TECHNICAL MANUAL

GENERAL DESIGN CRITERIA TO FACILITATE THE DECOMMISSIONING OF NUCLEAR FACILITIES

HEADQUARTERS, DEPARTMENT OF THE ARMY

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CHAPTER 1
INTRODUCTION

1-1. Purpose

This manual provides general facility design criteria and guidance to facilitate the decommissioning of nuclear facilities. A discussion of regulatory considerations is provided which will enable the user to understand nuclear facility decommissioning requirements. This document provides particular attention to the subject of radiation decontamination due to its importance as an option during decommissioning.

1-2. Scope

The manual is limited to a discussion of design features and criteria which are intended to minimize radiation exposure, reduce remediation costs, and ease implementation of facility radiological decommissioning. Guidance provided is applicable to U.S. Army power reactors, radiographic facilities, medical diagnostic and treatment facilities, medical laboratories, and research and development facilities. Criteria to facilitate maintenance of the facility in a normal operating mode is not within the scope of this document. However, criteria established for decommissioning may be applicable to operational maintenance. This manual also does not address problems which are often associated with the radiological aspects of decommissioning such as nonradioactive waste reduction and disposal requirements by federal and state agencies. General information concerning radiological hazards and source considerations are provided in appendices B and C to provide the reader important background information pertinent to decommissioning.

1-3. References

Appendix A contains a list of references used in this manual.

1-4. Background

When a decision to terminate operations at a nuclear facility is implemented, the building and site must be decommissioned to protect the public and DOD personnel from unacceptable residual contamination. The decommissioning process is intended to render a facility such that it poses no radiation health safety hazards which would limit use or demolition of the remaining facility. Decommissioning is required for all facilities which produce, use, handle, store, or maintain radioactive materials. Decommissioning may be directed toward the immediate removal or decontamination of the structure, directed toward securing and guarding the contaminated facility site to protect against exposure and thus deferring final decommissioning to a later date, or a combination of immediate and deferred actions.

1-5. Objectives

The basic objectives of this manual are to encourage consideration of decommissioning at the earliest possible stages of the design of nuclear facilities and to facilitate eventual decontamination and decommissioning. This will anticipate the eventual need for decommissioning plans and other actions which will result in a more efficient, less costly cleanup. This planning will help to:

a. Prevent the spread of radioactive material during both normal facility operation and decommissioning.

b. Provide for the containment of spilled or leaked radioactive material in order to prevent the spread of contamination.

c. Enhance access to contaminated material or equipment to facilitate its removal.

d. Enhance structural decontamination through improved surface preparation.

e. Improve decommissioning efforts by addressing the requirements for decontamination and waste handling.

f. Ensure that radiation exposure of both decommissioning personnel and the general public is as low as reasonably achievable.

CHAPTER 2

DECOMMISSIONING METHODS

2-1. Decommissioning methods

The US. Nuclear Regulatory Commission (NRC) final rule for decommissioning criteria published in 10 CFR. 30, 40,50, and 70 addresses methods and alternatives. This rule defined decommissioning as “to remove a facility safely from service and reduce residual radioactivity to a level that permits release of the property for unrestricted use and termination of license.” The rule also discussed the three decommissioning alternatives leading to unrestricted use. These are DECON, SAFSTOR, and ENTOMB. All three alternatives or combinations of these alternatives lead ultimately to unrestricted use, although SAFSTOR and ENTOMB defer reaching unrestricted use until after a storage period. Ultimately, all material having associated radioactivity in excess of acceptable residual levels must be removed from the facility or site before it can be declared released for unrestricted use and the operating and possession licenses terminated.

a. DECON. Decontamination, or DECON, is the alternative in which contaminated equipment, structures, and portions of a facility are physically removed from the site or are cleansed of radioactive contaminants by chemical or mechanically abrasive means such that the remaining property can be released for unrestricted use shortly after cessation of operations. Implementation of DECON can result in substantial amounts of low level radioactive waste requiring removal and disposal. DECON is the preferred approach to decommissioning. DECON has certain benefits in that it would prepare the property for unrestricted use in a much shorter period than SAFSTOR or ENTOMB, with acceptable effects on occupational and public health and safety. Decommissioning a facility and releasing the property for unrestricted use eliminates the potential problems that may result from having an increasing number of sites contaminated with radioactive material. This procedure also eliminates potential health, safety, regulatory, and economic problems associated with maintaining a nuclear facility. Because of the importance of decontamination in decommissioning, this topic is discussed in detail in chapter 3.

b. SAFSTOR. Nuclear facilities can be placed and maintained in such condition that the structure and contents can be safely stored and eventually decommissioned (deferred decommission), permitting release for unrestricted use. In general, in preparing a facility for the SAFSTOR option the structure maybe left intact, except that all nuclear fuels, radioactive fluids, and wastes must be removed from the site. In some cases where off-site disposal is unavailable, on-site storage of solidified waste may be necessary (see Section 2.4). The deferred completion of decommissioning through the use of SAFSTOR can be a viable alternative and should be considered when any of the following conditions exist:

(1) When the low level waste (LLW) disposal capacity is inadequate to implement the DECON alternative.

(2) When an adjacent nuclear facility would be adversely affected if the DECON alternative were implemented.

(3) When a positive benefit would be derived through a limited period of radioactive decay. This positive benefit would be determined by comparing the total cost and radiation exposure resulting from DECON to that resulting from the SAFSTOR.

c. ENTOMB. When using the ENTOMB decommissioning option, all nuclear fuels, radioactive fluids, and wastes are removed from the site and all structural and mechanical materials and components not decontaminated to acceptable levels are encased in a structurally long-lived material such as concrete. The entombed structure is appropriately maintained under continued surveillance until the radioactivity decays to a level permitting unrestricted release of the property. The ENTOMB alternative has limited application because all radioactive contaminants must decay to levels that will allow the facility to be declared released for unrestricted use within 100 years. The maximum duration of deferred decommissioning should not be greater than 100 years, as this is considered a reasonable period of time for reliance on institutional control. This will require careful characterization of the radioactive materials to remain. A concern with this approach to decommissioning is the possibility that, during the entombment period, the criteria on allowable levels of residual contamination may change, or even the results of the initial radiation characterization could be challenged and disqualified. Dismantlement of the entombed facility may then be required resulting in very large costs.

2-2. Selection of decommissioning alternatives

A decommissioning plan can use any one of three methods described in paragraph 2-1. Alternatively, a plan can be developed to use combinations of the three methods, where a portion of the facility is decommissioned immediately with the rest delayed. In the development of a plan, alternatives should be postulated which include the three decommissioning methods separately and one or more viable combinations of the methods. Each alternative must be evaluated individually to qualify, to the best extent possible, the result of implementation with regard to public health, occupational safety, environmental impact, waste management, initial investment, and long term costs. Public and worker health relate to the level of potential exposure to direct and airborne radiation. Environmental impact and waste management are functions of the quantities and types of radioactive nuclides and associated half-lives. Costs are driven by various factors all of which must be considered when selecting the best alternative. The final selection is made based on the alternative which will best accommodate the safety, environmental, waste, and cost issues. An assessment of the order of importance of these factors is a necessary part of the decision process, which can only be made on a case by case basis. Factors important to the evaluation and selection of decommissioning alternatives include the following.

a. Available Waste Disposal Capacity. Upon termination of operations at a facility, there may be inadequate LLW disposal capacity available at approved disposal sites to implement the DECON alternative. Decontamination methods typically result in large quantities of LLW requiring disposal. Therefore, it would be necessary to employ the SAFSTOR approach while additional disposal capacity is being provided or to permit a reduction in radioactive waste through the decay of the radioactive contaminants, provided the radionuclides present have half-lives which make this approach feasible.

b. Proximity of Other Facilities. There may be another operating facility in close proximity to the nuclear facility that has just ceased operation. The decommissioning of the shutdown facility using the DECON alternative may adversely affect the operating facility. Also, it may be easier or less expensive to delay decommissioning until all adjacent facilities can be finally decommissioned at once.

c. Critical/Abundant Radionuclides. The critical/abundant radionuclides, that is, the particular radionuclides most critical to decommissioning, must be identified and addressed in selection of alternatives. As an example, cobalt-60 which is prevalent in power reactors, has a half-life of *5.3* years. If SAFSTOR is implemented for a period of *35* years, a 99% reduction of cobalt-60 radionuclide will result. (Note: This represents a situation where the cobalt-60 is not part of a decay chain; that is, it does not result from the decay of another radionuclide.) Thus, in such situations where contamination levels are large, use of SAFSTOR can result in large dose reduction to workers. However, in situations where the half-life of the critical/abundant radionuclide is long, such as uranium, little benefit in dose reduction is derived from the SAFSTOR or ENTOMB decommissioning alternatives. Reference appendix C for a discussion on radionuclide half-life and calculation of concentration changes over a period of decay.

d. Implementation Costs. The cost of implementing a given alternative must be carefully evaluated. The cost differential between immediate and deferred decommissioning alternatives, however, can be difficult to estimate and is definitely site-dependent. Although the cost for immediate decommissioning can be estimated within an acceptable degree of accuracy, there are uncertainties in estimating the cost of controlling a site for long periods of time. In addition, factors such as exceedingly high annual escalation of LLW disposal rates can negate any postulated savings from the deferred decommissioning alternative, even if reduced waste volumes are a result of the deferred decommissioning. The burial rates at one disposal facility increased by a factor of 25 in a 13 year period. In evaluating the cost of deferred decommissioning, factors to be considered are as follows:

(1) Security systems including guards, fences including installation and maintenance costs, and electronic surveillance including installation and maintenance costs.

(2) Maintenance of facility access within the controlled area including roads, bridges, and parking.

(3) Maintenance of the facility enclosure for weathering of the construction materials.

(4) Collection, sampling, and remediation efforts, if necessary, until decommissioning is complete.

(5) Monitoring and maintenance of the radiation confinement boundaries within the facility.

(6) Maintenance of access ways within the facility for inspection.

(7) Maintenance of lighting and ventilation systems as well as any support systems.

(8) Facility inspection.

(9) Radiation surveys both inside and outside the facility.

(10) Decommissioning costs that can increase rapidly during the storage period - in particular, the potential escalation in the cost of LLW disposal.

(11) Reduced LLW disposal cost because of reduced waste volume resulting from radioactive decay.

(12) Reduced LLW disposal surcharge cost because of radioactive decay. This is not a reduction in base rate disposal costs but surcharges added to the base rate based on the radiation level and/or unit inventory associated with the waste.

(13) The benefits resulting from reduced personnel exposure during decommissioning because of lower radiation levels in work areas due to radioactive decay of the contaminants.

2-3. Standards for acceptable residual radiation levels, concentrations, and contamination

The ultimate objective of any decommissioning program, whether performed immediately after termination of operations or deferred for some period of time, is to have the facility declared released for unrestricted use and the NRC license terminated. To achieve this goal, the residual radioactivity levels associated with the decommissioned facility must be below acceptance limits. At this time, there are few standards on acceptable residual radiation levels. Those standards that do exist address only specific topics and not the entire scope of a decommissioning effort.

a. Nuclear Regulatory Commission Guidelines. The NRC has published values for acceptable residual surface contamination levels and is developing standards for residual radiation in decommissioning.

(1) Values are presented in the NRC's "Guidelines for Decontamination of Facilities and Equipment Prior to Release for Unrestricted Use of Termination Operating Licenses for Byproduct or Source Materials," and in Regulatory Guide 1.86, "Termination of Operating Licenses for Nuclear Reactors." The NRC values are in Table 2-1.

(2) The NRC is also developing standards for residual radiation in decommissioning. NRC policy defines acceptable radiation level as 10 mrem/yr, a base level which is subject to change but which may be used on an interim basis. The policy does not assert an absence or threshold of risk at low radiation dose levels but establishes a baseline level of risk beyond which further government regulation to reduce risks is unwarranted. It also establishes a consistent risk framework for regulatory exemption decisions should radiation levels exceed 10 mrem/yr at the time of decommissioning.

(3) ALARA (as low as is reasonably achievable) is applied in granting exemption to radiation levels which are below 100 mrem/yr but which exceed the acceptable level of 10 mrem/yr. ALARA means that every reasonable effort must be made to maintain radiation exposures as far below applicable dose limits as is practical consistent with the purpose for which the activity is undertaken. It takes into account the state of technology, the economics of improvements to public health and safety benefits, and other societal and socioeconomic considerations in the public interest. Considerations in application of ALARA are discussed in 10 CFR 20.

(4) NUREG/CR-5512, "Residual Radioactive Contamination from Decommissioning" describes a generic method for evaluating conditions of unrestricted release of slightly radioactive material in buildings and soil following decommissioning of licensed facilities. Major pathways of direct exposure to penetrating radiation are considered and a technical basis for translating contamination levels to annual dose is provided. Pathway analysis varies from site to site. Examples of pathways that must be considered include:

(a) Direct radiation from residual radioactivity.

(b) Airborne radioactivity from windblown contaminated soil.

(c) The food pathway, that is, eating food grown at the site of a decommissioned nuclear facility or eating meat of animals that grazed on such areas.

(d) Any possible water pathway, such as swimming in a pond which receives water runoff from a decommissioned nuclear facility.

(e) Any dose received as a result of using recycled decontaminated materials from the decommissioned facility.

b. Environmental Protection Agency Standards.

(1) The U.S. Environmental Protection Agency (EPA) has published emission standards for the release of radionuclides into the air in the revised 40 CFR Part 61. Consult that standard when developing applicable designs.

(2) The EPA provides promulgated soil standards for uranium mill tailing sites. These soil standards are presented in 40 CFR 192.

(3) The EPA is responsible for developing standards establishing acceptable levels of residual contamination. Until such standards are developed, guidance should be obtained from the NRC.

c. Survey Requirements. The progress of the decommissioning effort must be tracked and documented to ensure success. This is accomplished in part by radiological surveys

(1) Radiological surveys should be made to establish the baseline radiation and contamination levels prior to the initiation of construction efforts. Radiation surveys should also be conducted to obtain baseline data when an existing facility is rehabilitated or expanded.

(2) Prior to and throughout the decommissioning process, surveys will be used to evaluate the success of decontamination efforts, and to show that the radioactive materials involved are under control. Refer to Section *6-5* on this issue.

(3) Radiological data will be collected after decommissioning is complete to obtain a final result.

d. Survey Procedures. The following guidelines are provided for the conduct of radiation surveys:

(1) An accepted method for conducting this type of survey is to establish and document a grid system for the site. Direct radiation measurements should be made on contact and at a height of one meter at each grid intersection using portable radiation-survey instrumentation. The grid should be designed such that it can be duplicated in the future, thus permitting radiation measurements to be made after decommissioning for comparison with the original direct radiation measurements. In addition to survey instrument measurements, cumulative-radiation measuring devices such as thermoluminescent dosimeters may be positioned both on site and in adjacent areas offsite to determine exposure levels for long-term background direct radiation. These original radiological data should be incorporated into the Facility Decommissioning Plan to ensure that the information is available at the time of decommissioning.

