanks.

Final Disposition of Storage Equipment. In most cases, additional liquid storage equipment will need to be constructed or brought on-site to accommodate decontamination. This equipment may become contaminated and will ultimately require removal and storage or disposal. It is highly desirable to minimize the quantity of radioactive waste and the accompanying decommissioning and disposal cost. Forethought at the design stage can provide sludge removal capability and minimize the quantity of material to be disposed of. Strippable coatings, flexible liners, and surfaces that are easily decontaminated (polished) can all be used to minimize equipment disposal costs and radiation exposure. Standards requiring planning for decommissioning do not exist, but good financial and health physics practices make this planning important.

5.1.2.1.2 Emergencies During Storage. Good decontamination planning must include consideration of the potential for accidents such as major spills or pipe ruptures. Depending on the composition of the waste stored, a contingency plan or "Spill Prevention Control and Countermeasures Plan" may be required for storage of large quantities of liquids that may be environmental pollutants (40 CFR). The consequences of any probable accident should not be extremely severe, or if they are, measures should be in place to lessen the consequences. Double containment, such as a lined berm around tanks, may be needed. Emergency planning, such as that presently required of operating nuclear plants, will be more than adequate, in most respects, to deal with credible accidents during decontamination. Specific emergency preparations could include provision of an inventory of neutralizing chemicals, plastic sheeting to cover small spills, and sufficient tank capacity to contain any credible spill.

5.1.2.2 Water Separation and Solidification

Existing DOT regulations prohibit the transportation of radioactive liquids and make some form of solidification mandatory. Economic considerations make it advisable to concentrate the waste and purify the water for discharge or recycle. Water separation/concentration processes currently available include evaporation, ion exchange, and reverse osmosis, and some novel processes, such as electrophoresis and freezing.

Following water separation and/or concentration of the waste, the remaining liquid, slurry, or resin must be converted to a monolithic solid. Commercially available, licensed solidification processes for wastes of this type include the use of Dow polyvinylester, bitumen, and Portland cement.

5.1.2.2.1 Routine operation. The principal concerns in the application of the liquid volume reduction and solidification processes are:

- Materials Compatibility (see Section 5.1.2.1.1).

- Predictable Performance. The waste solidification process used must form a monolithic solid with no freestanding water. The equipment and process should be designed and tested to assure that this requirement is met. What constitutes an adequate demonstration of solidification is still under investigation.

- Maintainable Equipment. The cost, radiation exposure, and time delays involved in maintaining solidification equipment may be a major concern in reactor decontamination. Approaches to assuring that solidification equipment is operable include stocking spare parts, having redundant systems, placing vulnerable components in low-dose-rate areas, and performing remote operations.

- Final Disposition of Equipment (see Section 5.1.2.1.1).

- Acceptability of Final Waste Form. Existing transportation and disposal regulations require waste to be in the form of a monolithic solid with no freestanding water. Radionuclide leach rates for current solidification processes meet these requirements when other chemicals are not present. However, waste from chemical decontamination processes may contain chelating agents that increase the rate of leaching of some radionuclides. These potential problems have been addressed in CFR 20.311 by requiring waste which contains more than 0.1% chelating agents by weight to be identified and the weight percentage of chelating agents stated. Operators of waste disposal facilities should determine the acceptability of such wastes in their facilities.

5.1.2.2.2 Emergencies During Solidification. Planning should address fires and other credible emergencies in addition to the liquid spills discussed in Section 5.1.2.1.2.

5.1.2.3 Water Discharge

Most full-reactor decontamination schemes will produce large quantities of aqueous solutions that will be concentrated for disposal. Excess water may be purified, monitored, and discharged, or stored onsite for process use. The criteria in 10 CFR 20, Appendix B, Table II for water released to areas for unrestricted use are clear and must be applied to plant discharges.

Water quality criteria may be applied to the effluent stream directly or to the receiving body of water after some mixing. In most cases, the discharge will be governed by an NPDES permit and the utility's license and technical specifications. The criteria for discharges are not site specific, and should be well established prior to decontamination planning. Sampling and analysis must be adequate to assure that these criteria will be met (see Section 6.1.1).

5.1.2.4 Off Gas Handling

See Section 5.2.

5.1.2.5 Criticality Safety

Nuclear criticality is not expected to be a significant concern in commercial reactor decontamination. If there has been extensive fuel damage, or if the reactor has been fueled with material from an alternate nuclear fuel cycle (plutonium recycle), criticality safety should be evaluated. If there is a possibility of dissolving a critical mass of fissionable material, decontamination and waste handling apparatus must be designed in a critically safe configuration.

5.1.3 Radiologically Contaminated Chemical Waste

This category of waste will contain higher concentrations of radionuclides than waste from normal reactor operation and will generally contain chemical concentrations greater than 0.1%. The added chemicals may or may not be hazardous, and they could modify the chemical behavior of the radionuclides.

The concerns and criteria for the disposal of radiologically contaminated chemical waste are much the same as for other radioactive waste. The protection of people from chemicals and chemical fumes, the emergency planning, the acceptability of the final waste form, and the disposition of purified water may all be affected by the chemicals. Existing criteria do not address the presence of chemicals other than chelating agents in radioactive waste (also see Section 5.1.2.2.1). Separate criteria must be applied to the treatment, storage, transportation, and disposal of hazardous chemicals (see Section 5.1.1).

5.2 AIRBORNE WASTE

Airborne waste in the form of either gases or particulates may be generated at numerous points in the decontamination process. Airborne chemicals or radionuclides may be generated during the storage and mixing of decontamination chemicals, from breaks or leaks in piping systems, from vents and pressure relief valves in reactor systems, from liquid waste storage, volume reduction, and solidification processes, and possibly from solid waste storage and shipment. Airborne effluents may also result from accidents. The waste management difficulties and criteria are discussed below for each waste constituent.

5.2.1 Radiological Constituents

The radiological constituents of airborne waste may include particulates from dislodged crud, absorbable gases such as iodine from fuel failures, inert or relatively inert gases such as krypton from fuel failures, and tritiated water vapor from reactor coolant. Both routine processes and emergency procedures for dealing with these constituents should be addressed.

5.2.1.1 Routine Processes

5.2.1.1.1 Treatment. The technology for removal of radiological constituents from gaseous effluent streams is well established. The concerns are essentially the same as those discussed in Sections 5.1.2.1.1. and 5.1.2.2.1. The treatment system must have materials that are compatible with the process, a predictable performance, maintainable equipment, and a plan for the final disposition of the equipment.

5.2.1.1.2 Sampling. All gaseous waste streams must be adequately sampled and evaluated. This may include sampling of environmental media to assure compliance with the technical specifications and 10 CFR 20. Monitoring methods and criteria for radioactive gaseous effluents are well established.

5.2.1.1.3 Release. Concentrations of releases must not exceed the limits previously established in the facility, technical specifications, and/or the applicable limits of 10 CFR 20, Appendix B, 10 CFR 50, Appendix I, and 40 CFR 190.

5.2.1.2 Emergencies

It is possible to predict source terms for the most credible accidents identified previously and for possible failures of the air cleaning equipment in use. It is unlikely that the probability and consequences of failures would mandate the installation of additional air cleaning equipment (although respiratory protection for plant personnel might be required). No criteria have been established to clearly indicate when emergency preparedness would require additional air cleaning equipment. As discussed previously in Section 5.1.2.1.2, the probability and consequences of accidents and emergency preparations for them must be considered.

