Safety-Related
Innovative Nuclear Reactor Technology Elements

– R&D Network –

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TOPICAL REPORT

WORK PACKAGE 4
REDUCTION OF WASTE/EXPOSURES
BY NEW REACTORS

TASK 4.4
REDUCTION OF PERSONNEL EXPOSURES

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http://www-is.ike.uni-stuttgart.de/sinter/

1. Introduction

In this report the personnel exposure to radiation's is discussed. No reference is made to exposure to chemically toxic material instead.

Reduction of personnel exposure can be achieved by improvements at the design phase level and through technical as well as software developments for the management of risk associated operations.

All those aspects are addressed in the present report.

- Operational dosimetry.
- Dose rate reduction (Action on the source term, shielding etc).
- Duration (computerized data base of the plant, 3D models, training on models etc)
- Distance (tele-operation, robotics etc)
- ALARA studies (3D modeling, tele-operated radiological characterization, virtual reality etc).

Most of these aspects are discussed both for normal operations, and for incident and accidents, as well as, of course, for maintenance activities.

2. Requirements for innovation

The operational experience has shown in the last year that very important improvements are possible in reducing the occupational doses, both at the individual level as for the collective doses.

Problems associated with the management of some accidents, which occurred in current plants, has shown that additional attention shall be given to individual doses in case of accidents, in order also to demonstrate the practical feasibility of the actions planned in the procedures or assumed in the PSA.

Requirements derive also from the consideration of the recent standards produced by the ICRP and by other international organization such as the SG115 by IAEA and the EU directives.

3. Utility requirements

The EUR places a requirement to optimize maintenance and reduce the need for surveillance, thereby minimizing the exposure of plant personnel to radioactivity during plant life.

Structures, systems and components which perform level EUR F1 and F2 Safety Functions shall be designed for adequate reliability but they should also be designed to be calibrated, tested, maintained, repaired and inspected or monitored with respect to their functional capability throughout the life of the plant. The design shall be such that these activities can be without undue exposure of the site personnel to radiation.

If the structures, systems and components important to safety cannot be designed to be tested, inspected or monitored to the extent desirable to reduce personnel exposure then~~the ,~~ adequate safety precautions should be taken to compensate for potential undiscovered failures.

The design of the plant and systems should be such that the frequency of testing necessary to meet the required reliability should not be excessive in order to limit the number of demands on systems and to reduce personnel exposure. There should be provisions for re-qualification of equipment after maintenance or testing. The design should allow any necessary testing of equipment with the system on-line, with minimum chance of adversely affecting safety due to the use of complex procedures or of bypasses (jumpers). The possibility of repair of equipment in post-accident conditions should be taken into account where such repairs would give a significant benefit in meeting the probabilistic objectives.

Suitable provisions shall be made in the design and layout of the plant to minimize exposure and contamination from all sources of radioactivity. Such provisions shall include adequate design of systems and components with respect to low radiation exposure during maintenance and inspection, shielding from direct radiation, reduction of corrosion-product activation by specification of appropriate materials, means of monitoring, control of access to the plant, minimization of the time to be spent in contaminated and active areas, and suitable decontamination facilities.

The plant arrangements shall provide for control of access into radiation and contamination areas and should also minimise contamination resulting from the movement of radioactive materials and personnel within the plant. The plant arrangements should provide for efficient operation, inspection, maintenance, and replacement as necessary to minimise radiation exposure. The Designer shall provide a dose assessment which includes doses arising during maintenance.

Attention shall also be given to the actions that operators may be asked to perform during and after an accident condition or a DEC. Equipment accessibility and proper evaluation of radiation dose rate where the presence of the operator is required, shall be carried out. In order to claim main coolant-line Break Preclusion, the Designer shall specify the provisions to be implemented for these lines at an early stage of the design, notably concerning the monitoring of primary leaks and the in-service inspection of the lines. The accessibility and inspectability of each point of these lines shall be pre-requisites.

In recognition of the conflicting requirements that may come from designing for e.g. system performance and cost and the ISI, the following generally-accepted principles shall be implemented:

- design, material selection and manufacturing process shall allow inspectability of all parts. Exceptions are acceptable if there is a conflict with the other principles,
- the design and the arrangement of the main coolant lines and surrounding equipment (insulation, concrete, other metallic structures) shall allow access to all parts (from outside) either for ultrasonic testing or radiographic examination with a goal to minimise personnel radiation exposure,
- special provisions for easy inspection shall be made at the locations where ISI is most likely to be requested.