(2) Contamination surveys of the facility, such as wipe tests, should be performed as necessary throughout the decommissioning process.

(3) For some sites, it will be necessary to sample various environmental components as well as make direct radiation surveys. Collection of environmental samples is required for siting nuclear power plants and is recommended for other facilities whose releases could result in water, sediment, and soil contamination. Air, water, vegetation, sediment, and soil samples should be collected and their locations documented. The samples then should be evaluated using laboratory instrumentation to determine the quantity of radioactive material present in these

environmental components and, if required, the identity of the various radionuclides present. The results of these surveys should be incorporated into the Facility Decommissioning Plan to ensure that the information is available at the time of decommissioning.

2.4. Radiological standards for on-site contingency storage

The retention of radioactive waste at a nuclear facility would prevent the facility from being declared decommissioned and available for unrestricted use.

a. Implications. The retention of radioactive waste at any nuclear facility results in the following:

(1) The potential exists for significantly higher expenses due to rapid escalation of LLW disposal costs.

(2) Costs are incurred to provide adequate and safe on- site storage of low-level radwaste.

(3) The possibility of changing regulations on acceptable waste forms and packaging could result in waste having to be reprocessed and repackaged prior to its being shipped to a disposal facility.

(4) The retention of radioactive waste at a site for an extended period is likely to result in an adverse public reaction.

b. Standards and Requirements. Should it be deemed necessary that interim *(5* years or less) on-site storage of low-level radioactive waste is needed to support a decommissioning effort, guidance on providing such storage is given in SECY-81-383; NUREG-0800, Appendix 11.4-A; and Radiological Safety/Guidance for On site Contingency Storage Capacity, NRC Generic Letter 81-38. These references should be reviewed in planning for on-site storage of low-level radwaste. Provided below is a summary of radiological standards and requirements that should be addressed.

(1) ALARA design features.

(2) Off-site radiation exposure limits as set forth in 40 CFR 61 and 190. The contribution from direct radiation should be limited to about 1 mrem per year.

(3) Effluent monitoring of gases and liquids as required by 10 CFR 50, Appendix A.

(4) An analysis of postulated accidents. The resulting calculated exposures should be 10 percent of the limits established in 10 CFR 100.

(5) Prevention of contaminant spread due to weather and environmental conditions expected at the site and the potential for fires.

(6) Surveillance and security.

(7) Maintenance of detailed records of all waste material in storage.

c. Burial of Waste. Radioactive wastes will not be buried at nuclear facilities. This includes both during the operational life of the facility and decommissioning.

Table 2-1. Acceptable Surface Contamination Levels

Nuclide[a]	Average[bcf]	Maximum[bdf]	Removable[bef]
U-nat, R-235, U-238, and associated decay products	5,000 dpm α/100 cm ^{2}	15,000 dpm α/100 cm ^{2}	1,000 dpm α/100 cm ^{2}
Transuranics, Ra-226, Ra-228, Th-230, Th-228, Pa-231, 227, I-125, I-129	100 dpm/100 cm ^{2}	100 dpm/100 cm ^{2}	20 dpm/100 cm ^{2}
Th-nat, Th-232, Sr-90 Ra-223, Ra-224, U-232 I -126, I-131, I-133	1,000 dpm/100 cm ^{2}	3,000 dpm/100 cm ^{2}	200 dpm/100 cm ^{2}
Beta-gamma emitters (nuclides with decay modes other than alpha emission or spontaneous fission) except Sr-90 and others noted above	5,000 dpm $\beta\gamma$/100 cm ^{2}	15,000 dpm $\beta\gamma$/100 cm ^{2}	1,000 dpm $\beta\gamma$/100 cm ^{2}

[a]Where surface contamination by both alpha-and beta-gamma-emitting nuclides exists, the limits established for alpha- and beta-gamma-emitting nuclides should apply independently.

[b]As used in this table, dpm (disintegrations per minute) means the rate of emission by radioactive material as determined by correcting the counts per minute observed by an appropriate detector for background, efficiency, and geometric factors associated with the instrumentation.

[c]Measurements of average contaminant should not be averaged over more than 1 square meter. For objects with less surface area, the average should be derived for each such subject.

[d]The maximum contamination level applies to an area of not more than 100 cm ^{2}.

[e]The amount of removable radioactive material per 100 cm^2 of surface area should be determined by wiping that area with dry filter or soft absorbent paper, applying moderate pressure, and assessing the amount of radioactive material on the wipe with an appropriate instrument of known efficiency. When re movable contamination on objects of less surface area is determined, the pertinent levels should be reduced proportionately and the entire surface should be wiped.

[f]The average and maximum radiation level of surface contamination resulting from beta-gamma emitters should not exceed 0.2 mrad/hr at 1 cm and 1.0 mrad/hr at 1 cm, respectively, measured through not more than 7 milligrams per square centimeter of total absorber.

CHAPTER 3

DECONTAMINATION METHODS

3-1. Definition and application

Decontamination can simply be defined as the removal of radioactive material from where it is not wanted. A decommissioning program implemented immediately includes decontamination as the major effort. Numerous technologies exist, and the list of books, manuals, reports and similar documents addressing this topic is extensive. This section contains a brief description of the more common decontamination technologies and guidelines on typical application techniques. Additional information on decontamination technologies can be obtained from NUREG/CR-1915 (PNL-3706); NUREG/CR-2884 (PNL-4343); EPRI NP-2866; BNWL-B-90; EFRI NP-3508 and DOE/EV/1028-11RLO/SFM-80-3. Through an understanding of decontamination techniques, the designer can better incorporate features in the design of the facility to enhance decommissioning at a later date. Decontamination efforts can be directed toward the removal of surface contaminations accumulated due to entrapment of radioactive particulate in corrosion layers, in film deposits, or in surface crevices. Decontamination efforts can also be undertaken to remove subsurface or deep contamination resulting from activation of structural and mechanical materials or migration of deposited radioactive particulate into absorptive materials. Although decontamination techniques can be grouped into several discrete categories, two generic classifications are used for this manual; these are chemical and mechanical decontamination processes.

a. Surface Contamination. Examples of this type of contamination include the following:

(1) The buildup of corrosion products and films on the inside surface of piping or ducting in fluid systems which can entrap radioactive particles.

(2) The deposition of airborne contaminants on walls, floors, and components during the operating life of the facility.

(3) Deposition of radioactive contaminants on surfaces contacted by spilled radioactive fluids.

b. Deep Contamination. This can result from material activation due to exposure and from absorption of radioactive material. Examples are as follows:

(1) Neutrons are particularly effective in causing material activation which can occur deep into exposed material.

(2) Water with dissolved radionuclide, can be absorbed and diffused into concrete.

(3) Tritium gas will migrate into materials and can contaminate deep within that material. This deep contamination can migrate out to surfaces at later times.

3-2. Chemical decontamination

Chemical decontamination alternatives addressed here are high-concentration processes, low-concentration processes, foam cleaning, and electrochemical cleaning. Chemical decontamination is used to remove radioactive particulate entrapped on surfaces. These methods are particularly suited for decontamination of piping systems. The liquid decontamination material can be delivered through contaminated piping to remove contaminated deposits. It is useful to perform such decontamination before removal of piping systems during decommissioning. This will reduce worker exposure during removal operations. The effectiveness of chemical decontamination processes can be expressed in terms of a decontamination factor, DF, which is higher for more corrosive, reactive methods. In the selection of a chemical decontamination alternative, consideration should be given to those processes which will not create mixed waste products regulated by both NRC and Resource Conservation and Recovery Act, or similar local, state, or national hazardous waste regulatory programs.

a. High-Concentration Chemical Decontamination. These processes involve the use of chemical solutions with greater than 0.2 percent by weight of reagent. These processes have a high DF but are corrosive to the base metal, expensive, and difficult to use. In support of a decommissioning program, the corrosiveness of this decontamination process should not be a concern as long as the material is going to be discarded or the materials of construction will not fail during the decontamination process, resulting in a release of the solution.

(1) Many of these high-concentration processes are two-step processes such as AP-Citrox. The first phase is alkaline permanganate (AP), and the second phase is citric oxalic acid. These two-step processes are typically used when the radioactive contaminated corrosion film was formed in a reduced chemical environment (very low concentration free oxygen). The first phase oxidizes the corrosion film while removing very little of the radioactive material. The second phase removes most of the corrosion film and radioactive material.

(2) High-concentration decontamination processes typically produce large quantities of liquid waste which must be solidified and disposed of as LLW. This is because the concentration of dissolved solids in these solutions is very high. For example, with the AP-Citrox process, the AP phase is a 13 percent by weight solution and the Citrox phase is a 74 percent by weight solution. It is estimated that the solidified volume of LLW generated by this process is *1.5* times the volume decontaminated.

(3) High-concentration decontamination processes can remove significant quantities of radioactive corrosion films, but reduction of radioactivity concentrations to levels to allow unrestricted release of the decontaminated materials cannot be assured.

b. Dilute or Low-Concentration Chemical Decontamination. These processes include chemical solutions with less than 0.2 percent by weight reagent. These processes are less corrosive to the base metal and less costly to use than the high-concentration decontamination processes but their DFs are lower.

(1) Typically, dilute chemical decontamination techniques are one-step processes. Such processes are used when reduced personnel exposure is desired but near-total elimination of the radiation field from the radioactive corrosion film is not required.

(2) Because the concentration of chemicals in this process is dilute, waste cleanup can be achieved by recirculating the solution through ion-exchanges, thus eliminating the need for decontamination waste storage tanks required for high-concentration decontamination processes.

(3) Assuming ion-exchange cleanup of the dilute decontamination solutions, the residual, solid LLW can be estimated as one-tenth of the volume decontaminated.

c. Foam Decontamination. This technique is discussed in the literature dating back to 1971. Little interest has been shown in this technique because it is not very effective in the decontamination of piping systems at which chemical decontamination is principally directed.

(1) Foam decontamination should be considered for use on contaminated surfaces such as walls, floors, liners and any exterior surfaces.

(2) Foam decontamination uses the same foam technology as that used in foam fire-fighting apparatus. Chemicals on the order of two to three percent by weight solution are added to the foams to provide the cleaning action. A low to moderate expanded foam, less dense than shaving cream, would be used.

(3) To reduce rinse water volumes, the foam could first be vacuumed. The residue would then be rinsed away (and collected for processing) using a water rinse.

(4) Although this process does not have a high DF, residual radiation levels on walls and similar surfaces may be brought to within acceptable levels or reduce the amount of mechanical decontamination required.

d. Electrochemical Decontamination. Electropolishing essentially reverses the electroplating process, resulting in the removal of contaminated surface material. The amount of material removed depends on the duration of application, applied voltage, and current.

(1) This can be a very aggressive process resulting in both a high DF and the removal of significant amounts of base metal. When using this process in support of a decommissioning program, concern should be given to the quantity of base metal removed if reuse of a given item is proposed.

(2) Typically this process is performed in an electropolishing cell or vessel. Therefore, the use of this process could require the removal and transfer of contaminated materials prior to their decontamination.

(3) An electrobrush process can be employed using the electropolishing technique, provided that all contaminated surfaces are accessible.

3-3. Mechanical decontamination

Mechanical decontamination techniques typically involve the removal of some thickness of the material of construction of walls, floors, and pipes. The thickness of the layer of material removed depends on the process selected, which is dictated by the depth of contamination. Mechanical decontamination techniques are numerous and varied, and by no means are all processes addressed in this manual. Also, although it is likely that one or more of these methods would be used in the decommissioning, these processes have operational disadvantages that must be properly addressed when they are used. The processes are generally time-consuming, labor-intensive, create airborne contamination, create loose debris and, for wet processes, create discharged liquid waste. Recognizing these disadvantages, the use of these methods for removing contamination from surfaces can result in cost savings by eliminating the need to dispose of entire wall or floor sections as radioactive waste. Instead, only the removed contaminated material need be disposed of, thus minimizing the volume of LLW produced.

a. Concrete Surfaces. Numerous options exist, a brief list of which is provided below:

(1) Concrete Spaller. The tip (a bit with expanding wedges) of this tool is inverted into a predrilled hole. A push rod is pushed toward the end of the bit forcing it to expand radially against the wall of the hole. As the push rod approaches the bottom of the predrilled hole, it forces the wedges of the bit away, spalling a deep crater several inches deep.

(2) Scabbler/Scarifier. This tool is composed of multiple air-operated piston heads, each of which is faced with 5-or 9-point tungsten combined bits. It is effective on walls and floors when used in conjunction with a properly filtered vacuum system. This process was extensively used at Three Mile Island-Unit 2 (TMI-2).

(3) Jackhammers and Impactors. These tools are similar in effect and drive a pick or chisel point into concrete surfaces with high-energy impacts. Jackhammers are used primarily on floors because they are heavy and hard to maneuver. Impactors are more appropriate for removing contaminated surfaces from concrete walls and ceilings.

(4) Explosives. This method can be used for surface removal with excellent control of both the amount of material removed and the extent of airborne contamination generated. The first stage of concrete surface removal by explosives is to drill holes to hold the charges. When the entire length of the surface to be

removed is drilled, explosives are inserted and back-filled with sand, if necessary, to produce the desired amount of surface removal. The holes are then sealed with mortar. Blasting mats and a water spray are used to contain the dust and flying debris accompanying the explosion.

b. Piping Surfaces. Mechanical decontamination of piping surfaces was evaluated for use at TMI-2 (EPRI NF-3508). At TMI-2 the objectives of these techniques included the removal of loose debris and the removal of corrosion film. These mechanical decontamination techniques include the following:

(1) Rotating Brush-Hone. This tool consists of a large number of small, spherical silicon carbide pieces attached to the ends of a corresponding number of radially oriented stiff nylon bristles. The resulting assembly resembles a brush and can be obtained for tubing or pipe diameters from 1/4 to 36 inches. The tool is rotated inside the pipe at 150-200 rpm, using water as a lubricant and flushing medium. The configuration of this tool permits the small, individual pieces of silicon carbide to conform to the shape of the inside surface of the pipe. The individual bristle-mounted pieces can follow local irregularities and thus remove an adherent layer from the entire inner surface of a pipe.

(2) Rotating Brushes, Cutters, and Scrapers. These tools use centrifugal force to keep them in contact with the inside surfaces of the tube or pipe during cleaning. The cutters are hinged for outward movement, while the brushes and scrapers move out or expand in slots to maintain contact with the interior surfaces during solution. These devices are powered by air, water, or electric motor. They have been used for many years in industry to clean tubing or piping ranging from 112 to 13 inches in diameter.