5.2.2 Chemical Constituents

The major factors in the control of airborne chemicals are chemical selection and process design. Available guidelines range from a list of hazardous chemicals to manuals on ventilation system design. None of these provide definitive criteria, but they may guide the selection of chemicals and processes. Threshold limit values (TLVs) for toxic chemicals have been established by the American Conference of Governmental Industrial Hygienists (ACGIH) and incorporated into OSHA regulations. Threshold limit values are provided for most of the common industrial chemicals, but not necessarily for all of those used during a decontamination.

Respiratory protection is often prescribed when there is an absence of control criteria for a particular chemical. Respirators with high-efficiency particulate air (HEPA) filters, commonly used at power plants, are effective against dusts and most mists; however, special precautions may be required to avoid overloading these filters. Respirators with HEPA filters are not effective against vapors, volatile organics, or oxygen-deficient atmospheres. Some chemical cartridges will protect against specific volatile chemicals such as HCl, but for unusual organics, such as many of the inhibitors used in decontamination, only supplied-air respirators afford adequate protection (see Section 7.3.2 also). When questions arise concerning protection of personnel from hazardous chemicals, an industrial hygienist should be consulted.

The release of chemicals to the environment is subject to state and local regulations as well as EPA source restrictions (40 CFR 60). Normal decontamination operations would probably not lead to violation of these requirements, but the regulations should be reviewed to ensure compliance. Energy-producing equipment, such as boilers or generators installed for decontamination, may be subject to these restrictions (see Sections 5.2.1.1 and 5.2.1.2).

5.3 SOLID WASTE

Solid waste will be generated from decontamination activities in several forms. Equipment and materials that are recycled or reused are not considered waste in this discussion. Chemical containers, protective clothing, etc., will become waste if contaminated. Liquids from decontamination must be solidified into a disposable waste form, and decontamination equipment may also be disposed of at the completion of the operation. The management of these wastes is discussed below for both chemical and radiological constituents (see also Section 6.1.3).

The treatment of solid wastes by compaction, incineration, or acid digestion is not addressed in this report because the equipment required for such treatment would probably not be added solely for a decontamination project. However, if such equipment were available at a reactor site, it would certainly be useful in reducing the volume of solid wastes generated by a decontamination.

5.3.1 Uncontaminated Solid Waste

Some materials brought onsite for decontamination, such as chemical containers and shipping pallets, may become wastes. The problems of segregating uncontaminated solid wastes and then assuring that they remain uncontaminated during decontamination are not materially different from those that are routinely handled as part of normal reactor operation. The definition for uncontaminated material is given in 49 CFR 173.389 and in the licensee's technical specifications and/or operating license. Actual release limits are normally well below the defined limit of 0.002 µCi/gm. If proper segregation and survey procedures are followed, the release of uncontaminated materials to unrestricted areas should not be a problem during reactor decontamination. The uncontaminated materials will be disposed of either in a sanitary landfill, or in accordance with RCRA if they contain hazardous chemicals.

5.3.2 Radioactive Waste That is Free of Interfering Chemicals

Radioactively contaminated debris and solidified liquid waste are handled and disposed of as a part of normal reactor operations. The primary differences for decontamination are the larger-than-normal quantities and the higher-than-normal radionuclide concentrations and resulting dose rates. The primary concerns are discussed below.

5.3.2.1 Storage Prior to Shipment

Storage conditions are important in both routine operations and emergencies. In certain cases, long-term onsite storage of contaminated components or decontamination wastes may be a viable option. However, evaluation of this option is beyond the scope of this report.

5.3.2.1.1 Routine storage. Waste storage may be inside or out-of-doors, depending on the following safety concerns:

- Isolation. The waste must be sufficiently isolated from both workers and the public to assure that radiation exposures are within limits and as low as reasonably achievable. Low-level wastes that are stored, shipped, and buried in cardboard boxes should be protected from the weather to prevent release of the radioactive contents. Concentrated, solidified decontamination solutions in drums may be stored outside temporarily, but may require radiation shielding or isolation.

- Capacity. Storage facility capacity should be adequate to protect the maximum quantity of decontamination materials anticipated and to allow proper space for inspection and handling. Project planning should provide for adequate isolation of the maximum quantity of radioactive waste produced for the maximum possible time prior to shipment. A contingency should be provided in these assessments to accommodate labor strikes, disposal site closures, etc. Definitive criteria for this margin of safety have not been established.

- Final Disposition of Storage Facility. The storage facility, whether an outdoor storage pad or an elaborately designed structure, should be designed for easy survey and decontamination. Facilities constructed for decontamination activities should not materially contribute to the effort required for facility decommissioning.

5.3.2.1.2 Emergencies During Storage. The principal emergencies that may occur during storage of solid radioactive waste are fire or mechanical damage to containers. The selection of the solidification method and packaging will have a significant effect on the probability and consequences of fire. The consequences can be further reduced by storage in a building that is away from ignition sources and that has adequate fire detection and protection systems. There may be some reluctance to apply the criteria of the National Fire Code because of the temporary nature of the hazard. Any deviation from these established codes should be based on a thorough analysis of the factors discussed in Section 5.1.2.1.2: the probability and consequences of emergencies, and planning for them.

5.3.2.2 Waste Shipment

The requirements for the transportation of hazardous materials specified in 49 CFR have been shown to be adequate for routine operations. Criteria for emergency planning for transportation accidents are not as definitive, and additional criteria are being developed in this area.

5.3.2.3 Waste Disposal

5.3.2.3.1 Non-Transuranic (Non-TRU) Waste. Unless a reactor has undergone significant fuel failures, decontamination waste will be non-TRU; that is, it will contain less than 10 nCi of transuranics per gram of material (EROA 1975). Disposal of this material is permitted at licensed burial sites in the U.S.

5.3.2.3.2 Transuranic (TRU) Waste. The availability of disposal sites or retrievable storage sites for TRU wastes is not assured because of political uncertainties; hence, this may be a major factor in the decision to perform a decontamination during the operating life of a reactor. The restraints and higher disposal costs for TRU waste may force a decision against decontamination prior to decommissioning. If there have been sufficient fuel cladding failures, the decontamination waste may contain TRU waste. Decommissioning waste, if decontamination was not performed, would be non-TRU because of its larger volume and, therefore, its much lower concentration of transuranics.

5.3.3 Radiologically Contaminated Chemical Waste

Radiologically contaminated chemical wastes are normally treated, from a regulatory standpoint, like radioactive waste that is free of hazardous chemicals with the exception of waste that contain more than 0.1% chelating agents by weight. These wastes must be identified to the waste disposal site and the percentage of chelating agents estimated (10 CFR 20.311).

6.0 ENVIRONMENTAL EFFECTS

The environmental effects of decontamination operations must be monitored and controlled so as to minimize their impacts. The environmental effects of normal operations and those resulting from credible accidents are expected to be similar in nature but different in magnitude. The key elements of normal operations are discussed in detail in Section 6.1. The impacts of larger-magnitude effects that may result from credible accidents are described in Section 6.2. A MORT chart that illustrates the elements of environmental effects is shown in Figure 6.1.

6.1 NORMAL OPERATIONS

No environmental effects are anticipated during normal decontamination operations. Liquid and airborne effluents will probably be unavoidable, but their impact may be negated by adequate monitoring and the application of effluent treatment and controls. Solid wastes must ultimately be removed from the site. Preparation, transportation, and disposal of these wastes can be managed with little or no impact on the environment. Direct radiation from the decontamination site is not expected to affect the offsite environment. Socioeconomic impacts of a decontamination project are addressed in Section 6.1.5.