When designing filtering equipment to be used in radioactive service, the Plant Designer shall assess the merits of each filter compared with other possible techniques. Access to filtering equipment used in radioactive service shall be designed for ease of disassembly and assembly, and ready access for removal, maintenance, and replacement of internals. In particular, removable parts such as filter cartridges and seals shall be designed such that they can be easily replaced and evacuated without excessive exposure of personnel to radiation.

Process vessels which operate under pressure shall be designed to facilitate regulatory periodic Inspections.

Provisions for use of remote or semi-remote tools shall be provided, as required, for vessel and internals maintenance.

The Process radiation monitoring system shall be such to forewarning of any risk of personnel exposure. Exposure rate shall be measured in the reactor building, at the surface of the Reactor Cavity and of the spent fuel pit so as to detect lack of biological protection. Associated alarms shall be provided for personnel evacuation and for confinement of radioactive gases with automatic actions. In the reactor building, these monitors should only be used during plant shutdown modes. A radiological protection channel shall be provided at the air intake of the MCR to measure beta activity and, if needed, to start-up the iodine filtering system.

The Containment System shall be designed to limit, in all plant conditions, the exposure of on-site personnel and population to radiation generated in the primary circuit and associated systems. This function is accomplished mainly by concrete structures inside the Primary Containment and the containment concrete wall (if applicable). The design shall take into account the accessibility criteria and the zoning criteria.

The containment structure shall assure also that, in all plant conditions, including DEC, skyshine radiation is maintained below values compatible with personnel activities. Appropriate shielding is only one condition to assure containment accessibility. The HVAC system also has an important role.

Active or potentially active pipework should be located in areas where there is no normal personnel access. Where this is not practicable, it shall be shielded and separated from non-active pipework in order to reduce operational exposure of plant personnel. The routing of high energy pipework through areas containing safety equipment shall be avoided.

The arrangement of HVAC plant and ductwork shall take into account safety train separation, Fire Areas and zones, and logical grouping of components within a system. The layout of equipment shall also be arranged such that there is separation of the non-active and potentially active components, wherever practical. HVAC air flows should be arranged such that the flow is from "clean" to "dirty" areas.

For minimization of personnel exposure, controlled and supervised areas should be appropriately delimited. A controlled area is an area in which normal working conditions, including the possible occurrence of minor mishaps, require the workers to follow well established procedures and practices aimed specifically at controlling radiation exposures. The boundaries of these areas shall be protected against unauthorised entry , and all personnel access and minor equipment access shall be via one access control area which is permanently controlled either by card access or a guardian.
All personnel entering will be issued with film badges and monitored for radiation exposure. A supervised area is defined as an area where the individual occupational exposures can be

assessed from a review of the ambient conditions which are homogeneous. Specific provisions such as those applied to a controlled area are not normally needed.

The Designer shall design the equipment and its layout such that the radiation exposure of personnel from potentially active items of plant is minimized. Protection against radiation shall be provided by implementing measures to mitigate actual or anticipated exposure conditions.

Methods of achieving this include consideration of operation and maintenance requirements, e.g. remote operation and Redundancy, together with the use of shielding, to reduce the dose rates to personnel working in the neighborhood of equipment. Shielding shall conform to the ALARA principle. Provisions shall include the following :

- radioactive equipment such as tanks, heat exchangers, and filters, shall be located in shielded compartments, provided with local shielding, or located to reduce dose rate by distance to meet the radiation zones specified. Pumps and valves should be located in a separate room from the tank they serve,
- redundant radioactive equipment requiring maintenance, whether safety or not, shall be located in separate shielded compartments,
- pump head and flow indicators shall be located near the room entrance and their controls and motor control centers shall be located in low radiation areas,
- the operating stations for manual valves, valve actuators, local controls, remotely operated valves or components, and instrumentation panels, shall be located outside the shielding where access to the compartment is not permitted during system operation, due to high radiation levels. Access to necessary operating stations shall also remain possible following accident situations addressed in the design,
- removable local shielding shall be provided (and used as required) on equipment which has the potential of exceeding the radiation zone designation. Lead brick walls shall not be used addressed in the design. Removable local shielding should only be utilized in exceptional circumstances. Where it is necessary, facilities for its removal shall be provided.
- shielding between equipment inside compartments shall be provided if studies show that the qualification radiation dose (dose level for which a particular equipment has been qualified) would be exceeded,
- an alternative to shield walls should be evaluated during the plant layout design phase. Design alternatives include relocation of equipment, local higher density shielding on equipment, shielding by other non-radioactive equipment, etc.,
- space, support points, and handling facilities shall be provided for temporary
- shielding where it is part of the expected maintenance program,
- where it is necessary that a radioactive pipe crosses over a normally accessible space, a shielded chase shall be provided,
- the Designer shall separate highly radioactive components from low or non-radioactive components by shielding or distance, or arrange to reduce personnel exposures during operation, testing and maintenance activities,
- building arrangements shall make maximum use of common shielding walls and floors, and wherever practical shield walls should be integrated with the building structure,
- access labyrinths should be preferred to shielded doors, except where doors or physical Barriers are required to prevent unnecessary access to high-radiation areas,
- escape routes shall be provided with emergency lighting and floruescent signals.