(3) Pigs. These devices come in two basic forms. One is a plastic-bodied, bullet-shaped object that is forced through pipe or tubing by fluid pressure. It cleans by pushing loose dirt and sludge ahead of it. It can be coated with wire bristles or silicon carbide particles that scrape and abrade more tightly held material. The second type of pig includes spoke-like groups of wire bristles, arranged in a circular pattern, fastened to a center pipe section with rubber end caps to prevent by-pass of the driving fluid. Pigs are available for cleaning pipe in sizes from 112 to 60 inches in diameter. Pigs have been used extensively in non-nuclear applications.

c. Other Mechanical Decontamination Techniques. These include the following:

(1) Abrasive Blasting. In this process (applicable to metal and concrete surfaces), an abrasive material such as sand, glass beads or magnetite grit is propelled against the contaminated surface at a high velocity to remove contaminants and some of the substrate. By varying the size and conditions of the application, the surface can be scoured, polished, or peened. This process can be used with either a wet or dry application. There is no single technique or abrasive material that is universally applicable. The construction material, type of contamination, extent of decontamination desired, and complexity of the surface must all be considered.

(2) Hydrolaser. This process uses very high pressure (400 to 14,000 psi) water or steam to remove loose scale or crud. This method generates a large amount of liquid waste, but it may be possible to recycle the water since no chemicals are used. The distance between the spray nozzle and surface is important to the effectiveness of this process.

(3) Strippable Coatings. With this process a plastic membrane or coating (such as polyethylene, or polyvinylchloride) is put on the contaminated surface. This coating material is best applied with a brush. When the coating is peeled off, loose surface contaminants are removed with the coating. Strippable coatings are also often used to prevent the recontamination of decontaminated surfaces. This process has been extensively used in the nuclear industry.

3-4. Selection of decontamination process in support of a decommissioning

Each decommissioning situation must be evaluated relative to its specific conditions which influence selection of the type of decontamination processes to be adopted. Factors which affect this decision are presented below.

a. Contamination. The type of contamination that must be removed may include loose surface contamination, tough adherent film, and in- depth contamination.

b. Base Material. The contaminated material may include metal base material (vessel, pipe, liner), concrete or other material from which a surface layer could be removed.

c. Post Decommissioned Use of the Facility. The selected approach to decontamination may be different if there is no intended follow-on use of the facility (it will be totally demolished) as opposed to methods selected if the facility will be retained, refurbished, and reused.

d. Decontamination Objectives. Decontamination objectives can include the following:

(1) Reduce the radiation exposure to decommissioning personnel.

(2) Reduce the volume of low-level radwaste.

(3) Ensure that residual radioactivity levels are low enough to permit the property to be released for unrestricted use.

(4) Avoid creating a mixed waste (both hazardous and radioactive) through the proper choice of decontamination reagents.

e. Hazards Analysis and Site Safety Plan. Planning of the decommissioning process must include an activity hazards analysis and a site safety plan which shall address (but not be limited to) such factors as:

(1) Monitoring of radiation levels.

(2) Procedures to control exposures.

(3) Protective equipment.

(4) Medical surveillance.

(5) Heat stress.

(6) Staging of radioactive material.

(7) Decontamination

f. Cost Considerations. Evaluation of various decontamination choices is site specific and must be addressed on a case-by-case basis. The conditions specific to each case will determine the merits of implementing a decontamination program. Whether the objective is to reduce the personnel exposure associated with the decommissioning effort or to reduce the volume of waste, a cost-benefit analysis considering ALARA objectives should be performed. This analysis should address at a minimum the following items. (It should be noted that this is a generic list and that not every item listed is applicable to all decontamination processes).

(1) The decrease in radiation exposure to all decommissioning personnel.

(2) The personnel radiation exposure to individuals performing the decontamination.

(3) The impact of the decontamination program on the general public, which includes exposure levels related to the quantity of waste shipments and exposure due to particulate airborne and processed decontamination liquid releases. In addition, all decontamination methods described have the potential to be considered as Resource Conservation Recovery Act (RCRA) regulated wastes either because of corrosivity or the presence of dissolved metals.

(4) The cost to perform the decontamination, which includes:

(a) Process development. This includes, for example, development of the most effective chemical formulation and its application; evaluations to determine the most effective sources among several similar processes; and determination of support requirements such as flush water, electrical requirements, etc.

(b) Decontamination chemicals or equipment.

(c) Support equipment such as tanks, pumps, piping, and heat exchangers.

(d) Personnel requirements for the operation, including health physics support, engineering, and labor support.

(e) Processing of the decontamination waste which could include decanting equipment, filters, ion exchange material, volume reduction equipment, and solidification equipment.

(f) Process monitoring equipment for both the decontamination process and low-level waste processing.

(g) Interface requirements, demineralized water, power, steam, etc.

(h) Waste packaging, including containers and the labor involved.

(i) Installation and removal of process equipment.

(j) Management/supervision of the decontamination program.

(5) The impact on waste disposal costs; this would include increase or decrease costs associated with transportation, shipping cask rental and disposal fees, including appropriate surcharges and taxes.

(6) The cost reduction resulting from any salvage value gained through decontamination.

(7) A potentially significant positive cost factor would be the reclamation of a facility through decontamination. The replacement cost of the facility as it exists following decontamination should be included as a value gained and should be used to offset the cost of the decontamination.

g. General Considerations. General information on the implementation of decontamination processes in support of a decommissioning program is provided below:

(1) Radiation contamination imposed by activation represents a particularly difficult decommissioning issue. The contamination is a result of nuclear changes in the structural material due to radiation exposure during the operating lifetime of the facility. It can occur deep within structural material itself and is unlike a surface contamination resulting from entrapment of settled radioactive particles by corrosion, films, or absorption and attachment to porous surfaces. Typically, activated contamination cannot be successfully handled by decontamination. Demolition and removal is most often required. For instance, the outer layer of concrete slabs can be removed via mechanical decontamination to a depth where activation levels are lower than established limits for residual activity. This depth must be determined with certainty, which may be difficult. In addition, reinforcement steel is particularly susceptible to activation. Removal of concrete, rebar, or both could render the slab inadequate as a structural, load bearing member. When all considerations are made, it is likely that demolition and removal is required.

(2) An object of any decommissioning plan, which must be weighed against other factors, is to minimize LLW production. The volume of LLW is the important factor to consider (not weight). The removal and mechanical shredding of thin wall pipes, tanks and other components contaminated at low levels will result in a compact volume of disposable material. This option must be weighed against various decontamination options, related costs, the production of LLW through decontamination, and the salvage or reuse value of the system under consideration.

(3) Remove any buried pipes that are in need of decontamination to assure potential sources of contamination are removed and to comply with NRC criteria for release for unrestricted use.

CHAPTER 4

GENERAL CRITERIA AND DESIGN FEATURES TO ENHANCE DECOMMISSIONING

4-1. Site planning criteria

Since the magnitude of a decommissioning effort will vary greatly as a function of the type of facility being decommissioned, provisions for site planning to facilitate a decommissioning must he addressed on a site-specific basis. Presented below are items that should be considered in the conceptual site plan for a nuclear facility in order to support its ultimate decommissioning.

a. Waste Storage. A convenient location at or near the decommissioning site should be provided for temporary storage of LLW that is awaiting shipment for disposal. Factors affecting the location of this holding area are as follows:

(1) It should be distant from areas having uncontrolled access and able to be secured fenced and monitored for access control.

(2) It should permit the erection of any required temporary shielding.

(3) It should permit access of transport vehicles and cranes.

(4) Although not required, it should be close to the decommissioning area.

(5) The area should he located such that drainage from the surrounding areas does not result in the accumulation of water at the storage site. The storage site itself should be level, on impermeable soil and able to be graded to collect spilled contaminants. An optimum situation is one where the site is relatively flat; outside the site, a drop in grade occurs in all directions from the storage area perimeter.

(6) A detailed discussion on radwaste handling requirements is provided later in this chapter which includes additional site planning considerations.

b. Process Equipment. Space should be provided in the immediate area of the facility to be decommissioned to allow the placement of temporary process equipment such as solidification, volume reduction, and decontamination systems. Factors to be addressed in locating these areas are as follows:

(1) The area should be graded to ensure confinement of accidental spills of LLW.

(2) Area should be located close to the tie-in points within the facility in order to minimize extensive runs of temporary piping.

(3) Sufficient space should be provided to allow cranes to be used in placing and removing the temporary equipment as well as the removal of containers of processed waste. These waste containers could be as large as 200 cubic feet and weigh as much as 20,000 pounds.

(4) A detailed discussion on site requirements for decontamination methods in is provided in Section 4-7.

b. General Consideration. Other site planning criteria are given below.

(1) Access by cranes should be ensured to those areas of the facility that have roof or wall sections that have to be removed to permit equipment removal.

(2) Separate laydown areas should be provided for material that must undergo a radiation survey to determine if it is clean or must be handled as LLW.

(3) The site must be readily accessible to the various types of equipment and vehicles needed for the decommissioning effort. This could include heavy-duty trucks, bulldozers, cranes, and earthmoving equipment.

(4) Roads, waterways, and railroads in the area of the facility must be evaluated to ensure that at decommissioning it will be physically possible to remove contaminated materials. New roads must meet these design requirements. For example, large clearance and load requirements of the access route, although not needed during operation, may be needed during decommissioning.

(5) The location and routing of utilities (fire, sewage, potable water, etc.) must be established to ensure that service can be continued during decommissioning.

4-2. Conceptual design considerations

Criteria provided in the following sections are for specific design areas such as mechanical or electrical systems, or for specific types of facilities. General guidance to be considered during the planning and concept development of a facility follow.

a. Decommissioning Plan. A planned approach to decommissioning the facility should be established concurrently with the development of the facility concept design and the two should complement each other. Reference chapter 6 for a complete discussion of decommissioning plans. Safety and cost implications during construction, over the expected life of the facility, and during decommissioning should be considered. A concept which optimizes decommissioning efforts may result in greater design and construction costs, but has the potential for lower operational costs and enhanced safety. A facility concept which is developed to optimize construction and operational costs only may result in a facility which is difficult and expensive to decommission. To bring a balance between these factors, decommissioning should be considered as an important part of the life cycle of the facility. Life-cycle costs analyses which weigh both immediate and deferred expenses should be conducted. As part of this effort, the following actions should be taken:

(1) Evaluation of various decommissioning alternatives and decontamination methods appropriate for the planned facility. This includes an assessment of the type and extent of contamination expected over the lifetime of the facility.

(2) Identification of any actions that must be performed before any of the decommissioning options can be implemented.

(3) Identification of design features that would facilitate decontamination and waste processing activities that would be performed in support of a decommissioning program.

(4) Development of the facility floor plan and selection of systems to allow isolation of areas where contamination is expected thus avoiding contaminant spread to other areas and minimizing cleanup efforts.

(5) Consideration of design features that would serve to facilitate both decommissioning at the termination of operations and maintenance and cleaning of contaminated areas during operations. The better maintained and decontaminated the facility is kept during its lifetime, the easier decommissioning can be performed.

b. Decommissioning Technology. The following should be considered during facility concept development:

(1) Assurance that the use of current technology is not precluded by the design criteria. The need to decontaminate due to an accident or even decommission may occur at any time, even shortly alter facility startup. Therefore, technology available during the initial design effort may be the only technology that can he used for decommissioning.

(2) Avoidance, to the extent feasible, of reliance on only one specific decommissioning approach. It is possible that the recommended decommissioning approach would become outdated and not acceptable for use at the end of the facility's life.

4-3. Architectural and structural design criteria

The following is a summary of general architectural and structural design options.

a. Walls, Floors, and Ceilings. Surfaces should be smooth and coated, sealed, or provided with a surface liner to prevent contaminants from penetrating the materials of construction.

(1) Floor covering should be totally seamless, if possible. If not, the number of seams must be kept to a minimum. The use of tile segments should be avoided.

(2) Coatings and sealers should comply with the specifications of ANSI N512 of the American National Standards Institute and be selected for high impermeability.

(3) Cracks, crevices, and joints should be sealed to prevent the entrapment or spread of contaminants.

(4) Curbs, dikes, or other barriers should be provided to contain potential releases of radioactive liquids. The net containment volume should be at least 125 percent of the total volume of liquid contained in the area.

(5) Floors should slope toward floor drains. This will reduce the spread of contaminants resulting from accidental release or spill and aid in the cleanup.

(6) Repeated decontamination during operations of covered or sealed surfaces should not reduce the effectiveness of the barrier. The barrier should be capable of being returned to its original effectiveness or be replaced alter DECON before exposure to contaminants.

(7) Layered or porous materials that could entrap radioactive materials should not be used.

(8) Walls or other barriers with interior spaces should be sealed.

(9) Materials used on walls, floors, or ceilings that cannot be easily decontaminated should be easy to remove and dispose.

(10) The edges of the floors where they meet the walls should be easy to clean and decontaminate and shall be well sealed and easily maintained to prevent dust or liquid seepage into construction joints.

(11) There should be a minimum of protuberances from the walls, floors, and ceilings inside or upon which dust can settle.

(12) Block walls should not be used in areas where surface contamination can be expected to occur over the life of the facility. However, block walls may be used if it can be ensured that the finished surface is sealed and maintained to be smooth, nonporous, and easily decontaminable.

(13) Drop ceilings or interstitial spaces are not allowed where contamination of space is anticipated.

(14) Materials should be chosen which have a low probability of activation for the operations to be performed at the facility.

b. Penetrations. The number of wall, ceiling, and floor penetrations should be kept to a minimum and, wherever possible, located near each other.

(1) In an ideal situation, a well sealed, removable penetration panel would be used through which all electrical, plumbing and mechanical penetrations are made into a room. The panel should be designed to allow easy removal and DECO N of the area during decommissioning.

(2) Penetrations through walls, ceilings, and floors should be sealed.

c. Portable Shields and Enclosures. To minimize the costs associated with the construction and decommissioning of permanent partitions and shield walls, the facility can be constructed with fewer such walls, provided sufficient space is provided for:

(1) The use of temporary or portable enclosures during maintenance periods.

(2) The use of temporary shielding. For ALARA purposes, the temporary shield should be capable of being transported into the area in lieu of building the shield in

place. Also, the temporary shield should be covered to prevent contamination.

4-4. Mechanical, electrical, and heating, ventilating, and air conditioning systems design criteria

For each nuclear facility under design development, the following options should be evaluated:

a. Pipes and Ducts. Design and placement of pipes and ducts should allow easy access, cleaning and removal.

(1) Pipes, ducts, and equipment which potentially could be contaminated should not be embedded or sealed in walls, floors, or ceilings. Plan to allow access and removal of such systems.

(2) Pipes which potentially could be contaminated should not be run below concrete slabs on grade. Such pipes should be run in chases or trenches and be accessible through removable hatches or panels.

(3) Pipes and ducting which potentially could be contaminated should be kept as short as possible, and should not be routed through areas of lesser contamination.

(4) Flushing connections should be quick-disconnect type and should be provided on potentially highly radioactive systems so that the entire system or selected portions of the system can be easily flushed. The flushing water system should be separated from the radioactive system during normal operations.

b. Sumps and Drains. Design and placement of sumps and drains should prevent the spread of radioactive contaminants and facilitate cleanup.