6.1.1 Liquid Effluents

Liquid effluents with radioactive constituents are separated from those that are free of radioactivity in the following discussion.

6.1.1.1 Radioactive Effluents

Radioactive liquid effluents are subject to the requirements of the facility license, technical specifications, NPDES permits, and 10 CFR 20.106, 20.303, and Appendix B. The effluents must be monitored and controlled in order to comply with these requirements.

6.1.1.1.1 Monitoring Programs. A liquid effluent monitoring program will probably be required for any major decontamination project. Monitoring instruments and/or sampling stations will be needed at or near the discharge points on all liquid effluent streams. If instruments are used to continuously monitor effluents, readouts should be included at appropriate locations so that each effluent stream can be promptly stopped or controlled if preset action levels are exceeded. A wide variety of monitoring instruments are commercially available for such applications. Procedures for effluent sample collection are well established (APHA 1980). Although any operating nuclear power plant should have an ongoing environmental sampling program, some additional environmental sampling may be necessary during a major decontamination project.

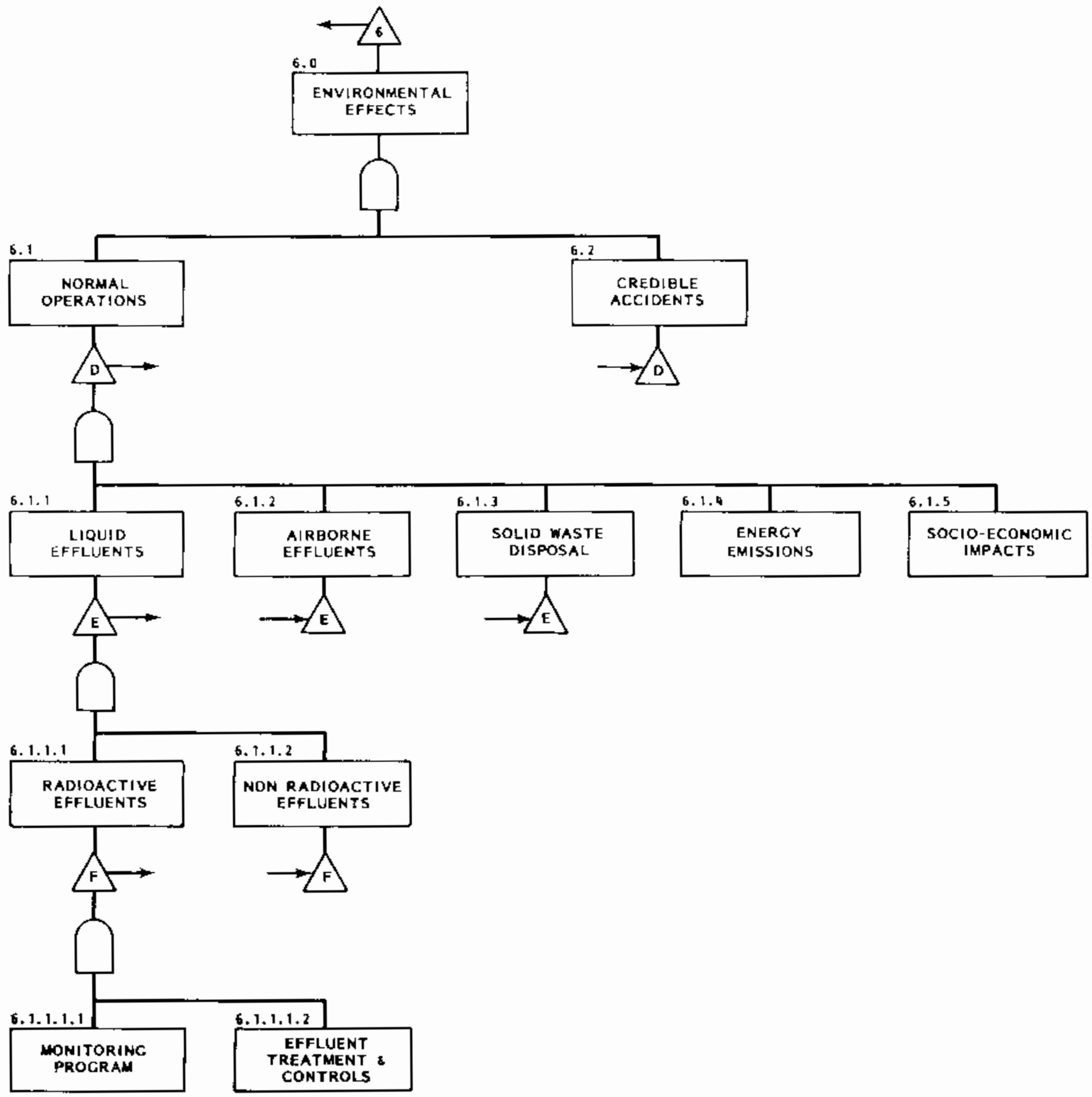

FIGURE 6.1. Environmental Effects

The objective of the monitoring program will be to measure radioisotope release fractions, rates of release, and effluent concentrations. Standard methods for sample preparation and analysis are provided in NCRP Report No. 50, "Environmental Radiation Measurements," NCRP Report No. 58, "A Handbook of Radioactivity Measurement Procedures," and other references. The results of the monitoring and sampling program should be properly recorded and compared to the applicable limits to assure compliance. Results should also be compared to base-line and background data to identify significant changes. Recordkeeping requirements are specified in 10 CFR 20.401.

6.1.1.1.2 Effluent Treatment and Controls. Several kinds of effluent treatment and control equipment may be needed to deal with radioactive liquid discharges. Effluent treatments may include evaporation to reduce volumes, or precipitation, ion exchange, or adsorption to remove certain radioisotopes from solution. If aqueous solutions are successfully decontaminated by such treatments, the water may be recycled to other plant systems or discharged (see Section 5.1.2.3). Standard equipment and procedures are available for treatment of effluents from decontamination solutions.

Radioactive constituents that are separated out of liquid effluents may be retained for additional treatment or prepared for disposal. It may be expedient to connect decontamination radioactive waste streams to the plant radioactive waste system (if capacity is adequate), where more complete treatment equipment and processes may be available. This approach may eliminate the need for some redundant operations.

Radioactive concentrations in liquid effluents may exceed preset action levels at times, in spite of a well-planned monitoring and treatment program. If this happens, it will be necessary to activate controls to stop or divert and retain liquid discharges. Control equipment should be carefully engineered and located to facilitate prompt mitigative actions.

If radionuclide concentrations are only slightly above release limits and volumes are relatively large, it may be desirable to mix the discharge with an uncontaminated waste stream to achieve dilution. Dilution and dispersion may be accomplished in other ways, depending upon site-specific factors such as onsite water bodies, flow rates, proximity of site boundaries, etc.

6.1.1.2 Nonradioactive Effluents

Nonradioactive liquid effluents are subject to the provisions of the Clean Water Act and the EPA's NPDES permit program (40 CFR). Physical and chemical standards for release of liquid effluents to navigable waters are set forth in 40 CFR 122-125. An NPDES permit may be required if decontamination effluent volumes are greater than 50,000 gallons per day or if the concentrations exceed the standards of the Clean Water Act. If the regional EPA office determines that a permit is not needed, the matter may be referred to local authorities who may place additional requirements on effluent discharges, but these are generally less stringent than federal requirements.