Means shall be provided to minimise or eliminate the need for plant personnel to enter areas greater than 1 mSv/h for routine operation such as reading of gauges or adjustment of valves, or for routine maintenance, e.g. more than 6 times per year. The following design methods shall be considered to minimise radiation levels where operation and maintenance personnel are required to carry out their functions :

- provide remote viewing devices for routine visual surveillance,
- locate valve actuators in a low radiation zone,
- locate instrumentation indicators, solenoid valves, control panels, and electro-pneumatic converters in a lower radiation zone,
- for sensing elements in high radiation areas, locate transmitter readouts in a low radiation zone,
- locate instrument isolation valves just beyond the penetration on the low radiation side of a shield wall to allow maintenance during plant operation,
- instruments and their isolation valve should be located so that they are accessible for use, calibration, and repair without disassembly or removal of piping, grating or other structures,
- design instrumentation for long service life and low frequency of maintenance and calibration,
- provide features which permit periodic calibrations of radiation monitors in high radiation rooms from adjacent low level areas,
- locate penetrations for piping, HVAC ducts, etc., through shield walls above personnel head height e.g. 2,0-2,2 m to minimize personnel exposure by streaming effects. Penetrations shall not be located in line of sight between radiation sources and occupied areas,
- valves shall be located to enable maintenance on the valves without significant radiation exposure,
- piping layout should minimize the existence of highly radioactive pass-through piping (for example, the header pipe of the branch pipe to the equipment within the cubicle being serviced) which could cause high radiation levels even when the cubicle equipment has been flushed,
- reach rod shafts and associated valves shall be such that the drive shaft does not block or cross access ways or corridors that are necessary for maintenance of equipment.

The Plant Designer shall evaluate the areas where transient high radiation could be experienced (i.e. adjacent to fuel transfer tubes and, at reactor cavity sumps) and design to minimise the potential for large radiation doses (greater than 1mSv/h) from such transient sources.

The Plant Designer shall identify areas where, under Design Basis Category 1 and 2 Conditions personnel could receive a radiation dose of 0,1 Sv or more in one hour. The need for personnel to access these areas shall be avoided by design, or when elimination by design is not possible, physical Barriers shall be provided to prevent unauthorized access.

Access to rooms shall be of height and width sufficient for easy walk-in from a service corridor, and for transport of necessary maintenance parts and tools, with protective clothing.

All staff including Subcontractors, must enter and leave the controlled area at one point which shall be at the entry/exit of the main change room. Entry should be controlled by dosemeter operated turnstiles and exit by monitor operated turnstiles. A guardian operated gate (for trolleys) shall also be provided. A second access point may be accepted for certain

circumstances (e.g. maintenance). Within the controlled area, the extent of contamination controlled areas is reduced
ALARA and each contamination area shall be separated from adjacent contamination areas of different levels by the provision of a sub-change room at the point of personnel entry/exit. These sub-change rooms shall define the boundary of each contamination area.

Access to the controlled area for fuel transport flasks, large items of plant, waste drums etc. shall be via an "airlock" type plant handover arrangement which ensures that a contamination controlled area is never directly open to areas where access is uncontrolled.

The access control and main change area shall include entry turnstiles, exit monitors and turnstiles, accommodation for the access guardian, and clothing storage and locker/shower rooms for male and female staff and Subcontractors.

The layout shall provide space for offices and facilities for supervisory and health physics staff as required by the Owner.