(1) Sumps which potentially could be contaminated should be doubled walled to provide secondary containment. The sump walls should not be bolted. Seams should be minimized and welds ground flush.

(2) Connections should be provided at appropriate locations to ensure complete drainage of a system alter shutdown. Vents should be provided to permit draining.

(3) Drains can be equipped with quick disconnects so hoses can be connected to direct liquids to a contaminated sump in lieu of permitting radioactive liquids to run across the floor to a drain.

(4) Pumps should be equipped with collection pans for leakage.

(5) Loop seals should be provided in drains where they enter a sump.

(6) Drains should be routed to appropriate sumps. This routing should consider the fluid quality (including high- or low-level activity or requirements for chemical treatment).

(7) Drains which enter sumps should be designed so that piping extends below the minimum water level to ensure that air-borne activity will not pass to other areas through the drain system.

c. Tanks. Tank locations and connections with operating systems should be selected to minimize spread of contaminants.

(1) Tanks containing contaminated fluids should not be buried but placed in above grade rooms. If this cannot be accomplished, the following alternatives are acceptable:

(a) Tanks can be placed in a buried concrete vault with a sump that allows remote pumpout. In addition, the vault should be coated, sealed, or lined to prevent both in and out leakage. Access should be provided to allow decontamination of the interior surface of the vault.

(b) Tank can be buried if a double-walled design is used. The area between liners should be monitored to provide an early indication of leakage. The design and method of installing the buried tanks should facilitate their removal (e.g., buried tanks should not be tied into other structural members.)

(2) Overflow lines from tanks containing radioactive liquids should be routed to a contaminated sump or collection tank.

(3) Vent lines from tanks containing radioactive liquids should be connected to the contaminated ventilation-system exhaust upstream of the filtration equipment. This will minimize both in-plant airborne activity and plant releases.

d. Integration of Radioactive and Clean Facility Areas. Planning and proper design can minimize the area of a facility which can be exposed to contamination. The following are examples of how isolation and separation should be used to prevent the spread of contaminants:

(1) Uncontaminated systems should not receive influents from contaminated areas.

(2) Equipment should be grouped based on activity inventories and process stream so that higher radiation areas may be segregated from non- or lesser-radiation areas and to minimize runs of interconnecting radioactive piping.

(3) Drains from "clean equipment" in contaminated areas should be treated as contaminated. All floor drains in potentially contaminated areas are to be treated as containing contaminated fluids and are not to be cross-connected with floor drains from clean areas.

(4) If radioactive and nonradioactive systems must be interconnected, connections must be isolated by a check valve and a stop valve. Connections to potable water systems will be protected by an air gap or by two American Water Works Association approved, positive displacement, backflow prevention devices placed in series. Consideration should be given to the use of a quick-disconnect hose system when the lines are small enough.

(5) Consideration should be given to providing separate ventilation systems for contaminated and clean portions of a facility.

(6) Air flow must always be from areas of lower radioactivity to areas of higher radioactivity. However, differential air pressures resulting from flow balancing to ensure the proper air flows must not be so high as to make **it** difficult to open doors.

e. Crud Traps. Crud traps are those features in the design of fluid systems that promote the buildup of radioactive material. These should be eliminated to the greatest degree possible. This will reduce personnel exposure not only during periods of operation and maintenance but also during decommissioning. Design features that would eliminate or reduce the number of crud traps are:

(1) Instrument taps that come off the side of piping.

(2) Drain connections that are designed to minimize crud collection or provisions to open valves periodically to flush any collected radioactive material to the waste-collection tank/pump.

(3) Lines that are sloped to drain points so that crud can be flushed.

(4) Long radius bends on radioactive systems and resin-transfer systems.

(5) Orifices located in vertical runs of pipe rather than in horizontal runs.

(6) Tanks provided with sloped bottoms and a bottom drain.

(7) Loops that are above rather than below the pipe run when thermal expansion loops are required on piping.

(8) Piping that is sloped in the direction of flow.

(9) Unavoidable deadlegs on process systems that are designed so that crud can be flushed out by opening a valve.

(10) Piping that is butt-welded as much as practicable without use of backing rings. In additions, socket welds should be avoided where possible since they are also crud traps.

(11) Valve selection that is based on minimum internal dead spots and crevices where crud will accumulate.

(12) Radioactive waste sumps are referenced throughout this text. This is to ensure the general applicability of this manual. However, some facilities may use waste-receiver tanks to collect inputs from equipment and floor drains. Whether a drainage system feeds a tank or a sump, the guidance relating to designs to enhance decommissioning is applicable.

f. Ventilation. The ventilation system shall be the primary means by which the spread of airborne contamination is minimized and controlled.

(1) Proper design of the ventilation system is critical in that it must ensure that clean areas do not receive contaminated air flows due to perturbations in the ventilation system resulting from such incidences as doors in other than their normally intended position either open or closed, roof plugs, floor plugs or access hatches being open, or temporary isolation of any part of the ventilation system.

(2) Filters should be located as near to the ventilated area as possible to minimize contaminated ductwork. Filter maintenance area should be designed to allow easy access and removal of contaminants.

(3) High Efficiency Particulate Accumulator (HEPA) filters should be used on the exhaust from areas expected to have high airborne activity. Where necessary, roughing filters should be located upstream to prevent premature loading of the HEPA filters.

(4) Outside filters should be provided on the ventilation intakes to reduce the dust loading on the contaminated exhaust filters.

(5) If a component can generate high airborne levels, local filters should be provided on exhaust vents from the component or the component area prior to tie-in with the main ventilation system. This minimizes downstream contamination.

(6) Consideration should be given to frequent air changes and filtering in areas where radioactive gases are expected in order to minimize contamination and subsequent migration of such gases.

(7) Normally closed cubicles should be designed with ventilation hookups to control ventilation flow prior to opening the cubicle.

(8) Air locks may be used where appropriate.

(9) Seams and joints in fume hoods and ventilation ductwork should be kept to a minimum and should be sufficiently tight to prevent leakage.

g. Electrical and Equipment. Design and placement of electrical systems and equipment should allow isolation from contaminants where possible or facilitate removal and cleaning during decommissioning.

(1) All equipment subject to contamination should be designed for easy and effective decontamination; it should be easily disassembled to permit access to contaminated portions.

(2) When possible, electrical connections on equipment m high radiation/contamination areas should be of a quick-disconnect type.

(3) Equipment such as transformers, switchgear, motor control centers, and panelboards should not be installed in areas subject to contamination.

(4) Cable trays should be enclosed to limit their contamination.

(5) For equipment to be moved, a path should be provided which allows for straight lifts and runs that do not allow the contaminated equipment to pass into or over uncontaminated areas.

(6) For situations where large components are not accessible by mobile cranes, the placement of permanent jib, bridge, or monorail cranes should be considered to facilitate disassembly and removal.

(7) For medium and small components, pad-eyes should be installed so that rigging can be easily used.

(8) Components should be provided with appropriate lugs to minimize rigging setup time.

(9) Lighting Fixtures should be sealed and flush with the ceiling.

(10) When redundant power sources are required, cable tray routings to critical equipment should be independent.

4-5. Radioactive waste handling

The handling, sorting, processing, packaging and temporary storage of LLW is an integral part of any decommissioning program. This section discusses provisions which should be adopted in the facility design which will facilitate LLW handling during decommissioning.

a. Process Design Provisions. Where applicable, areas should be provided for large shredders capable of shredding thin wall pipe and sheet metal, compactors, and LLW processes including mobile incinerators, liquid-waste processing assemblies, and solidification systems. Design provisions for these processing areas are:

(1) Access paths that are as direct as possible without unnecessary passage through clean areas.

(2) Processing area ventilation releases that are treated or filtered before they are discharged to prevent contamination of nearby clean areas.

(3) Processing areas that are capable of confining any accidental liquid release, thus preventing the contamination of any adjacent clean area. The net containment volume should be at least 125 percent of the total volume of liquid contained in the area.

(4) Services required for LLW processing areas would include HYAC, lighting, electrical power, instrument air supply, demineralized water, and compressed air.

b. Process Space Requirements. Specific guidance cannot be provided for the space and support services required for the various LLW processes that could be used in support of a decommissioning effort. Such process requirements are facility dependent. Also, attempts to define the LLW processing requirements should be initiated during the conceptual design development for the facility when the initial decommissioning plan is started. For information, some space requirements are as follows:

(1) Mobile Incineration. Low level waste mobile incinerators require space for three standard trailers, approximately 30 by 60 feet. These trailers provide the incinerator, pollution abatement system, control room, and packaging area for the ash. Space must still be provided for sorting of the LLW feed to the incinerator and storage, until shipping, of the packaged ash.

(2) Mobile Solidification. Space is required for a cement carrier with some cement metering equipment, approximately 10 by 50 feet and for a standard lowboy transporter with a shielding cask on board, approximately 10 by 40 feet. Finally, space is required for a mobile crane to remove the shipping cask lid and space to lay down the lid.

(3) Super Compactor. Space is required for one standard tractor-trailer truck, approximately 10 by 40 feet. This provides for the compactor only. Space for preparation of the compactor feed and storage of the compacted waste is additional.

(4) The Equipment Identified Above is the Largest Equipment. Much of the other equipment including shredders and demineralizers require space envelopes of 12 by 12 feet or less. However, provisions for shield walls, access, and cranes must also be addressed when the decommissioning approach is developed and provisions to accommodate the LLW processes are defined.

4-6. Decontamination

This section defines those provisions that can be made during the initial planning of a nuclear facility to facilitate its later decontamination.

a. Fluid Systems. The decontamination of fluid systems may be necessary to support the decommissioning of a given facility. Upon completion of the preliminary piping systems designs, a review of the designs should be made with the following objectives:

(1) Based on the processes performed at the facility, identify the types of decontamination processes that should be used in the various fluid systems.

(a) High chemical concentration DECON.

(b) Low or dilute chemical concentration DECON.

(c) Mechanical DECON.

(2) For each decontamination process selected, the applicable portion of the fluid system should be segmented providing the boundary for each independent decontamination application. With the chemical decontamination processes, it may only be necessary to divide the appropriate portion of the system into a few discrete decontamination segments. However, for mechanical processes, several discrete decontamination segments might be necessary.

(3) Provide for the addition of any new valves needed to accomplish the desired segmenting of the fluid systems.

b. Support Requirements for Chemical DECON of Fluid Systems. Space or fittings should be provided for the future installation of equipment and temporary piping for inplace chemical cleaning of contaminated fluid systems. Examples of the types of equipment, temporary piping tie-ins, and process capabilities that will be required are given below.

(1) Facilities to mix and prepare the chemical solutions. These may be temporary skid-mounted assemblies.

(2) Heaters to raise the solution to the proper temperature.

(3) Fittings to fill and drain the system being decontaminated.

(4) The ability to bring the entire fluid system being decontaminated to the proper process temperature.

(5) Fittings to allow feed and bleed to and from the system being decontaminated.

(6) The ability to purge, with demineralized water, any component that might be adversely attacked by the chemicals and thus fail during the decontamination process. For example, reactor coolant pumps may use stellite seals. During a decontamination, these pumps would be used to recirculate the chemical solution. However, the chemicals would attack the seals. The seals can be protected by a water purge past the seals.

(7) The ability to collect and process waste. (The requirements depend on the chemical process selected.)

(8) Adequate space for recirculation pumps, motor control centers, instrumentation, and control panels.

(9) The ability to rapidly drain the system in order to prevent or mitigate an accident.

(10) This list does not provide all the interfaces that would be required when performing a chemical decontamination. It does, however, identify space provisions that should be accounted for during initial design efforts but that would be almost impossible to provide once the facility was built. In a similar manner, the fittings called for here are easier to install during construction rather than after the system has been installed and becomes contaminated.

c. Support Requirements for Mechanical DECON of Fluid Systems. Provisions that should be considered for the inplace mechanical cleaning of fluid systems are as follows:

(1) Necessary fittings to allow the insertion and removal of mechanical decontamination tools such as pigs, brushes, or scrapers should be provided.

(2) Pipe bends should be smooth with large radius bends. This design criterion is limited to the contaminated process pipes, not utility pipes.

(3) Electrical supply, compressed air supply, and demineralized water supply should be provided as necessary.

(4) The ability to collect and process flushwater resulting from decontamination activities.

d. In Place DECON of Surfaces. Provisions that should be considered for the inplace decontamination of surfaces are:

(1) Adequate electrical outlets for air samplers as well as electrically operated tools.

(2) Compressed air outlet for air-operated tools.

(3) Convenient demineralized water outlets for foam or hydrolaser decontamination equipment.

(4) Adequate and appropriate drains if chemical or hydrolaser decontamination is planned.

(5) Means for the collection, storage, and processing of wastes.

e. Remote DECON Provisions. Processes such as electropolishing, freon cleaning, and grit-blasting are likely decontamination processes to be used in support of a decommissioning. These processes could be called remote decontamination processes in that the item to be decontaminated is normally brought to a processing area rather than decontaminated in place. Provisions that should be considered for the remote decontamination processes are:

(1) A central decontamination area design to prevent the airborne release of radioactive material and to contain any liquid spills.

(2) The design should allow materials to be easily moved to a central decontamination area. The transport path should be as direct as possible without unnecessary passage through uncontaminated areas.

(3) Material-handling equipment should be provided in the central decontamination area. Some components will have to be lowered into, and removed from, decontamination tanks or booths.

(4) Liquid decontamination wastes will have to be collected and transferred to the waste processing area.

(5) Provisions will have to be made for electrical power, compressed air, and demineralized water supplies.

4-7. Fire protection

Fire protection requirements are placed on both the facility at which the decommissioning effort is directed and any temporary onsite process and LLW storage facilities in support of the decommissioning effort. In addition, should the fire protection system be activated, preventive measures must be taken to restrict the spread of contaminants.

a. Facility. The decommissioning should progress in such a manner that the fire-protection system installed for normal facility operation remains intact and operable up to the point that the facility is totally decontaminated. The need to maintain fire protection from this point on depends on:

(1) Whether or not the facility is to be reused.

(2) The time interval between complete decontamination and demolition of the facility.

(3) Requirements to protect any adjacent building or facility.

(4) Requirements imposed by site fire marshals.

b. Temporary Process and LLW Storage. The potential fire hazard created by the use of temporary process and decontamination equipment exists and thus fire protection must be provided to process areas. Additionally, temporary LLW storage areas must be protected from fires to prevent a situation where the spread of contaminants is likely. Such temporary facilities may require:

(1) Installation of fire and smoke detection equipment.

(2) Extension of the existing fire protection system if automatic protection is necessary.

(3) Installation of a manually operated fire protection system.

c. Containment Systems. Where sprinkler or other liquid-type fire suppression systems are used, containment systems must remain intact and capable of retaining and storing the volume of contaminated liquid produced by a 15 minute flow of the suppression system.