6.1.1.2.1 Monitoring Program. The liquid effluent monitoring and sampling program described in Section 6.1.1.1.1 also applies to nonradioactive liquid effluents. The selected decontamination process must be examined to identify the major chemicals to be used and their relative toxicity. This evaluation should characterize typical volumes, concentrations, and chemical impurities that may be highly toxic. The chemical effluents most likely to exceed specified concentration limits should be monitored. Instruments should be carefully selected for the specific physical properties, chemicals, and concentrations to be monitored. Samples collected from effluent streams can be used for both radioactive and nonradioactive chemical analyses. Standard procedures for sample preparation and analysis are well established (APHA 1980). The results of the monitoring program should be properly recorded and compared to the applicable limits to assure compliance.

6.1.1.2.2 Effluent Treatment and Control. The liquid effluent treatment and control program described in Section 6.1.1.1.2 also applies to nonradioactive liquid effluents. Nonradioactive chemicals that are separated from liquid effluents may be recycled to the decontamination project, retained for additional treatment, or prepared for disposal. The effluent control equipment described in Section 6.1.1.1.2 may be applied to control nonradioactive effluents that exceed discharge limits. Dilution and dispersion may also be applied to nonradioactive effluents, particularly if the volumes are relatively large.

6.1.2 Airborne Effluents

As in Section 6.1.1, radioactive airborne effluents are separated from airborne effluents that are free of radioactive constituents in the following discussion.

6.1.2.1 Radioactive Effluents

Radioactive airborne effluents are subject to the requirements of the facility license and technical specifications as well as 10 CFR 20.106 and Appendix B. The effluents must be monitored and controlled in order to comply with these requirements.

6.1.2.1.1 Monitoring Program. The liquid effluent monitoring and sampling program described in Section 6.1.1.1.1 can be applied directly to radioactive airborne effluents by simply substituting the word "airborne" for "liquid." The only differences will be in the monitoring instruments and sample collection and analysis methods used. Airborne effluent monitoring instruments must be selected for the specific radionuclides, concentrations, release rates, and release fractions expected in the discharge. Sample collection methods vary for vapors, radiogases, and particulates. Sample preparation and analysis procedures can be selected for each type of sample and radionuclide in question. Standard procedures for sample collection, preparation, and analysis are readily available (40 CFR).

6.1.2.1.2 Effluent Treatment and Controls. Several kinds of effluent treatment and control equipment may be needed to manage radioactive airborne discharges. Since both gases and aerosols may be generated during decontamination, it may be necessary to physically separate them prior to, or in conjunction with, treatment. Normally, aerosols and particulates are removed from airborne effluent streams by HEPA filters. However, centrifugation, scrubbing, or electrostatic precipitation may be applied. After aerosols and particulates are removed, gases may be concentrated by chemical reaction, absorption, adsorption, condensation, liquifaction, or pressurization techniques. Standard equipment and procedures are available for treatment of airborne effluents. If the concentrations of airborne discharges are reduced to levels below the specified limits, the air can be released directly to the atmosphere.

Radioactive contaminants that are separated out of airborne effluents may be retained for additional treatment or prepared for disposal. Again, it may be expedient to connect radioactive airborne waste streams to the plant radioactive waste system in order to avoid some redundant operations.

6.1.2.2 Nonradioactive Effluents

Nonradioactive airborne effluents are subject to the provisions of the Clean Air Act, and standards for the release of airborne effluents are set forth in 40 CFR 61. Releases may also be regulated by local or regional air pollution control authorities.

6.1.2.2.1 Monitoring Program. The airborne effluent monitoring and sampling program described in Section 6.1.2.1 also applies to the nonradioactive airborne effluents.

6.1.2.2.2 Effluent treatment and controls. Nonradioactive airborne effluent treatment and controls are essentially the same as those for radioactive effluents, which are described in Section 6.1.2.1.2.

6.1.3 Solid Waste Oisposal

Normally, solid waste is treated, packaged, and disposed of with minimal generation of liquid and airborne effluents. If significant effluents are generated, monitoring, sampling, treatment, and control methods described in Sections 6.1.1 and 6.1.2 should be used.

Release of solid decontamination waste directly to the immediate environment of the plant is not anticipated. Since solid wastes are relatively easy to concentrate and package, the preferred disposal method is to transport the waste to a licensed disposal site. Disposal of solid wastes by this method is subject to the requirements of the Resource Conservation and Recovery Act (RCRA). Although RCRA applies primarily to hazardous solid wastes, it may apply to liquids and gases if they are solidified or absorbed and mixed with solid wastes. Hazardous wastes, as defined by RCRA, include those that are flammable or ignitable, corrosive (pH <2 or pH >12), reactive, or toxic (containing heavy metals or pesticides). The RCRA includes an extensive list of chemicals that are considered hazardous. The actual chemicals to be used in a decontamination should be checked against this list to identify specific RCRA requirements.

The requirements of RCRA and those of DOT go hand-in-hand in their application to the pretreatment, packaging, and transportation of hazardous wastes. Strict compliance with these requirements will be a key element in the success of a decontamination project.

Disposal sites are licensed and regulated by federal and state agencies. Site licensing is beyond the scope of this document. However, the disposal of solid wastes containing chelating agents is an unresolved problem at sites where waterborne migration occurs (see Section 5.3 for additional discussion on this subject).

6.1.4 Energy Emissions

Energy emissions from decontamination projects are not expected to significantly affect the offsite environment. However, the following forms of energy are considered for completeness.

Ionizing radiation, in the form of alpha and beta particles and gamma rays, will certainly be a concern to the work force on a decontamination project, but direct emissions to the offsite environment from waste tanks or other sources should be minimal. The relatively isolated locations of nuclear power plants and the surrounding "buffer zones" should provide adequate protection from direct radiation. Offsite direct radiation should be indistinguishable from natural background radiation.

Thermal emissions may be a minor concern since heated solutions and vapors will be used as decontamination agents. However, heat released to the environment from decontamination operations will be insignificant compared to the waste heat generated by an operating nuclear power plant.

Electromagnetic energy, including such forms as ultraviolet, static fields, UHF/VHF, lasers, etc., are not now employed in decontamination work in any significant way.

Mechnical energy in the form of ultrasonic (cleaners) and vibration (abraders and spallers) may be a concern to decontamination workers, but direct emission of such energy to the environment is not expected.

6.1.5 Socioeconomic Impacts

A large decontamination project will no doubt have some socioeconomic impacts on the community near a nuclear power plant. The impacts may be similar to those experienced during refueling outages. The impacts resulting from smaller decontamination projects are likely to be undetectable.

A work force of trained and experienced specialists will be needed for decontamination projects. Numerous observers may also be present. Since some of these workers will not normally be on the plant staff, they will come to the site from other locations. The size of this transient worker population and its impact on the community will vary with the magnitude and duration of the decontamination project. Short-term projects will affect motels, restaurants, and tourist-type services and will probably have a positive effect on the local economy. Larger decontamination projects of longer duration may affect temporary housing, schools, health care, utilities, and other community services. Unless the local tax system is structured to cope with transient workers, these impacts could have a significant negative effect on the local economy. Larger decontamination projects will also require both skilled and unskilled workers, at least some of whom will be supplied by the local community. The temporary employment of resident workers will help to alleviate unemployment and add to the local economy.