As a design target, main corridors should be uncontaminated and with low dose rates. Where this is impractical the length of personnel routes through radiation and contamination areas shall be minimised to reduce the time spent in transit through such areas. Bulk civil quantities shall not be reduced if this results in a significant increase in operator radiation exposure. The design shall ensure that working times on active components will not be increased by inaccessibility.

Of outmost importance is avoiding the use of stellite or cobalt in components in which fluid flows that will eventually pass through the core.

To control both the radiation dose incurred by site personnel working in the controlled area, and the spread of contamination, the layout of the controlled area shall be such that personnel should not pass through areas of high radiation to gain access to an area of lower contamination. This design requirement is achieved by identifying at the design stage the access requirements and sources of radiation and contamination that will arise in the installation once it is in operation.

It should not be necessary to cross radiation/contamination controlled areas for the maintenance of equipment in non-controlled areas.

The Designer shall consider the requirement for escape routes. As a basic principle, there should be no emergency exits from non-controlled areas to controlled areas. Where necessary, emergency exits are permitted across control boundaries to corridors of the controlled area.

Pipework between connecting equipment shall be routed using the following guidelines :

1) Pipelength and number of fittings shall be kept to a minimum with due consideration given to piping flexibility.
2) The number of high and low points in piping runs shall be kept to the absolute minimum. High points in pump suction lines should be avoided.
3) Permanent or temporary access shall be provided for maintenance, and periodic inspection.
4) Consideration shall be given to the separation of clean and radioactive piping. Pipework carrying radioactive fluids should, as far as possible, only be routed through controlled areas, and should be of minimised length.

5) High and moderate energy piping shall be separated from safety classified components, where required by the safety case.
6) Redundant safety divisions should be protected adequately to meet pipe break hazards. Within each division the equipment shall be arranged to minimise the consequence of such pipe breaks.
7) Pipework shall be arranged such that adequate space exists for vents and drains where required.
8) Grating platforms shall be located at the optimum levels for access to valves, and to enable ISI and maintenance activities to be carried out. Pipe insulation parts shall be quick-disconnect and of small size and weight to be handled by a single person.
9) The use of flanged connections shall be restricted to those components which require regular maintenance, such as pumps. Flange connections should preferably not be located above walkways and equipment, where leakage could hinder man access.
10) Piping shall be laid out in such a manner that it shall not impede access for operation or maintenance of other major plant **system**.
11) Pulled bends shall be used in preference to elbows wherever practical.
12) Pipes carrying radioactive fluid shall be routed in pipe chases reserved for this purpose or behind structures or away from normal access areas to minimise personnel exposure during normal operation and maintenance, wherever practical.
13) Special attention shall be given to avoid high radiation crud traps (collection and build-up points) in the equipment and piping arrangements. For spent resin and radioactive slurries, pipes shall be continuously sloped, with backflushing to the tanks.
14) The location of flow restrictors shall accommodate any requirements for straight pipe lengths needed for proper operation.
15) Local sampling points shall not be permitted in radioactive or potentially radioactive systems. Samples shall be routed to sampling stations.
16) Seismic piping shall not be rated directly below non-seismic piping, and should, where possible, be routed separately.

The following design rules should be used to minimise build-up of crud :

- instrument tapping points to be taken off slightly below the parent pipeline midplane to avoid crud traps and gas entrapment,
- flow paths to be as free as possible from abrupt changes in direction,
- the origin of branch process lines having little or no flow during normal operation to be taken off above the horizontal midplane of the parent process pipe,
- thermal expansion loops to be raised instead of depressed, wherever practicable,
- sloping piping to be provided with low point drain and flush connections.

Internal surfaces of liquid flow paths should be smooth and as free from abrupt discontinuities in cross-section as practicable.

The plant design shall include human factors considerations that assure adequate space, illumination, noise levels, and environment control. Adequate illumination shall be provided in all areas of the plant. Experience has shown that illumination is generally inadequate for the work areas of concern often necessitating extra time consuming measures to provide enough light and avoid undue handicaps to personnel. The design of the plant shall consider reduction and attenuation of noise sources to decrease exposure to operation and maintenance personnel. Personnel shall be provided with acoustical environments which will not cause personnel injury, interfere with voice or other communications, cause fatigue or degrade overall system effectiveness.

All ventilation and environmental control systems required for normal operation conditions shall be available continuously. This may be achieved through equipment redundancy, and appropriate combination of design margin and recommended intervals of components replacement.

All areas in the plant shall be provided with a suitable environment ensuring the safety and comfort of plant personnel and operability of plant equipment during normal operation conditions, and for some areas, as requested, in incident and accident conditions.