CHAPTER 5

CRITERIA FOR VARIOUS TYPES OF FACILITIES

5-1. General

This chapter presents criteria and design guidance specific to several types of facilities. This guidance complements the general criteria and design features presented in Chapter 4. Appendix C provides radioactive source considerations for each of the facilities presented in this chapter.

5-2. Power reactor

The potential for contamination in a power reactor facility is very great. Fission products released from containment failure of the sealed source can be carried throughout the coolant system. Leaks may have occurred. Neutron activation is very likely. General criteria for decommissioning reactors is covered in 10 CFR 50. The following recommendations are made.

a. Decommissioning Methods. Due to the long-lived activation products produced both in the materials of construction of the reactor and the surrounding bioshield, ENTOMB should not be considered a viable decommissioning alternative. Therefore, the design of the nuclear power supply system should facilitate its total removal either immediately following defueling through DECON or following some limited decay period through SAFSTOR.

b. Materials. Materials that are less susceptible to activation should he used. Alternatively, use materials that, when activated, produce a lower radiation field than conventional construction materials. Avoid construction materials that produce gaseous radioactive activation or decay products. Examples of this approach are as follows:

(1) The use of zircaloy in place of stainless steel for some reactor internals.

(2) The use of heavily borated concrete. The boron captures the neutrons and prevents the generation of normal concrete activation products. The boron capture does produce tritium which is long lived and emits a low energy beta. The resulting radiation levels are much lower than those normally encountered from activated concrete.

c. Component Assembly. Use construction methods and systems and equipment components wherever possible which can be easily dismantled to minimize demolition of the facility. Examples are as follows:

(1) Equipment arrangement should facilitate removal with the fewest number of cuts and, if possible, as complete components.

(2) Bulk or mass shielding walls should be designed as interlocking segments that can be placed and removed using a crane.

(3) The spent fuel pool should be designed to facilitate underwater segmenting of radioactive components. Since all fuel will be removed from the facility prior to the initiation of any decommissioning option, the spent fuel pool will not be required. With the fuel racks removed, an adequate quantity of shielding water could be maintained over very radioactive components requiring segmenting. Provisions that could be made to allow the spent fuel pool to be used for segmenting components are:

(a) The installation of, or provisions for the installation of, materials handling equipment.

(b) Sizing of the spent fuel pool to ensure it can accept components for segmenting.

5-3. Research reactors and accelerators

The DECON method of decommissioning is the preferred method for such facilities. Therefore, these research facilities should be designed to facilitate their total removal following defueling or termination of facility operation. The guidance given above for power reactors related to DECON is basically applicable, with a few obvious exceptions, and should be followed when considering design of research facilities. General criteria for decommissioning research reactors is provided in 10 CFR 50 and criteria for accelerators is provided in 10 CFR 30.

5-4. Radiographic facilities

Radiographic Facilities are utilized to non-destructively examine items for defects and foreign material. Radiography may be conducted using electromagnetic radiation or neutron sources. General criteria for decommissioning radiographic facilities is provided in 10 CAR 30. The following recommendations are made:

a. Source. Radiographic facilities are designed based on an assumption that only sealed radiographic sources are present at the facility. It is important that the source remain sealed. The quality of the source containment and appropriate care in handling are imperative in reducing the risk of spread of contaminants while using the radiographic source.

b. Maintenance. Design features that should be addressed are those that would permit frequent and easy checking of the sealed source in order to ensure the integrity of the seal. Checking of the sealed source should be able to be performed in an ALARA manner. The potential for neutron activation when using a neutron source must be considered.

5-5. Facilities for depleted uranium munition

Munitions and projectiles with depleted uranium (DU) components are test proven in practice firings. Fragments of the tested component and radioactive dust particles liberated during impact with targets will be generated during testing. General criteria for decommissioning DU facilities is provided in 10 CFR 40. This type of facility is currently in operation at Aberdeen Proving Ground, Maryland. It is recommended that a review of the design, construction, and operation of this facility be made prior to initiation of a new facility design.

a. Structural Features. Testing should be conducted whenever possible in enclosed facilities with air handling and filtering capabilities to prevent release of contaminants to the outside. The explosive yield involved in the test may make indoor testing impractical. The following structural features are recommended for a test cell:

(1) The interior surfaces shall be coated with impermeable, non-combustible and sealed material. Radioactive dust and particle settlement will be washed and collected for disposal.

(2) The coatings used on cell walls and floors should not present a fire hazard during testing. Explosion tests release significant amounts of heat which can cause combustible wall coatings to burn.

(3) A concrete floor slab design is preferred over a concept which includes covering the floor with one to two feet of gravel. If gravel material is used, design to allow access for removal and disposal of the gravel which will be contaminated.

b. Holding Tanks. Holding tanks used to collect wash-down from the target facility should be above grade. Containment of accidental spills should be provided.

5-6. Research, development, testing and medical laboratory facilities

General criteria for decommissioning research development and testing facilities is provided in 10 CFR 30,40, and 70, and general criteria for medical laboratories is provided in 10 CFR 30. The following design recommendations are made:

a. Work Stations. Counter tops should be designed to contain spills and prevent loss off the counter. The counter top design should, in particular, prevent radioactive liquids from seeping between the counter and wall. A sealed perimeter lip to contain spills is appropriate. Nonporous, impermeable materials should be used on work surfaces. Work stations shall be modular to allow removal and disposal of contaminated units.

b. Hoods. Laboratory hoods should be stainless steel rather than fiberglass. The hood flow rate should be great enough to ensure turbulent flow.

c. Surfaces. Counters, walls, floors, or any surface on which contaminants could collect should be nonporous, sealed, lined, or coated in order to prevent the migration of contaminants into the materials of construction and to facilitate the cleanup of these surfaces.

d. Glove Boxes. For facilities requiring glove boxes, the following design criteria should be considered:

(1) Glove boxes should be provided with collection systems to handle spills and leaks.

(2) Service lines must be designed so that they do not provide a leak path.

(3) Glove boxes should be sized to facilitate their disposal or rearrangement.

(4) Glove boxes shall be designed so that they are easy to separate.

(5) Pipes, ducts, conduits, or other attachments to the glove box shall be easy to disconnect.

(6) The glove box should be designed for ease of decontamination inside and out.

(7) Glove boxes should have lighting fixtures which are flush with the top of the glove box and sealed.

(8) Glove boxes should have rounded edges.

(9) Enclosed conveyors should be used to connect long glove box segments.

(10) Enclosed conveyor systems should be connected to glove boxes in a manner to facilitate easy removal.

(11) Glove boxes should have prefilters and HEPA filters on both the ventilation system inlets and exhaust.

(12) Glove boxes shall maintain a negative pressure for any activity involving the handling of radionuclides. This causes leakage through flaws to be directed into the box and prevents the spread of contamination.

CHAPTER 6

DECOMMISSIONING PLANS

6-1. Types of plans

A preliminary decommissioning plan document is recommended for all nuclear facilities and required by the NRC for power reactors. A final decommissioning plan is required for all nuclear facilities. The initial version of the preliminary plan should be prepared in conjunction with the design of a facility. This plan will establish feasible decommissioning schemes that can be accomplished without undue risk to the health and safety of the public and decommissioning personnel, without adverse effects on the environment, and within established guides and limits of the appropriate regulatory agencies. While not a detailed document, this preliminary plan will serve to ensure that the decommissioning and ultimate disposition of a facility are considered during the initial design and construction of that facility. The preliminary plan will remain a "living document," and revisions will be made throughout the operating life of a facility. It must be reviewed periodically and revised to reflect any changes in facility construction or operation that might affect decommissioning. Prior to the initiation of actual decommissioning activities for a facility, a detailed final disposition plan is required. The final plan should be based on the preliminary plan and revisions, and will define specific work activities and include safety evaluations of planned decommissioning methods, new technology, and the facility status that will result from the decommissioning program. In addition, this plan must contain sufficient information to obtain any approvals needed from the appropriate regulatory agencies to proceed with decommissioning activities. The level of detail presented in a decommissioning plan will correspond to the complexity of the facility, type of source, potential for contamination, and perceived difficulty to perform the future decommissioning.

6-2. Preliminary plan

a. Plan Purpose. The preliminary plan serves to establish decommissioning as an important consideration from the inception of the project, during design and throughout the operation of the facility. The plan has the following purposes:

(1) The primary purpose of the preliminary plan is to ensure that facility designers are cognizant of decommissioning during the initial design of a facility. Thus, where design choices that would enhance decommissioning are available for types of materials and system components, and location of components, these choices should be made.

(2) Another purpose of the preliminary plan is to identity the ultimate decommissioning options and final facility status. Options should identity either the immediate, complete removal of all radioactive materials to permit unrestricted use of the facility or the deferred decommissioning approach of portions or all of the facility. These options would be evaluated and narrowed to the decommissioning method of choice as the end of facility life is approached.

(3) The final purpose of the preliminary plan is to demonstrate to regulatory agencies that important aspects of decommissioning are considered as early as possible during the initial design of a facility. The plan serves as the starting point to demonstrate that areas such as decommissioning methods, costs, schedules, and operating impact on decommissioning will be reviewed and refined throughout the operating life of a facility.

b. Plan Content. The preliminary plan will provide a general description of decommissioning methods considered feasible for the facility, including the management of radioactive waste resulting from each method. The description should demonstrate that the methods considered are practical and that they protect the health and safety of the public and decommissioning personnel. Design personnel should study the proposed decommissioning methods and take steps to ensure that the design incorporates features that will facilitate decommissioning. Considerations include:

(1) Provisions for adequate material-handling equipment.

(2) Provisions for separation of, and remote maintenance of, highly radioactive components.

(3) Provisions for effective decontamination or sealing of surfaces that may become radioactively contaminated.

(4) Location and adequate size of doors to permit movement of materials and components.

(5) An estimate of manpower, materials, and costs anticipated to support each decommissioning method considered.

(6) A description of the anticipated final disposition and status of the facility and site.

(7) A discussion demonstrating that adequate financing will be programmed for decommissioning.

(8) An estimate of the type, amount, and location of significant radionuclides and radioactively contaminated materials within the facility at the end of its operating life.

(9) Identification of records that should be maintained during facility construction and operation which might facilitate decommissioning, including a set of "as built" drawings.

(10) Identification and quantification of each radionuclide naturally present in the air, soil, and surface- and groundwater on-site as well as in the immediate area

around the site before the facility is operated. Measurements shall be made of the ambient direct-radiation levels in the area around the site before nuclear materials are brought onto the site. Reference Chapter 2 for a discussion on-site surveys for the sampling and measurement of radiation.

c. Plan Updating. The preliminary plan will evolve throughout the life of the facility. The plan is initially developed during design of the facility. Updates to the plan shall changes in the facility, changes in operations, and new technology.

(1) There is no definitive guidance governing the frequency at which a preliminary decommissioning plan should be reviewed and updated. The size of the facility, the activities which occur at a facility, the quantities of radioactive materials present, and the frequency of facility modification are examples of considerations that would affect the review frequency. For a large facility conducting a variety of activities involving large quantities of radioactive materials, a review frequency of every 2 to 3 years would be in order. For a facility where radioactive materials are only stored, a review frequency of every *5* or 6 years might be adequate. The plan-review frequency for other facilities would fall somewhere between these example frequencies.

(2) A review schedule and milestones for updating the decommissioning plan must be established in the preliminary plan and not be left undetermined. This schedule can be modified during the lifetime of the facility.

(3) The 10 CFR 50.75(f) requires that each reactor licensee submit a preliminary decommissioning plan approximately five years prior to the projected end of the operation of the nuclear facility. For these facilities, this milestone must be added to the review schedule developed.

(4) In addition to the scheduled plan review for a facility, the preliminary plan must be reviewed and updated as necessary whenever activities occur that might affect decommissioning. Examples of such activities are the alteration or addition of structures, changes in components or operations, and the addition of activities at a facility.

(5) Each time the plan is updated, any new decommissioning techniques shall be considered for incorporation in the plan.

d. Records. As previously mentioned, an important aspect of a preliminary decommissioning plan is the maintenance of appropriate records. These records should cover not only design but also events during the operating life of a facility. The 10 CFR 50.73(g) requires the maintenance of records that are important to safe decommissioning. The NRC should be consulted for current applicable guidance for maintenance of records. Records for all types of facilities should include:

(1) Structure and component material specifications.

(2) Plant-design documents.

(3) Methods, procedures, and order of assembly and construction.

(4) "As-built" drawings.

(5) Photographs of areas and component locations.

(6) Relevant facility operational parameters and any abnormal incidents in facility operation that could affect decommissioning. This includes records of spills or any other unusual occurrences involving the spread of contamination in and around the facility equipment or site.

(7) Surveys of radiation levels, contamination levels, and airborne radioactivity levels, as well as locations that were contaminated during facility operations.

e. Models. For complex facilities, such as nuclear reactors and hot cells, a model of the facility should be considered. A physical model can prove to be a valuable tool during design, construction, operation, and decommissioning of a facility. A model should be built to scale and should be completed prior to facility operation. This permits accurate modeling by actual field measurements before radiation hazards are present (instead of relying on drawing measurements only) and thus ensures an "as built" model. A model can effectively serve the following functions:

(1) Demonstrate adequate cleanance and access for the installation and removal of system components and other equipment.

(2) Show effects of the installation of temporary shielding and staging.

(3) Demonstrate rigging techniques and the location of attachment points.

(4) Show the location of radiation hot spots.

(5) Show emergency equipment locations.

(6) Serve as a training tool for operating personnel and craftsmen during facility operation and decommissioning activities. A model should be revised as necessary during the operating life of a facility to reflect any structural or component alterations, additions, or deletions.

6-3. Final plan

a. Purpose. The primary purpose of the final decommissioning plan is to demonstrate that decommissioning can be accomplished, how it will be carried out, and that radiation exposure to the public both during and after decommissioning will be within ALARA limits.

b. Plan Content. The final plan should be based on the preliminary plan as revised during the operating life of the facility and should include:

(1) A description of the facility before and after decommissioning activities.

(2) A description of the techniques and procedures to be used.

(3) An estimate of the type and quantity of radioactive and nonradioactive wastes to be generated and the plans for treatment, transportation, disposal, and storage.

(4) A safety analysis that includes assessment of the probability and severity of accidents that might occur during and after decommissioning.

(5) An environmental assessment of the facility during and after decommissioning. A dose assessment must be performed which demonstrates that the total radiation exposure from all pathways is within acceptable limits.

(6) An estimate of costs and identification of funding.

(7) Identification of organizations participating, including key staff and the responsibilities of each.

(8) An estimate of occupational and public radiation exposures resulting from decommissioning.

(9) Details on how the radiation protection program will function and how occupational and public radiation exposures will be maintained within regulatory and ALARA limits.

(10) Bases, criteria, and derived values for radioactivity levels that are acceptable for the release of facilities and materials for unrestricted use.

(11) A description of the quality control program.

(12) A description of the security program.

(13) Plans to respond to emergencies or unexpected occurrences.