Transportation routes may be affected by the shipment of mobile decontamination equipment, hazardous chemicals, and radioactive waste. These shipments and the movements of the transient workers will require heavier use of the roads and may add to local congestion. Special or additional modes of transportation may be needed.

The risks of spills or accidents involving hazardous materials will also increase slightly. This may have a significant impact on the public, depending upon the nature of news media coverage. Decontamination is a subject relatively unknown to the public and it will be very important for the nuclear power plant's public relations staff to explain the work.

Successful decontamination of a nuclear power plant will permit continued operation with reduced exposure to the resident work force. This reduced exposure and the related reduction in risk should be seen as a benefit to the resident population.

6.2 CREDIBLE ACCIDENTS

During a major system decontamination, the containment vessel may not be isolated (or isolable). This consideration must be included in the evaluation of credible accidents. The effluent monitoring and control program used for normal operations can also be used to mitigate the environmental effects of credible accidents during decontamination work. Effluent control equipment and procedures should be designed to handle accidental, as well as routine, releases. If control systems function properly and contain an accidental release, then the in-plant monitoring and sampling program must be capable of handling higher concentrations of radionuclides or hazardous chemicals. Sample preparation and analysis systems must also be capable of handling the higher concentrations. With this conservative approach to effluent monitoring and control, the environmental impacts of credible accidents should be minimal. (See Sections 5.1.2.1.2, 5.1.2.2.2, 5.2.1.2, and 5.3.2.1.2 for a more thorough discussion of hazardous waste management under emergency conditions).

7.0 OCCUPATIONAL SAFETY

Occupational safety includes measures to protect the health and safety of all personnel who may be on the reactor site during decontamination, and the prevention of unexpected damage to equipment or facilities. No distinction is made among personnel employed by the reactor operator and subcontractors, vendors, observers, and regulatory personnel. A MORT chart for occupational safety is shown in Figure 7.1.

7.1 INDUSTRIAL SAFETY

Industrial safety is the prevention of injuries to personnel. The principal safety hazards include falling objects, falls, cuts, and burns from chemicals or heat. These concerns must be addressed by the plant safety staff. Certified industrial safety consultants should be used to augment the permanent staff as necessary.

7.1.1 Accident Prevention

In addition to the accident prevention, loss prevention, or safety program normally used by the reactor operator, there are specific additional concerns related to the decontamination operation.

Decontamination may require personnel to enter areas that are not normal work areas. To minimize the risk of industrial accidents in these areas, the right combination of plant physical design (e.g., railings, lighting, platforms), maintenance (e.g., lighting, equipment repair), selection of personnel, training, housekeeping, and personnel protective equipment (e.g., air lines, safety lines, eye protection, gloves) is essential.

Criteria that cover physical plant design and construction include building codes and the standards of OSHA and the American National Standards Institute (ANSI). However, judgment must be used in applying these standards to decontamination. Because decontamination is not a routine and repetitive job, not all "work area" criteria are applicable to locations that are only entered during decontamination. Job planning must include an assessment of the hazards of the physical plant and their correction as necessary.

The maintenance, inspection, and testing of items such as cranes, hoists, and pressure systems that must be used during decontamination can have a direct effect on personnel safety. The best source of criteria for an adequate program in this area is ANSI standards.

The selection of personnel with adequate physical abilities, experience, and emotional suitability will minimize the likelihood of an accident. If individuals are assigned to do work (such as lifting or climbing) that they do not have sufficient strength for, the likelihood of injury will increase. Experience in dealing with similar industrial situations in the past may increase a worker's knowledge of the hazards and of appropriate preventive measures. However, experience may also lead to overconfidence, which could

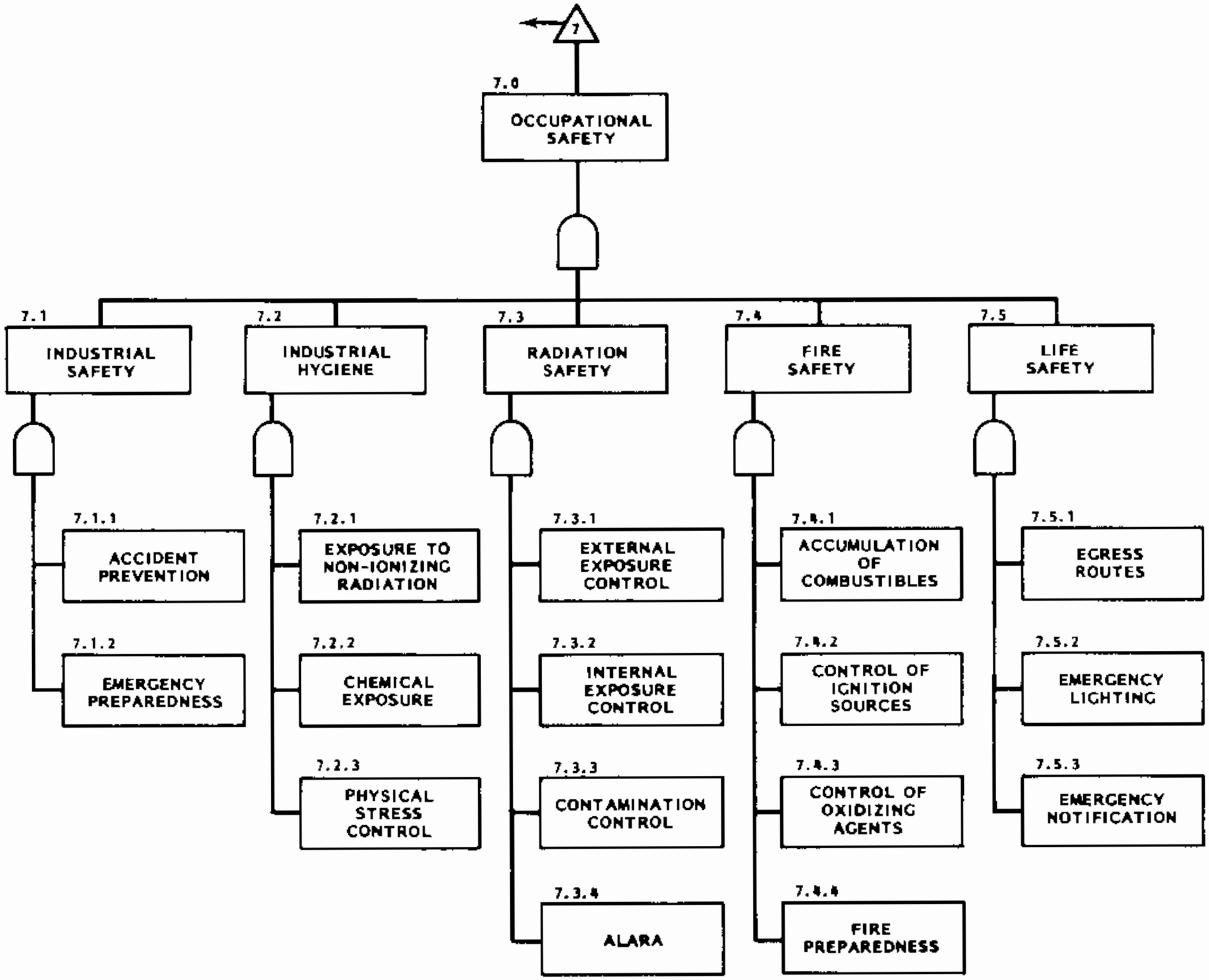

FIGURE 7.1. Occupational Safety

have an adverse effect on caution and safety awareness. Emotional instability, particularly fear of radiation or confined spaces, or more deep-seated psychological problems may increase the possibility of industrial accidents.