(14) Records and reports to be generated during decommissioning, and the disposition of such documents.

(15) A description of the environmental monitoring, surveillance, and maintenance program that will be implemented during decommissioning.

(16) A description of the final radiation survey to release the facility for unrestricted use.

c. Plan Outline. In August 1989, the NRC issued Regulatory Guide 3.65, "Standard Format and Content of Decommissioning Plans for Licenses Under 10CFR Parts 30,40, and 70." This Regulatory Guide should be used by all nonreactor facilities in the preparation of their decommissioning plan. In addition to providing general information on format and provisions for revising the plan, it provides information on what the plan should contain. The NRC guidance is covered by 10 CFR 50. The general contents of the plan are summarized below:

(1) General Information.

(2) Description of Planned Decommissioning Activities.

(a) Decommissioning Objective, Activities, Tasks, and Schedules.

(b) Decommissioning Organization and Responsibilities.

(c) Training.

(d) Contractor Assistance.

(3) Description of Methods Used for Protection of Occupational and Public Health and Safety.

(a) Facility Radiological History Information.

(b) Ensuring that Occupational Radiation Exposures are ALARA.

(c) Health Physics Program.

(d) Contractor Personnel.

(e) Radioactive Waste Management.

(4) Planned Final Radiation Survey.

(5) Funding.

(6) Physical Security Plan and Material Control and Accounting Plan Provisions in Place During Decommissioning.

d. Submittal Schedule. The final plan should be completed at least one year prior to the end of facility operation or as required by the approval agency, even if there will be. a delay between the end of facility operation and the commencement of decommissioning activities. This period will serve two important functions: it will ensure that key facility personnel are still available to provide input to the plan, and it will given regulatory agencies lead time to review the plan for approval. If decommissioning is delayed using SAFSTOR or ENTOMB alternatives, then an additional submittal and update of the plan is necessary prior to the start of final decommissioning.

6-4. Approval agencies

Depending on the activities performed at a facility, approval for a final decommissioning plan will be needed from one or more agencies:

a. NRC. The NRC will be the approval agency, after DOD agency review, for decommissioning plans related to NRC licensed ionizing radiation sources.

b. DOD. If a facility has no radioactive materials licensed by the NRC but does have other sources of radiation, such as X-ray machines and radium, which are regulated by a DOD agency then this agency will be the approval agency for the decommissioning plan.

c. Joint Regulation. For a facility with a combination of radiation sources regulated by both the NRC and other agencies, approval of the decommissioning plan will fall within the jurisdiction of two or more agencies. In addition to DOD and NRC approval agencies, state approval agencies must be included, where required, during the plan development and approval process.

6-5. Control of deferred decommissioned facilities

The final plan must address security and maintenance of facilities which must remain in effect until decommissioning is complete. A nuclear facility that has been successfully decommissioned and released for unrestricted use requires no further control or maintenance with respect to protection against radiation. Deferred decommission of a facility or part of a facility (SAFSTOR or ENTOMB) results in non-operational buildings or other entities containing radioactive contamination in excess of limits permitting uncontrolled release of the facility. In addition, on-site storage (five years or less) of LLW on-site may be considered necessary. The decommissioning plan must address restriction of unauthorized entry into such facilities and the maintenance of those facilities. Limited guidance on preparation of facilities for deferred decommissioning is presented below

a. Physical Security. The use of multiple locked barriers and intrusion alarm systems to prevent inadvertent exposure of personnel is required. The presence of these barriers must make it extremely difficult for an unauthorized person to gain access to areas where radiation or contamination levels exceed those specified in chapter 2. To prevent inadvertent exposure, radiation areas above *5* mR/hr, such as near the activated primary system of a power plant, must be appropriately marked and should not be accessible except by cutting of welded closures or by disassembling and removing substantial structures and shielding material. Means such as a remotely monitored intrusion detection systems must be provided to indicate to designated personnel that a physical barrier has been penetrated. Security personnel who control access to a facility may supplement or be substituted for the physical barriers and the intrusion alarm systems.

b. Inspections and Surveys. The decommissioning plan shall identify all inspection and survey requirements and establish a schedule for these activities. At the very least, the following are required:

(1) Physical barriers and the facility structure should be inspected at least quarterly. This is to assure that these barriers have not deteriorated, that locks and locking apparatus are intact, and unauthorized entry has not occurred.

(2) A facility radiation survey should be performed at least quarterly to verify that no radioactive material is escaping or being transported through the containment barriers in the facility. Sampling should be done along the most probable path by which radioactive material such as that stored in the inner containment regions could be transported to the outer regions of the facility and ultimately to the environment.

(3) An environmental radiation survey should be performed at least semiannually to verify that no significant amounts of radiation have been released into the environment from the facility. Samples such as soil, vegetation, and water should be taken at locations for which statistical data have been established during reactor operations.

(4) Inspect the facility for signs of damage or weathering.

c. Administrative Controls. The decommissioning plan shall establish administrative controls and identify responsibilities of personnel related to managing, monitoring, and securing deferred decommissioned facilities At the very least, the following are required:

(1) A site representative must be designated to be responsible for controlling access into and movement within the facility.

(2) Responsibilities for performing inspections, radiation surveys and record keeping must be established.

(3) Administrative procedures must be established for the notification and reporting of abnormal occurrences such as the entrance of an unauthorized person or persons into the facility, a significant change in the radiation or contamination levels in the facility or the off-site environment.

(4) Responsibility for maintenance of the facility for the repair of damage due to weather, aging, or other factors along with maintenance of electrical, mechanical, and fire protection systems which will be used in support of the final decommissioning.

d. Guidance Documents. Limited guidance on preparation of facilities for deferred decommissioning of facilities along with control and surveillance requirements of such facilities is given in Regulatory Guide 1.86. Guidance on providing LLW interim storage is given in SECY-81-383; NUREG-0800, Appendix 11.4-A; and USNRC Generic Letter 81-38. These sources should be reviewed when preparing decommissioning plans.

APPENDIX A
REFERENCES

GOVERNMENT PUBLICATIONS

U.S. Nuclear Regulatory Commission

Federal Register, Vol. 50, No. 123, pp. 24018-24056, dated June 27,1988	General Requirements for Decommissioning Nuclear Facilities
Regulatory Guide 3.65 (Task CE 304-4), August 1989	Standard Format and Content of Decommissioning Plans for Licensees Under 10CFR Parts 30,40 and70
Unnumbered Document, May 1987	Guidelines for Decontamination of Facilities and Equipment Prior to Release for Unrestricted Use or Termination of Licenses for Byproduct or Source Materials
NUREG/CR-5513	Residual Radioactive Decontamination from Decommissioning (January 1980)
DOE/EV/10128-1	Decommissioning Handbook by William J. Manion and Thomas S. LaGuardia (November 1980)

U.S. Environmental Protection Agency

40CFR	Code of Federal Regulations, Protection of the Environment

APPENDIX B

RADIOLOGICAL HAZARDS AND THEIR CONTROL

B- I. Types of ionizing radiation

At any facility which produces, processes, uses, or stores radioactive materials, radiological hazards will be present to some degree. The basic hazard associated with radioactive material is the emission of ionizing radiation. Radioactive material, whether naturally occurring or manmade, is unstable and is constantly seeking a stable, atomic configuration through a process called radioactive decay. As radioactive material decays to stable, nonradioactive material, or to other types of radioactive material, ionizing radiation is emitted. This ionizing radiation will be emitted in either particle or electromagnetic waveform. The four basic types of radiation of concern are alpha radiation (particles), beta radiation (particles), gamma radiation (electromagnetic waves), and neutron radiation (particles).

a. Alpha Radiation. Alpha radiation is composed of positively charged particles. Each particle is composed of two neutrons and two protons, making an alpha particle identical to the nucleus of a helium atom (2^4He). Alpha radiation is less penetrating than either beta or gamma radiation and may be completely stopped by a sheet of paper. Alpha radiation is not a hazard external to the body but becomes a hazard if the alpha-emitting radioactive material gets inside the body. Alpha radiation is denoted by the Greek letter a.

b. Beta Radiation. Beta radiation is composed of negatively charged particles. Each particle is identical to an electron (-1^0e). Beta radiation is more penetrating than alpha but less penetrating than gamma radiation and may be completely stopped by a thin sheet of metal such as aluminum. Beta radiation is an external hazard to the skin of the body and to the eyes, and is also an internal hazard if the beta-emitting radioactive material gets inside the body. Beta radiation is denoted by the Greek letter β.

c. Gamma Radiation. Gamma radiation is high energy, short wavelength electromagnetic radiation, frequently accompanying alpha and beta radiation. Gamma radiation is much more penetrating than either alpha or beta radiation because of its wave form. Gamma is similar in form and energy to K-radiation. Gamma radiation is not entirely stopped by materials but can be almost completely attenuated by dense materials like lead or depleted uranium, and with greater thicknesses of materials such as water or concrete. Because of its penetrating power, gamma radiation is a hazard to the entire body, whether or not the gamma emitting radioactive material is inside or outside the body. Gamma radiation is denoted by the Greek letter γ.

d. Neutron Radiation. Neutron radiation is composed of particles with no electrical charge (1^0n). Neutron radiation is less penetrating than gamma radiation, but more penetrating than either alpha or beta radiation and may be completely stopped by an appropriate thickness of a hydrogenous material like water or concrete. Neutron radiation has the unique property of being able to convert nonradioactive material to radioactive material. Neutrons are external hazards. They are emitted by machines such as nuclear reactors. They could be an internal hazard if a source emitting neutrons enter the body. Neutron radiation is denoted by the small English letter n.

B-2. Types of radiological hazards

The radiations described above are hazards because each has the ability to ionize, either directly or indirectly, cells which make up body organs and structures. This exposure can be either internal or external. If the body is exposed to large doses of ionizing radiation, cell damage may be sufficient to interfere with normal body functions and can cause undesirable biological effects, both in the individuals exposed and in the future offspring of these individuals. During the decommissioning process, radiological hazards may be present in the form of radiation only, or in the form of radiation together with the radioactive material emitting the radiation. These hazards may be grouped as external radiation, surface radioactive contamination, airborne radioactive contamination and waterborne radioactive contamination.

a. External Radiation. External radiation hazards to an individual are those presented by exposure to emissions from radioactive sources and contaminants that are external to the person. External radiation can be emitted from contained or partially contained sources. Examples include sealed radioactive sources and radioactive material contained in a closure such as a pipe, equipment, or a system component of some type. External radiation hazards may also be posed by surface contamination, airborne contamination, or waterborne contamination. Radiation dose to individuals must be measured to show compliance with regulatory limits. This measurement is accomplished by film badges, thermoluminescent dosimeters (TLDs). direct-reading dosimeters, or a combination of the three. Radiation dose rates are measured by portable and fixed instruments to quantify the external radiation hazard. Individuals may be protected from external radiation, or at least have their radiation dose minimized, by three methods: time, distance, and shielding.

(1) Time. Minimizing time spent in areas where external radiation is present minimizes radiation dose.

(2) Distance. The greater the distance from a source of radiation, the less the dose rate.

(3) Shielding. Installing materials such as lead or concrete around a source of radiation will reduce the dose rate.

b. Surface Radioactive Contamination. Surface contamination occurs in two basic forms: fixed and removable. Fixed contamination is that which tightly adhered to a surface. The hazard is from radioactive material emissions. Removable contamination is readily spreadable. It poses an external hazard through exposure to its emissions and is available to be taken inside an individual by ingestion, inhalation, through the skin, or through open wounds. Surface contamination can be caused in many ways; for example, opening a system containing radioactive material for maintenance, leakage from a sealed source, or an accidental spill of radioactive material during a process of some type. It can also be transported from contaminated to uncontaminated areas by the movement of individuals and equipment or by air movement through the HVAC system. Protection and removal procedures are as follows:

(1) Individuals are protected against skin contamination by removable surface contamination through the use of protective clothing which protects from head to foot. This clothing is removed before leaving a containmated area, thus preventing the spread of surface contamination.

(2) Any items removed from a contaminated area are put in appropriate containers to prevent the spread of contamination.

(3) Removable surface radioactive contamination can be removed from walls, floors, items, even skin much in the same manner that dirt is removed from these surfaces, by the use of soap and water and other routine cleaning techniques.

(4) Fixed contamination can be dislodged from a surface and become removable contamination by processes such as scrubbing a surface with a wire brush, filing on the surface, flame cutting, welding, and grinding.

c. Airborne Radioactive Contamination. Airborne contamination may result from several situations; for ex ample, disturbing surface contamination by walking through a contaminated area or working in a contaminated area, performing an operation such as welding or grinding on a contaminated surface, or the release of radioactive material from a system during operation. Airborne contamination is usually only a minor external radiation hazard but can pose a serious internal radiation hazard because the contamination is easily inhaled by an individual.

(1) Individuals are protected against the inhalation of airborne contamination by the use of respiratory protective equipment. This equipment may be a filter respirator or an air-supplied respirator depending on the concentration of radioactive material in the air.

(2) Airborne contamination can be minimized, or prevented, by the use of ventilation through filtration and by performing airborne producing operations in contained areas.

d. Waterborne Radioactive Contamination. Waterborne contamination may result from such sources as leaks from systems containing contaminated water and water used for surface decontamination. If contaminated water dries, surface contamination results. Waterborne contamination is usually only a minor external radiation hazard but can pose a more serious internal radiation hazard if the water is ingested.

(1) Individuals are protected against waterborne contamination by the use of plastic clothing and, if necessary, respiratory protective equipment.

(2) Contaminated water must be handled and disposed of in a controlled manner.

APPENDIX C

RADIOACTIVE SOURCE CONSIDERATIONS IN NUCLEAR FACILITY DESIGN

C- 1. Radiation sources

Radiation sources encountered in facilities which produce or use radioactive materials may be generally divided into four generic types including radioactive waste, radioactive components, radioactive contamination, and test and radiographic sources.

a. Radioactive Waste. Facilities using radioactive materials can generate liquid and or solid wastes. In addition, accelerator facilities are also capable of generating waste. If the waste is liquid, there may be collection and holding tanks where the liquid is held for sampling, for delay until decay reduces the radioactivity levels, or for storage prior to solidification. These tanks would be radiation sources. There can be packaging areas for solidified liquid waste and other solid wastes where final preparations are made for the shipment of radioactive waste. If the solid waste is not shipped immediately, a waste storage area will be required. These areas would also be sources of radiation.

b. Radioactive Components. The numbers and types of components in a facility which may contain radioactive material and therefore be a source of radiation will vary greatly from facility to facility. Typical components would include:

(1) Pumps.
(2) Valves.
(3) Heat exchangers.
(4) Filters and filter housings.
(5) Vessels and tanks.
(6) Vent ducts.
(7) Connecting piping.

c. Radioactive Contamination and Activation. Any areas of a facility which are contaminated with radioactive materials will be sources of radiation. Contamination can occur by contact with unsealed radioactive materials entrapment. Exposure of structural materials to emitted radiation can result in those materials becoming radiation sources themselves. In this case direct contact with radioactive source material is not required; exposure to the emitted radiation is the activating mechanism. For example, reactors and high energy accelerators, particularly those resulting in the production of high energy neutrons, pose particular problems of this nature. Typical affected areas would include:

(1) Laboratories.
(2) Maintenance and manufacturing areas.
(3) Decon areas.
(4) Storage areas.
(5) Test areas.
(6) Reactor containment.
(7) Accelerator room.
(8) Medical treatment areas.

d. Test and Radiographic Sources. Low radioactivity sources will be present at every facility to check for the proper operation of radiation monitoring instrumentation. Additionally, higher radioactivity sources may be present in some facilities to permit calibration of radiation monitoring instrumentation. These sources may emit alpha, beta, gamma, or neutron radiation. They may be sealed, partially sealed, or unsealed in form (para C-3). If radiography is performed at a facility, sealed radiation sources will be present.

C-2. Half-life considerations

Approximately 2,000 nuclides have been identified. Of these, some 235 are stable, nonradioactive; some 44 occur in nature as radioactive nuclides; and the remainder of the nuclides, over 1,700, are artificially, man-made, radioactive. Each radioactive nuclide, man-made or naturally occurring, has a property called half-life which is defined as the time required for half the atoms of a radionuclide to disintegrate to another nuclear form. This new nuclide form is usually stable (nonradioactive) but, for some nuclides, the new nuclide may also be radioactive. The half-lives of radionuclides range from a fraction of a second to millions of years. The approximate half-life of some commonly encountered radionuclides are listed in the following table taken from the "Radiological Health Handbook."

Radionuclide	Half-Life	Radionuclide	Half-Life
N-16	7.13 sec.	H-3	12.30 years
Xe-133	5.27 days	Cs-137	30 years
I-131	8.05 days	Am-241	458 years
Fe-59	45.00 days	Ra-226	1602 years
Ir-192	74.20 days	C-14	5730 years
Mn-54	313.00 days	Pu-239	24390 years
Pm-147	2.62 years	U-235	7.1×10^8 years
Co-60	5.26 years	U-238	4.51×10^9 years
Kr-85	10.76 years		

a. Calculation of Residual Concentration of a Single Radionuclide Source. The effect of radioactive decay, particularly for shorter half-life radionuclides, may be to reduce or eliminate levels of contamination and radiation exposure prior to decommissioning activities. For example, seven half-lives of decay will result in less than one percent of the original radioactivity of a radionuclide. The concentration of any radionuclide following a period of decay can be calculated using equation C-1.

$$C = C_0 \exp(-\lambda t) \qquad \text{(eq. C-1)}$$

where: C_0 = The initial concentration

λ = The decay constant = 0.693/half-life (units are in time-1)

t = The decay period in half-life units of time; (the time units for "λ" and "t" must be the same)

C = The concentration following decay period "t"

From this equation the remaining concentration has been calculated for several decay periods and are given in the following table:

Decay Period (in half-lives)	Reduction Factor (%)	Fraction of Original Concentration Still Remaining
3.32	90.0	0.1
6.64	99.0	0.01
9.96	99.9	0.001

For example, if the objective of a SAFSTOR program is to provide a 99-percent reduction in a colbalt-60 contaminant, the SAFSTOR period would be calculated as follows:

SAFSTOR period = (decay period)(half-life) (eq. C-2)

Where: decay period = 6.64 half-lives (99% reduction)

half-life = 5.26 years/half-life (cobalt 60)

or

SAFSTOR period = (6.64)(5.26) = 35 years

This reduction in the concentration of a given radionuclide due to radioactive decay is graphed in figure C-1.

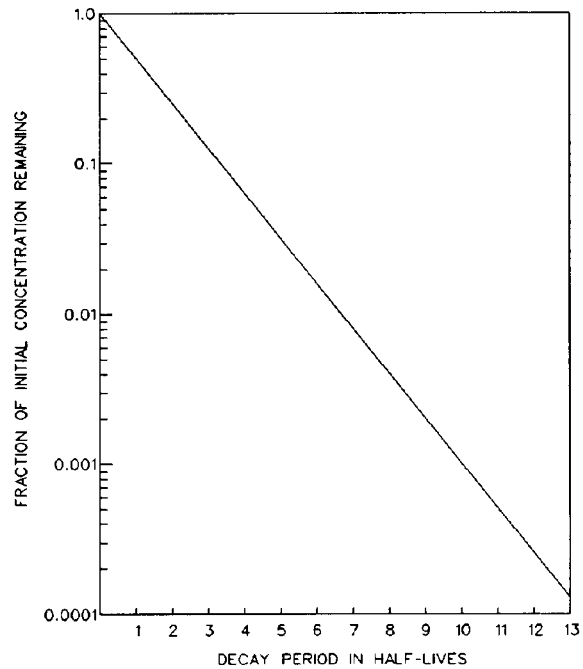

Figure C-1. The Reduction In The Concentration Of A Radionuclide Due To Radionuclide Decay.

Note that this plot represents the values indicated in columns 1 and 3 of the table above. It should be noted that the above discussion represents a situation where the radionuclide of interest is not part of a decay chain; that is, it does not result from the decay of another radionuclide. However, when a decay chain is involved, the radionuclide of interest (daughter product) is being increased in concentration, while it decays, by the decay of another radionuclide (parent radionuclide). Depending on the half-lives and initial concentrations of the parent and daughter radionuclides, it is possible that the concentration of the daughter product will increase for some period of time after primary production method (e.g., fissioning) for these radionuclides has stopped. The concentration of the daughter product in a parent-daughter decay chain following a period of decay is calculated using equation C-3.

(eq. C-3)

$$C_d = C_{do}\exp(-\lambda dt) + \frac{C_{po}\lambda_d}{\lambda_d - \lambda_p}(\exp(-\lambda_p t) - \exp(-\lambda_d t))$$

Where: C_{do} = The initial concentration of the daughter radionuclide

C_{po} = The initial concentration of the parent radionuclide

C_d = The concentration of the daughter following decay period t

λ_d = The decay constant for the daughter radionuclide

λ_p = The decay constant for the parent radionuclide

t = The decay period

b. Composite Radionuclide Source. The presence of only a single radionuclide during a decommissioning is a special case. Usually, several radionuclides would be involved. For the typical case of a composite radionuclide source, selection of a period of deferred decommissioning could be based on various considerations. Presented in figure C-2 is a graphic representation of the total dose rate and its major constituents as a function of the period of radioactive decay. This figure shows that after 2.5 years, all short-lived contributors have decayed out and the total dose rate is due strictly to the radionuclide, cobalt-60. A 90 percent reduction in the total dose rate is achieved after *4.5* years of decay, while an additional 90 percent reduction in the total dose rate would require an additional 17.5 year period of radioactive decay. Either total dose rate or total radioactivity inventory can be represented in the manner shown in figure C-2. Such a graphic representation would be useful in determining the duration of the deferred decommissioning. Again, the case presented in figure C-2 does not involve a decay chain. However, the approach presented would still be valid if a decay chain were involved.

C-3. Containment or sources

Radioactive sources can be classified by the type of containment provided to the material when in normal use or storage. This includes sealed, partially sealed, and unsealed sources. In general, the less containment provided radioactive materials in normal operations, the greater the risk of contamination.

a. Sealed. Sealed sources have the radioactive material contained in a sealed enclosure, usually fabricated from metal. This sealed enclosure permits emissions without concern for the release of radioactive material and subsequent contamination. Sealed source enclosures are inherently secure, but can be breached by mechanical damage such as severe abrasion, impact, or crushing. Sealed sources are used in a variety of applications such as industrial radiography, medical radiation therapy, and radiation monitoring instrument calibration. Sealed sources may be placed in a permanent storage area but require shielding protection to reduce radiation exposure while in transport and storage.

b. Partially Sealed. The radioactive material in a partially sealed source is contained in a manner which prevents the spread of radioactive material during normal handling of the source, but is not sufficient to provide protection if the source is mishandled. For example, alpha and weak energy beta sources are usually covered by a thin mylar sheet. This covering prevents the spread of radioactive material unless the mylar is torn.

c. Unsealed. Unsealed radioactive material can be easily spread if handled improperly. Such material can be

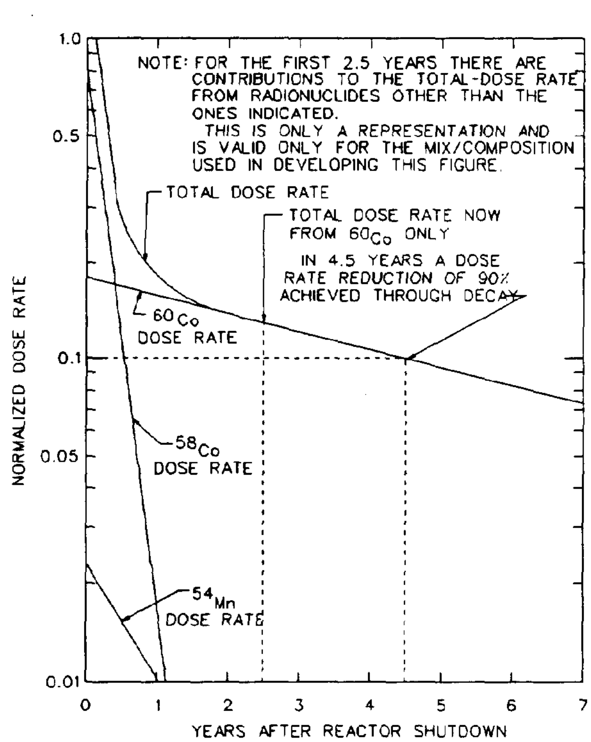

Figure C-2. Reduction Due To Radioactive Decay In The Total Dose Rate From A Composite Radiation Source Term.

liquid, gas, powder, or solid form and, when spread, anything contacted by them becomes contaminated.

C-4. Specific DOD facilities which have radioactive sources

a. Research Laboratories. Depending on its mission, a research laboratory may be involved in a wide variety of activities such as the analysis of material activation by neutrons, the study of radiation exposure effects, and the use of radioactive tracers in experiments. Various radionuclides may be used in a typical laboratory environment or may be used in closed, shielded cells to protect personnel from radiological hazards. Reactors or particle accelerators may also be used at such facilities.

(1) Types of Radiation Expected Depending on the facility mission, a number of different radionuclides may be used. Alpha, beta, and gamma emissions can be expected.

(2) Types of Sources Present. Sealed, partially sealed, and unsealed sources can be expected to be used.

(3) Radioactive Contamination Potential. There is a high potential for contamination in any area of a laboratory where unsealed sources are used in experiments and studies.

(4) Radioactive Waste Generated Moderate to large volumes of solid radioactive waste can be expected. Small to moderate volumes of liquid radioactive waste will be generated.

(5) Potentially Contaminated Areas. Areas of potential contamination include the following:

(a) Laboratory areas (bench tops, fume hoods, glassware, hot cells).

(b) Animal cage areas.

(c) Solid radioactive waste handling and packaging area.

(d) Liquid radioactive waste system (tanks, pumps, valves, piping).

(e) Ventilation system (ducting, filters, filter housings).

b. Medical Facilities. Medical facilities perform a variety of diagnostic and therapeutic procedures using radioactive materials and radiation producing machines. For diagnostic procedures, radioactive material may be injected into a patient in liquid form or taken orally. Radiation producing machines such as X-ray units and Computer Aided Topography (CAT) scanners may be used. For therapeutic procedures, radioactive material may be injected into a patient in liquid form, taken orally, or implanted in solid form (and later removed). High radioactivity cobalt-60 units and linear accelerators (para C-4.e) are also used for radiation therapy.

(1) Types of Radiation Expected Beta and gamma radiation can be expected to be used.

(2) Types of Sources Present. Sealed, partially sealed, and unsealed sources can be expected to be used.

(3) Radioactive Contamination Potential. There is a high potential for contamination where unsealed sources are used for diagnosis or therapy. There is a low potential for contamination when sealed sources are implanted unless the sources are mishandled. There is no potential for contamination from properly utilized sealed sources, such as cobalt-60 units, or from low energy radiation producing machines such as X-ray units or accelerators operating below 10 MeV. Contamination potential is increased for units operating at higher energy levels.

(4) Radioactive Waste Generated Small to moderate volumes of solid radioactive waste can be expected. Small to moderate volumes of liquid radioactive waste will be generated.

(5) Potentially Contaminated Areas. Areas of potential contamination include the following:

(a) Laboratories where liquid sources are prepared for use.

(b) Operating rooms where sources are implanted.

(c) Rooms where patients who have been administered radioactive materials are located.

(d) Solid radioactive waste handling and packaging areas.

(e) Liquid radioactive waste system (tanks, pumps, valves, piping).

(f) Areas where liquid radioactive sources are stored prior to preparation for administration.

c. Fast Burst Research Reactors. A fast burst reactor is an air cooled assembly used to produce a quick burst of fast neutrons and gamma radiation. The radiation bursts are used to simulate nuclear weapons effects for the evaluation and testing of materials and systems.

(1) Types of Radiation Expected From the reactor, primarily gamma and neutron radiation is expected. Irradiation of the test items or reactor structure will cause neutron activation and result in beta and gamma radiation.

(2) Types of Sources Present. The reactor utilizes a sealed source of uranium fuel and fission products. Activated material or test items can be present and would be classified as partially sealed sources.

(3) Radioactive Contamination Potential. In general, the potential for contamination outside the containment structure due to spread of the reactor material is low unless the containment structure becomes damaged. Contamination potential becomes high if the fuel containment fails. The potential for neutron activation of test items or the structure surrounding a reactor is high.

(4) Radioactive Waste Generated No radioactive waste is expected at this type of facility.

(5) Potentially Contaminated Areas. Areas of potential contamination include the area housing the reactor and test items.

d. Pool Research Reactors. Pool reactors are atmospheric pressure, water cooled assemblies generally used to produce long-term or steady-state, low flux thermal neutron radiation. Some pool reactors can also produce high flux thermal neutron radiation for a very short period of time. The neutron radiation is made available for use outside the reactor by beam ports which penetrate the reactor structure. Items to be irradiated are placed in front of the beam ports. Activation of test items, cooling water impurities, and surrounding structures can occur.

(1) Types of Radiation Expected From the reactor, primarily gamma and neutron radiation are expected. Beta and gamma radiation are expected from activated items or activated impurities in the cooling water.

(2) Types of Sources Present. The reactor can be considered a sealed source because the uranium fuel and fission products are contained in cladding. The water and air in the area of the reactor core may become activated and can be considered an unsealed source. Neutron activated test items or reactor structures would be classified as partially sealed radioactive sources. Sealed and partially sealed sources will be present for instrument checks and calibrations.