The NRC's Regulatory Guide 1.8 and reactor licenses include criteria for the qualification of key personnel at reactors. However, personnel selection criteria are not specifically applicable to decontamination activities; therefore, the physical and emotional health of decontamination workers should be evaluated by a competent health care professional (medical doctor or physician's assistant) to ensure that personnel are able to do the work safety. Regulatory Guide 8.15, NUREG-0041, and ANSI Z88.2 contain criteria for the physical qualifications of personnel who are required to perform work in a respirator.

Any previous experience of decontamination workers must be evaluated and taken into account in establishing a training program. The standards of ANSI and OSHA address the qualifications of the instructor, duration of training, frequency of retraining, and testing required. Few standards, however, are applicable to the job-specific training required to prevent accidents during decontamination activities.

Housekeeping is an important part of accident prevention. Regulatory Guide 1.39, "Housekeeping Requirements for Water-Cooled Nuclear Power Plants," and ANSI N45.2.3, "Housekeeping During the Construction Phase of Nuclear Power Plants," detail housekeeping requirements. The standards of OSHA also require good housekeeping to promote personnel safety. In spite of these requirements, housekeeping tends to be neglected at some nuclear power plants to conserve personnel exposure or manpower costs. Such tendencies should be avoided by planning for the housekeeping that will be needed during decontamination.

Personnel protective equipment must be used where it is not feasible or cost effective to make permanent modifications and where a second barrier against personnel injury is required. Numerous National Institute of Safety and Health (NIOSH), ANSI, and other standards give qualifications for protective equipment such as safety harnesses, safety shoes, respirators, hard hats, and safety glasses. The criteria governing the use of such equipment, except for respirators and safety lines, are less definitive than the qualification criteria. Careful job planning, which includes a job safety analysis, and compliance with applicable standards should lead to an acceptably low risk of industrial accidents.

A job safety analysis (JSA) should be prepared by the person scheduled to perform each procedure. It should include each step the worker will take, the hazards the worker will be exposed to, and an analysis of the steps required to reduce the risks. A JSA is an excellent training tool. It may be used in conjunction with a mockup, job-specific training, or prejob briefing. A JSA forces workers and planners to look at the relationship between hazards and protective measures. This is an advantage over attempting to apply all of the individual safety standards. For example, a NIOSH-approved airline respirator may provide the surest protection against chemicals or airborne radioactivity, but worker mobility and vision needs must also be considered in equipment selection.

7.1.2 Emergency Preparedness

The emergency preparedness required for industrial safety during plant decontamination activities differs only slightly from that required for other maintenance activities, but it will require careful analysis. The use of certain chemicals may require the addition of emergency showers, eyewash stations, neutralizing chemicals, and safety equipment (such as oxygen). Personnel must be trained in the proper use of these devices. Some of this special equipment may be required by OSHA and other applicable standards. Specific requirements will become apparent through review of the Materials Safety Data Sheets that can be obtained from chemical manufacturers and through the JSA discussed in Section 7.1.1.

7.2 INDUSTRIAL HYGIENE

The industrial hygiene problems associated with decontamination are comparable to those of many other industrial situations. The specific problems will become apparent during the JSA.

7.2.1 Exposure to Nonionizing Radiation

In-situ decontamination will probably not involve exposures to ultraviolet light, microwaves, ultrasonic generators or other sources of nonionizing radiation; however, if these forms of energy are involved in other decontamination processes, special precautions may be necessary to prevent personnel exposures. OSHA regulations provide criteria for allowable exposure and acceptable monitoring equipment. An adequate surveillance program should be designed and implemented by qualified specialists who are familiar with the system in which the sources will be used.

7.2.2 Chemical Exposure

In-situ reactor decontamination will almost certainly involve the introduction or generation of chemicals that are capable of adverse reactions with biological systems. They may be toxic, carcinogenic, mutagenic, or teratogenic. Exposure standards are available for most chemicals that may be introduced into the reactor system. Chemicals that may be formed during the decontamination are less likely to be understood. Maintaining exposure to potentially harmful chemicals at ALARA levels will require a combination of good equipment designs (including closed systems and local exhaust ventilation), exposure monitoring, personnel protective equipment, and training. Reactor decontamination could employ or generate a chemical for which adequate exposure standards have not been developed. The need for new standards must be evaluated on a case-by-case basis (see also Section 5.2.2).

7.2.3 Physical Stress Control

Decontamination will involve noise-generating equipment and the potential for heat stress. Noise generation by mixers, pumps, etc., can be controlled by equipment selection and placement. Present OSHA standards for noise are adequate for decontamination operations. Hearing protection devices and audiometric testing may be required if exposures exceed established limits. Heat stress may occur when a worker's body temperature rises too far above normal conditions. Impermeable protective clothing, high humidity, long exposure times, and the physical exertion of the worker may all contribute to heat stress. Industrial hygiene standards and measurement methods for exposure to heat stress are not entirely adequate for many situations, and decontamination may be among them. However, a conservative approach applied by knowledgeable professionals should keep all industrial hygiene risks at an acceptable level.

7.3 RADIATION SAFETY

The limits of acceptable radiation exposure for decontamination are the same as for other licensed plant activities and are stated in 10 CFR 20. However, dose rates that change with time and location are a special problem in the control of radiation exposure during decontamination. Decontamination, by design, mobilizes significant quantities of radionuclides, which affect dose rates and can relocate contamination and airborne radioactivity.

7.3.1 External Exposure Control

External radiation exposure control is a normal activity during nuclear plant maintenance and operation. An expansion of the surveillance and control programs will be required by decontamination activities. Decontamination may cause radioactive crud dislodged from one location in the primary system to redeposit elsewhere within the primary system. Piping dead legs, valves, instruments, and sample lines are likely spots for redeposition. Decontamination planning should include identification of these locations, and wherever possible, actions should be taken before decontamination to prevent crud accumulation or to provide for dislodging it remotely. Preventive actions may include removing internal components from a valve, installing flush lines on dead legs, and introducing solutions into the primary loop through sample lines to flush them. An expanded monitoring surveillance program will also be required. The licensee's health physics staff must have a thorough understanding of the potential problems and be involved in decontamination planning and JSAs to control radiation exposures.

7.3.2 Internal Exposure Control

Internal exposure to radioactive materials usually results from the inhalation of contaminated dusts or mists, although it may occur from ingestion or from contamination of a wound. The deposition hazards presented by decontamination are not substantially different from those presented by other maintenance activities, although some hazards may be of a greater magnitude. Existing health physics and respiratory protection criteria and programs should be sufficient to control internal exposure.

7.3.3 Contamination Control

While contamination control is a normal part of reactor health physics work, extra precautions may be required because of the large quantity of radioactive material mobilized by the decontamination. A contamination survey program, designed by a health physicist who is familiar with the reactor systems and the decontamination plans, should provide for early detection and correction of any problems.

Decontamination solutions containing dissolved radioactive material may present unusual skin contamination hazards. Decontamination of skin may be difficult because of chemical burns or the chemistry of the solution involved. Normal health physics practices should minimize the potential for skin contamination. Some special reviews may, however, be required to ensure that protective clothing and equipment will maintain their integrity when exposed to decontamination chemicals under the conditions of use.