(3) Radioactive Contamination Potential. There is a moderate potential for contamination in a pool reactor facility. The radioactive material in the cooling water, which results from neutron activation of impurities, is carried through the cooling system and deposits in pipes, valves, pumps, and other system components. Anytime these components are opened for maintenance or repair or if leaks occur, contamination is likely. The coolant radioactive material inventory will be increased if the fuel cladding leaks or is damaged in some manner, releasing fission products into the cooling water. The potential for neutron activation of test items or the structures surrounding a reactor is high.

(4) Radioactive Waste Generated Moderate volumes of solid and liquid radioactive wastes will be produced at this type of facility. In addition, radioactive gases may be present.

(5) Potentially Contaminated Areas. Areas of potential contamination include the following:

(a) Area housing the reactor.

(b) Areas housing reactor auxiliary system.

(c) Test items.

(d) Maintenance areas.

(e) Solid radioactive waste handling and packaging area.

(f) Liquid radioactive waste system (tanks, pumps, valves, piping).

(g) Ventilation system (ducting, filters, filter housings).

(h) Decontamination areas.

e. Power Reactors. The DOD no longer operates power reactors. There are no plans to construct any such facilities in the future. The user of this manual may have need to manage the decommissioning life cycle of an old existing DOD power reactor which has been shut down. For this reason, a limited discussion of radioactive source considerations is provided.

(1) Types of Radiation Expected From the reactor, primarily gamma and neutron radiation are expected. Irradiation of the reactor structures or impurities in the cooling water will result in beta and gamma radiation.

(2) Types of Sources Present. The reactor can be considered a sealed source because the uranium fuel and fission products are contained in cladding. Impurities in the primary system cooling water which become activated can be considered an unsealed source. Any radioactive material resulting from neutron activation of reactor structures would be classified as partially sealed sources. Sealed and unsealed sources will be present and used for instrument checks and calibrations. Radioactive gases may also be present.

(3) Radioactive Contamination Potential. The potential for contamination in a power reactor facility is high. The radioactive material in the primary system cooling water, which results from neutron activation of impurities, is carried through the primary system and deposits in pipes, valves, pumps, the steam generator, and in other primary system components. When these components are opened for maintenance or repair, or if leaks occur, contamination is likely. The primary system radioactive material inventory will be increased if the fuel cladding leaks or is damaged in some manner, releasing fission products into the primary cooling water. The potential for neutron activation of the structures surrounding a reactor is high.

(4) Radioactive Waste Generated Large volumes of solid and liquid radioactive wastes are produced at this type of facility. Radioactive gases may also be present.

(5) Potentially Contaminated Areas. Areas of potential contamination include the following

(a) Area housing the reactor.

(b) Area housing reactor auxiliary systems.

(c) Maintenance areas.

(d) Equipment decontamination areas.

(e) Personnel decontamination areas.

(f) Protective clothing laundry area.

(g) Respiratory protective equipment decontamination area.

(h) Solid radioactive waste handling and packaging area.

(i) Liquid radioactive waste system (tanks, pumps, valves, piping).

(j) Ventilation systems from radioactive gases (ducting, filters, filter housings).

f. Accelerator Facilities. Facilities may include the use of electron linear accelerators (linacs), which are radiation producing machines used for medical and industrial purposes. Other types of particle accelerators are used for physics and medical research. Electron linacs can emit a primary beam of electron radiation (similar to beta) or a secondary beam of X-radiation (X- rays, similar to gamma) for use in radiation therapy. The patient is positioned relative to the output beam port and the machine is energized for the time required to produce the amount of radiation desired for the therapy. Electron linacs are also used in industrial applications to produce X-rays used for the radiography of such items as welds, castings, and munitions. Electron linacs are used in research applications to determine the effects of irradiation on various materials under study. In addition, the electron beam can be used to directly expose the test item. Test items may be exposed to electrons or X-rays.

(1) Types of Radiation Expected At the time of decommissioning neutron activated materials may be present. Radioactive gases may also be present.

(2) Types of Sources Present. The neutron radiation may activate areas of the linac around the output beam port and the structure surrounding the linac. If this occurs, the radioactive material would be considered a sealed source.

(3) Radioactive Contamination Potential. The potential for neutron activation contamination exists, particularly for units operating above 10 MeV.

(4) Radioactive Waste Generated. No liquid or solid radioactive waste is expected unless the electron linac exceeds 10 MeV, in which case very small volumes of solid waste resulting from neutron activation may be produced. Small volumes of radioactive waste may be generated by other types of particle accelerators.

(5) Potentially Contaminated Areas. The surrounding structure and the area around the electron linac output beam port can be contaminated if the output energy is greater than 10 MeV. Special precautions may be necessary for nuclear reactions with low energy thresholds, such as Be-9 and H-2.

g. Radiography Facilities. The primary purpose of radiography facilities is to nondestructively test items for defects. For example, welds are radiographed to reveal any hidden porosity or cracks; castings are radiographed to reveal any hidden voids; aircraft structural components are radiographed to detect early signs of corrosion; and munitions are radiographed to check for proper assembly. Electromagnetic radiation penetrates a test item and exposes a sheet of film in the same manner that light exposes film to produce an image. Radiographic films are processed and checked for defects in the item radiographed. The electromagnetic radiation needed for radiography may be produced by a sealed source of radioactive material such as cobalt-60 or iridium- 192, by X-ray machines, or by electron linear accelerators (para C-4.f.). Sealed radioactive sources must be housed in shielded containers when not in use. The containers may be fixed or portable. X-ray machines require no shielding when not in use because radiation is produced only when a machine is electrically energized. Shielding may be required when a machine is energized. X-ray machines may be installed in a fixed configuration or may be portable.

(1) Types of Radiation Expected Gamma radiation is expected to be encountered during decommissioning from sealed sources. In addition, radiation from test items and structures which have been activated due to exposure to neutrons may be encountered.

(2) Types of Sources Present. Sealed radioactive material and partially sealed neutron activated material can be expected.

(3) Radioactive Contamination Potential. Contamination through spread of radioactive material is not expected for sealed sources unless the source is damaged in a manner which breaches the integrity of the material used to encapsulate the radioactive material, or if the sealed source leaks for any other reason. The potential for neutron activation of materials is present.

(4) Radioactive Waste Generated None is expected except through neutron activation

(5) Potentially Contaminated Areas. None is expected unless exposed to neutrons.

h. Radioluminous Device Storage Facilities. These facilities store new and used radioluminous devices such as clocks, aircraft instruments, and gun sights.

(1) Types of Radiation Expected The radioactive materials primarily used to provide luminosity are tritium, promethium-147, and radium-226. Tritium emits beta radiation only, promethium- 147 emits beta radiation only, and radium-226 emits alpha and gamma radiation. (There will also be beta radiation emitted by the decay products of radium-226 which are also radioactive).

(2) Types of Sources Present. Radioluminous devices are considered partially sealed sources because the radioactive material can usually be exposed easily in a device such as a clock or an instrument.

(3) Radioactive Contamination Potential. Devices containing tritium are subject to leakage so there is a potential for contamination.

(4) Radioactive Waste Generated Any item exposed to tritium contamination may have to be considered radioactive waste.

(5) Potentially Contaminated Areas. Areas can become contaminated from leaking devices. Special precautions are necessary for items exposed to tritium.

i. Depleted Uranium Test and Storage Facilities. Depleted uranium (DU) is used to manufacture various types of munitions and projectiles. These munitions are stored in various facilities and are used in test and practice firings.

(1) Types of Radiation Expected Alpha and gamma radiation can be expected.

(2) Types of Sources Present. The DU in the stored munitions is painted so these sources would be considered partially sealed. In test areas, after the munitions are detonated or projectiles fired into a target, the sources present would be unsealed. Fragments are launched and dust particles of DU are dispersed in the air and eventually settle on surfaces.

(3) Radioactive Contamination Potential. None while the munitions are in storage. After the munitions are fired, there will be contamination of target areas and target materials.

(4) Radioactive Waste Generated None from storage. The DU after firing must be collected and disposed of as waste.

(5) Potentially Contaminated Areas. Firing ranges and targets are areas of potential contamination.

BIBLIOGRAPHY

Government Publications

Department of Energy

DE82-014246 BNL 51444, Rev. 1, Sep. 1986	Nonreactor Nuclear Facilities: Standard and Criteria Guide (September 1981)
DOE/ET/741-1	Decontamination and Decommissioning (February 1982)
PNL-SA-7381	Impact of LWR Decontamination on Radwaste Systems
TREE-1250	Decontamination and Decommissioning Long Range Plan. Volume 1 (June 1978)
UNI-SA-117	Evaluation of Nuclear Facility Decommissioning Projects (September 1983)
UNI-SA-118	DOE Decontamination and Decommissioning Program Experiences (November 1983)
	U.S. Department of Energy Guidelines for Residual Radioactivity at Formerly Used Sites Remedial Action Program and Remote Surplus Facilities Management Program Sites (February 1985)
DOE/-88-02	Defense Decontamination and Decommissioning (D&D) Program Overview (Jun 1988)

Department of the Army

HNDSP-84-086-ED-PM	Criteria for Decommissioning Nuclear Facilities Phase I Final Report (August 1984)

Energy Research and Development Administration

ARH-CD-984	Survey of Decontamination and Decommissioning Techniques (May 1977)
PP-704-990-002	Decontamination and Disposition of Facilities Program Plan (January 1975)

Environmental Protection Agency

Federal Register, Vol. 48, No.3	Standards for Remedial Actions at Inactive Uranium Processing Sites (January 5,1983)
Federal Register, Vol 48, No. 196	Environmental Standards for Uranium and Thorium Mill Tailings at Licensed Commercial Processing Sites (October 7, 1983)
PB 83-178343	Characterization of Contaminated Nuclear Sites, Facilities and Materials: Accelerations (February 1983)

National Committee on Radiation Protection and Measurements

NCRP No.38	Protection Against Neutron Radiation (1971)
NCRP No.39	Basic Radiation Protection Criteria
NCRP No.49	Structural Shielding Design and Evaluation for Medical Use of X-rays Gamma-rays of Energies Up to MeV (1976)
NCRP No.51	Radiation Protection Design Guidelines for 0.1-100 MeV Particle Accelerator Facilities (1977)
NCRP No.79	Neutron Contamination from Medical Electron Accelerators (1984)

Nuclear Regulatory Commission

Generic Letter 81-38	Radiological Safety/Guidance for On-site Contingency Storage Capacity
N11-25-002	Task 1 Report: Identification/Development of Techniques to Facilitate the Decommissioning of Light Water Reactors (January 1984)
NUREG/CR-0130, Vol. 1 & 2	Technology, Safety and Costs of Decommissioning a Reference Pressurized Water Reactor Power Station (June 1978 Addenda August 1979, September 1984, July 1988)
NUREG/CR-0569	Facilitation of Decommissioning Light Water Reactors (December 1979)

NUREG-0810	Design Guidance for Temporary On-site Appendix 11..4-A Storage of Low Level Radioactive Waste (July 1981)
NUREG/CR- 1754	Technology, Safety and Costs of Decommissioning Reference Non-Fuel-Cycle Nuclear Facilities (February 1981, and Addendum 1, October 1989)
NUREG-1307	Report on Waste Burial Changes (October 1989)
NUREG-0586	Generic Environmental Impact Statement on Decommissioning Nuclear Facilities (August 1988)
Policy Statement	Below Regulatory Concern (June 1990)
NUREG/CR-1756, Vols. 1 & 2	Technology, Safety and Costs of Decommissioning Reference Nuclear Research and Test Reactors (March 1982 Addendum July 1983)
NUREG/CR-1915	Decontamination Processes for Restorative (PNL-3706) Operations and as a Precursor to Decommissioning: A Literature Review (May 1981)
NUREG/CR-2241	Technology and Cost of Termination Surveys ORNL/ HASRD-121 Associated with Decommissioning of Nuclear Facilities (February 1982)
NUREG/CR-2884	Decontamination as a Precursor to (PNL-4343) Decommissioning (May 1983)
NUREG/CR-3587	Identification and Evaluation of Facilitation Techniques for Decommissioning Light Water Reactors (June 1986)
NUREG/CR-5512	Residual Radioactive Decontamination from Decommissioning (January 1990)
SECY-81-383	Storage of Low-Level Radioactive Wastes at Power Reactor Sites (June 1981)
Pages 11 and 12	Inside N.R.C. Article Titled “Fear of Improper Dose of Plant Parts Influences Decommissioning Strategy” (November 12, 1984)

Oak Ridge National Laboratory

CONF-800416-4ORNL	Decontamination and Decommissioning Program, by J. P. Bell (April 1980)
ORNL/TM9638	Nuclear Reactor Decommissioning: An Analysis of the Regulatory Requirements

Nongovernment Publications

American Institute of Chemical Engineers

ANSI N300-1975 — American National Standard Design Criteria for Decommissioning of Nuclear Fuel Reprocessing Plants (1976)

ANSI N512 — Protective Coatings (Paints) for the Nuclear Industry

American Society of Mechanical Engineers (ASME)

82-NE-22 — Engineering and Planning for Decommissioning of Nuclear Power Plants, by G. M. Gans, Jr.

Battelle Pacific Northwest Laboratories

BNWL-B-90 — Equipment Decontamination with Special Attention to Solid Waste Treatment: Survey Report by J. A. Ayres (June 1971)

Commission of the European Communities

PB82-254467 — The Communities Research and Development Programme on Decommissioning of Nuclear Power Plants (1981)

Decommissioning of Nuclear Power Plants, Edited by K. H. Schaller and B. Huber (1984)

EG&G Idaho. Inc.

EGG-M-15983 — Low-Level Waste Volumes from Decommissioning of Commercial Nuclear Power Plants, by J. B. Clark and B. J. Sneed

Idaho National Engineering Laboratory

Decontamination and Decommissioning of the MTR-603 HB-2 Cubide

Electric Power Research Institute

EPRI NP-2866 — An Assessment of Chemical Processes for the Post-accident Decontamination of Reactor Coolant Systems (February 1983)

EPRI NP-3508 — Laboratory Evaluations of Mechanical Decontamination and Descaling Techniques (July 1984)

EPRI Journal — Decommissioning Nuclear Power Plants (July/August 1985)

International Atomic Energy Agency

IAEA Report 23 — Radiation Protection Standards for Radioluminous Timepieces

IAEA Report 30	Manual on Safety Aspects of the Design and Equipment of Hot Laboratories
IAEA Report 42	Radiological Safety Aspects of the Operation of Neutron Generators
LAEA Report 52	Factors Relevant to the Decommissioning of Land-Based Nuclear Reactor Plants
IAEA Report 188	Radiological Safety Aspect of the Operation of Electron Linear Accelerators

Institution of Mechanical Engineers

Decommissioning of Radioactive Facilities (Papers Presented at a Seminar Organized by the Nuclear Energy Committee of the Power Industries Division of the Institution of Mechanical Engineers) (November 1984)

Department of Health, Education, and Welfare

Public Health Service	Radiological Health Handbook, January 1970

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

Osterhout, M. M., Decontamination and Decommissioning of Nuclear Facilities, 1980

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