7.3.4 ALARA

The radiation safety program in place during decontamination should ensure that radiation exposures for individuals and the collective work force are maintained ALARA. Regulatory guidance and criteria concerning the ALARA philosophy are provided in Regulatory Guides 8.8 and 8.10 and in numerous other documents. No new criteria are needed to apply the ALARA philosophy to reactor decontamination, but it is important that this philosophy be applied to all phases of a decontamination project.

7.4 FIRE SAFETY

Fire requires combustible material, a source of ignition, and an oxidizing agent, which may be atmospheric oxygen. A fire safety program involves control of all these elements, but because none of them can be eliminated entirely, a fire preparedness program is also needed to ensure that any fire that does start is quickly extinguished and does not spread. Protection of the plant and public from fire may or may not be materially altered by decontamination. If the decontamination and waste treatment processes require only aqueous decontamination solutions, no construction of new facilities, and solidification of waste with concrete, then fire protection may not be a significant additional concern. In all other cases, fire protection should be given additional consideration.

7.4.1 Accumulation of Combustibles

Combustibles that may be associated with full-reactor decontamination include ion-exchange resins, flammable solvents or gases, asphalt, or other organic solidification agents. Increased quantities of ordinary combustibles such as shipping pallets, protective clothing, and paper will also be present. The criteria for storage of combustible materials in isolated and/or properly protected areas do not generally apply to a temporary situation such as a major decontamination. A case-by-case assessment is therefore required.

7.4.2 Control of Ignition Sources

The principal sources of ignition associated with decontamination are expected to be: 1) cutting and welding associated with system modification or construction of temporary facilities, 2) electrical and instrument wiring to service decontamination equipment or temporary facilities, and 3) heat-producing equipment such as evaporators. When combustibles or highly flammable solvents or gases are present, ignition sources must be excluded entirely or isolated. The control of these ignition sources is not expected to have a major impact on decontamination. A combination of professional review and conformance to applicable criteria, such as the National Fire Code and building codes, should preclude significant problems.

7.4.3 Control of Oxidizing Agents

Decontamination may involve strong oxidizing agents, such as hydrogen peroxide, pure oxygen, ozone, or potassium permanganate, that represent an increased fire hazard. Chlorine or fluorine gas, although they are common oxidizing agents, are not likely to be used because they cause extensive corrosion of stainless steel. Oxidizing and reducing agents must be carefully separated during their storage and use. Existing criteria, adherence to the manufacturers' recommendations, and review by a fire safety professional should ensure that the use of oxidizing agents does not present an undue fire risk.

7.4.4 Fire Preparedness

Measures to protect against fire should be consistent with the approved fire protection program for the plant and may include: 1) installed protection systems, such as sprinklers and Halon suppression systems, 2) portable fire-fighting equipment, such as extinguishers and hoses, 3) alarm systems, 4) fire surveillance procedures, 5) training of plant personnel, and 6) availability of trained and equipped fire-fighting teams. The final safety analysis report (FSAR) for an operating reactor will provide criteria for installed protection devices, training, and fire-fighting plans. In the case of decontamination of a reactor that has been shut down for some time, specific criteria may have to be developed. Professional fire safety review is needed to ensure that the installed and portable fire-fighting equipment in new and modified facilities conforms to the FSAR criteria and that fire protection training for both plant crews and fire brigades adequately covers decontamination facilities and hazards.

7.5 LIFE SAFETY

Life safety includes all the measures necessary to preserve the life of facility occupants during a fire or other emergency. There are three major components of life safety: 1) the availability and designation of egress routes to be used in an emergency, 2) lighting to enable workers to find and use emergency exits, and 3) the notification of workers that an emergency exists.

7.5.1 Egress Routes

Modifications required for decontamination may involve blocking either normal or emergency egress routes, extending egress routes through temporary structures, and rerouting egress routes. The principal criteria for adequate emergency egress are given in the National Fire Protection Association's (NFPA) life safety code. However, the code is not specifically applicable to a reactor containment structure. The OSHA life safety standards taken from the NFPA code are applicable. The number and width of egress routes are dependent on the maximum numbers of people occupying the facility. Although egress route requirements are not expected to be major constraint, they should be considered.

7.5.2 Emergency Lighting

The regulations of OSHA establish minimum illumination levels for both routine work and emergency egress. These criteria are applicable to decontamination operations. New and modified facilities should be inspected for adherence to these criteria.

7.5.3 Emergency Notification

The ability to notify workers of an emergency is essential to their evacuation from the facility. Emergencies for which evacuations might be required include fire, high radiation levels, airborne radioactivity or toxic chemicals, rising water levels (in certain locations), and failure of the air supply system for building ventilation or airline breathing. Criteria for fire alarms are established in the NFPA codes. Criteria for notification of airline respirator users in case of supply contamination or interruption are given in NRC regulatory guides and in ANSI standards. Criteria for notification of other emergencies may be included in the reactor FSAR. However, specific emergencies that might require worker notification should be reviewed and a system established to ensure that required notifications are made.

REFERENCES

Allen, R. P., et al. 1978. "Electropolishing as a Decontamination Process: Progress and Applications." PNL-SA-6858, Pacific Northwest Laboratory, Richland, Washington.

American Conference of Governmental Industrial Hygienists (ACGIH). 1977. TLVs: Threshold Limit Values for Chemical Substances and Physical Agents in the Workroom Environment. ACGIH, Cincinnati, Ohio.

American National Standards Institute (ANSI). 1980. Practices for Respiratory Protection. ANSI Z88.2-1980, ANSI, New York.

American National Standards Institute (ANSI). American Nuclear Society (ANS). 1979. American National Standard for Solid Radioactive Waste Processing System for Light Water Cooled Reactor Plants. ANSI/ANS-55.1-1979, ANSI, New York.

American National Standards Institute (ANSI). American Nuclear Society (ANS). 1979. American National Standard for Gaseous Radioactive Waste Processing Systems for Light Water Reactor Plants. ANSI/ANS-55.4-1979, ANSI, New York.

American National Standards Institute (ANSI). American Nuclear Society (ANS). 1979. American National Standard for Liquid Radioactive Waste Processing System for Light Water Reactor Plants. ANSI/ANS-55.6-1979, ANSI, New York.

American National Standards Institute (ANSI). American Society of Mechanical Engineers (ASME). 1979. Housekeeping During the Construction Phase of Nuclear Power Plants. ANSI/ASME N45.2.3-1973 (including supplement ANSI/ASME N45.2.3a-1978), ANSI, New York.

American National Standards Institute (ANSI). 1974. American National Standard Specification and Performance of On-Site Instrumentation for Continuously Monitoring Radioactivity in Effluents. ANSI N13.10-1974, New York.

American Public Health Association (APHA). 1980. Standard Methods for the Examination of Water and Waste Water. 15th edition. APHA, New York.

Ayres, J. A., ed. 1970. Decontamination of Nuclear Reactors and Equipment. Ronald Press, New York.

Buys, J. R. 1977. Standardization Guide for Construction and Use of MORT-Type Analytic Trees. ERDA-77-45/8, SSDC-8, EG&G Idaho, Inc., Idaho Falls, Idaho.

Choppin, G. R., et al. 1979. Literature Review of Dilute Chemical Decontamination Processes for Water-Cooled Nuclear Reactors. EPRI-NP-1033, prepared for Electric Power Research Institute by Battelle, Pacific Northwest Laboratories, Richland, Washington.

Code of Federal Regulations (CFR), Title 10, Part 20, Standards for Protection Against Radiation.

Code of Federal Regulations (CFR), Title 10, Part 50, Domestic Licensing of Production and Utilization Facilities.

Code of Federal Regulations (CFR), Title 29, Part 1910, Occupational Safety and Health Standards.

Code of Federal Regulations (CFR), Title 40, Protection of Environment.

Code of Federal Regulations (CFR), Title 49, Transportation.

Cohen, P. 1969. Water Coolant Technology of Power Reactors. Gordon and Breach, Science Publishers, Inc., New York, New York.

Cunningham, L. J., J. E. Wigginton, and E. D. Flack. 1982. Health Physics Appraisal Program. NUREG-0855, U.S. Nuclear Regulatory Commission, Washington, D.C.

Demmitt, T. F., A. P. Larrick and T. M. Hall. 1981. "Cost Benefits Resulting from Decontamination of Nuclear Power Plants." Paper presented at the International Corrosion Forum sponsored by the National Association of Corrosion Engineers, April 6-10, 1981, Toronto, Ontario, Canada.

Dow Chemical Company. 1977. Technical Study for the Chemical Cleaning of Dresden-I. DNS-OI-016, Vol. 1-8, Midland, Michigan.

FitzPatrick, V. F., et al. 1981. The Criteria for Evaluation of a Dilute Decontamination Demonstration. PNL-4D55, Pacific Northwest Laboratory, Richland, Washington.

Grant, E. L., W. G. Ireson, and R. S. Leavenworth. 1976. Principles of Engineering Economy. 6th ed. Ronald Press, New York.

Hall, T. M., A. M. Dodd, and R. F. Haight. 1979. Determining Effectiveness of ALARA, Design and Operational Features. NUREG/CR-0446, United Nuclear Industries, Inc., Richland, Washington.

Johnson, W. G. 1975. Accident/Incident Investigation Manual. ERDA 76-20, Energy Research and Development Administration, Washington, D.C.

Kathren, R. L., and J. M. Selby. 198D. A Guide to Reducing Radiation Exposure to As Low As Reasonably Achievable (ALARA). DOE/EV/1830-T5, Pacific Northwest Laboratory, Richland, Washington.

LeSurf, J. E., and H. E. Tilbe. 1980. "Decontamination for Continued Operation: An Industry-Wide Approach." In Decontamination and Decommissioning of Nuclear Facilities, ed. M. M. Osterhout, pp. 131-144. Plenum Press, New York.

LeSurf, J. E., and G. D. Weyman. 1981. "Cost Effectiveness of Dilute Chemical Decontamination." Paper presented at the American Nuclear Society Winter Meeting, November 29-December 3, 1981, San Francisco, California.

National Council on Radiation Protection and Measurements (NCRP). 1976. Environmental Radiation Measurements. NCRP Report No. 50, NCRP, Washington, D.C.

National Council on Radiation Protection and Measurements (NCRP). 1978. A Handbook of Radioactivity Measurement Procedures. NCRP Report No. 58, NCRP, Washington, D.C.

National Fire Protection Association (NFPA). 1982. National Fire Codes. NFPA, Quincy, Massachusetts.

Nelson, J. L., and J. R. Divine. 1981. Decontamination Processes for Restorative Operations and as a Precursor to Decommissioning: A Literature Review. PNL-3706, NUREG/CR-1915, Pacific Northwest Laboratory, Richland, Washington.

Nertney, R. J., J. L. Clark, and R. W. Eicher. 1975. Occupancy-Use Readiness Manual. ERDA-76-45-1, SSDC-1, Aerojet Nuclear Company, Idaho Falls, Idaho.

Newman, D. G. 1980. Engineering Economic Analysis. Rev. ed. Engineering Press, Inc., San Jose, California.

Nuclear Safety, NRC Research Information Letter 6.RIL 80, Vol. 21-3, May-June, 1980, U.S. Government Printing Office, Washington, D.C.

NUS Corp. 1969. Guide for Economic Evaluation of Nuclear Reactor Plant Designs. NUS-531, Rockville, Maryland.

Perrigo, L. D., et al. 1979. The Impact of Decontamination on LWR Radioactive Waste Treatment Systems. PNL-3297, NUREG/CR-0986, Pacific Northwest Laboratory, Richland, Washington.

Perrigo, L. D., and J. R. Divine. 1979. Decontamination Methods. PNL-SA-7770, Pacific Northwest Laboratory, Richland, Washington.

Smith, G. W. 1979. Engineering Economy: Analysis of Capital Expenditures. 3rd ed. The Iowa State University Press, Ames, Iowa.

Stermole, F. J. 1980. Economic Evaluation and Investment Decision Methods. 3rd ed. Investment Evaluations Corporation, Golden, Colorado.

Treasury Board. 1976. Benefit-Cost Analysis Guide. Ministry of Supply and Services, Canadian Government Publishing Centre, Quebec, Canada.

U.S. Atomic Energy Commission (AEC). 1974. Measuring, Evaluating, and Reporting Radioactivity in Solid Wastes and Releases of Radioactive Materials in Liquid and Gaseous Effluents From Light-Water-Cooled Nuclear Power Plants. Regulatory Guide 1.21, USAEC, Washington, D.C.

U.S. Energy Research and Development Administration (ERDA). 1975. "Radioactive Waste Management." In ERDA Manual, Chapter 0511. USERDA, Washington, D.C.

U.S. Nuclear Regulatory Commission (NRC). 1976. Manual of Respiratory Protection Against Airborne Radioactive Materials. NUREG-0041, USNRC, Washington, D.C.

U.S. Nuclear Regulatory Commission (NRC). 1976. Acceptable Programs for Respiratory Protection. Regulatory Guide 8.15, USNRC, Washington, D.C.

U.S. Nuclear Regulatory Commission (NRC). 1977. Personnel Selection and Training. Regulatory Guide 1.8, Rev. 1-R, USNRC, Washington, D.C.

U.S. Nuclear Regulatory Commission (NRC). 1977. Housekeeping Requirements for Water-Cooled Nuclear Power Plants. Regulatory Guide 1.39, Rev. 2, USNRC, Washington, D.C.

U.S. Nuclear Regulatory Commission (NRC). 1977. Operating Philosophy for Maintaining Occupational Radiation Exposures As Low As Reasonably Achievable. Regulatory Guide 8.10, Rev. 1-R, USNRC, Washington, D.C.

U.S. Nuclear Regulatory Commission (NRC). 1977. Quality Assurance Requirements for Installation, Inspection, and Testing of Mechanical Equipment and Systems. Regulatory Guide 1.116, Rev. 0-R, USNRC, Washington, D.C.

U.S. Nuclear Regulatory Commission (NRC). 1978. Initial Test Programs for Water-Cooled Nuclear Power Plants. Regulatory Guide 1.68, Rev. 2, USNRC, Washington, D.C.

U.S. Nuclear Regulatory Commission (NRC). 1978. Information Relevant to Ensuring that Occupational Radiation Exposures at Nuclear Power Stations Will Be As Low As Reasonably Achievable. Regulatory Guide 8.8, Rev. 4, USNRC, Washington, D.C.

Zima, G. E., et al. 1981. Some Aspects of Cost/Benefit Analysis for Inservice Inspection of PWR Steam Generators. NUREG/CR-1490, PNL-3388, Pacific Northwest Laboratory, Richland, Washington.

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A modified MORT (management oversight risk tree) method has been used to identify the elements that are necessary for a successful restorative decontamination of a typical light water reactor. The established criteria for successful planning in key areas is discussed.

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