In radiation areas where activities will be performed, temperature and humidity shall be maintained at a level required for worker efficiency and eliminate as much as possible the potential for difficult working conditions. Experience at operating plants has shown that worker efficiency suffers considerably in high temperature and humidity environments, resulting in corresponding increases in radiation exposure.

The design shall be such as to simplify and reduce the amount and difficulty of the maintenance required over the lifetime of the plant.

The plant design shall optimise maintainability by including human factors considerations and providing adequate space, illumination, platforms, lifting equipment, handling gear, shielding, communications, HVAC, and services supply.

Features to facilitate critical maintenance activities shall be provided.

The Designer shall define and propose training tools such as mock-ups, and CAD, for critical equipment to facilitate training, minimise the potential for maintenance errors, and reduce personnel exposure to high radiation.

Consideration shall be given to facilitate maintenance of equipment in-situ or easy exchange of components. Similarly, where modular construction techniques are used, consideration shall be given to maintenance of all components in-situ or easy exchange of the complete module. In high radiation areas, the plant layout should consider the use of robotics.

The accessibility (orientation and surrounding space) of the equipment shall be in a way that facilitates maintenance operations, particularly for critical components or those expected to be replaced on a regular basis.

The specific support systems required for the critical maintenance activities shall be determined and provided for in the design.

The plant design shall include provisions for handling and processing personnel to control contamination and radiation exposure, including the following :

- only one controlled area within the plant, although this may be segregated into zones, and in normal operation one unique access to this controlled area,
- facilities for storage and issue of protective clothing that do not interfere with the flow of personnel traffic (some plants have had to add "satellite facilities" because the design only provided one centralized facility. Such facilities shall be located near major buildings or work area as opposed to a centralised facility),
- facilities for storage, issue, and processing of respiratory equipment,

- protected areas for assignment and processing of dosimetry equipment,
- storage areas/facilities for contaminated equipment that is frequently used for operations and maintenance,
- buffer zones located near work areas subject to contamination, with at least one change room located at the entrance to the controlled area. These change rooms shall accommodate both males and females and shall include sanitary facilities. The necessary number of lockers specified by the Operator shall be provided within the plant. Buffer zones shall not be located in close proximity to radiation sources.

Some existing plants are experiencing large values of occupational exposure and there is great variation between plants.
These exposures result from :
- non-routine maintenance on components not originally designed for replacement,
- large increases in radiation fields,
- lack of features for easy maintenance.

Changes from the designs of current plants will result in the elimination of these non-routine maintenance items. Based upon existing radiation fields and the need for routine maintenance, the actual exposure at current plants should run from 1,5 to 6 man-Sv/an. Reduction in radiation fields through improved chemistry control and materials selection will further reduce the exposure. Reductions in occupational exposure will reduce costs and enhance investment protection. Based upon today's experience, the requirement of 0,7 man-Sv/(GW an) could be met through better design, robotics, and reduced radiation fields. It is essential to minimise radiation levels.

In the following requirements are listed that concern the reduction of personnel exposure in connection with the dismantling operations.

The main technical features for easy and economical dismantling are, in general, the same as those for achieving easy maintenance. The following features are especially relevant:

1) easy isolation of systems,
2) systems designed with minimum interdependences,
3) easy disassembly allowing heavy component replacement,
4) choice of materials, so as to reduce hazards resulting from dose rate in material vicinity. For instance, the activity of the structural material of the vessel pit should be minimised using one or several of the following means: reduction of the fast neutron fluence out of the vessel, addition of neutron absorbers or moderators in the concrete, limitation of the composition of the elements, the activity from which may be hazardous for Decommissioning, particularly when dealing with concrete and rebar.
5) achievement of good surface condition for potentially contaminated metallic components, thus facilitating subsequent possible decontamination :
   a) to minimise the amount of waste to be stored,
   b) to allow good handling.
6) ready accessibility and easy removal of components and internals in order :
   a) to minimise the radiation exposure to the personnel,
   b) to reduce the required number of personnel for Decommissioning* work.

URD

The ALWR will be designed for ease of maintenance to reduce operations and maintenance costs, reduce occupational exposure, and to facilitate repair and replacement of equipment.

Metallic materials in contact with reactor coolant shall be corrosion resistant, such as austenitic stainless steel, or carbon and low alloy steels with an adequate consideration for corrosion; resistant to detrimental forms of corrosion such as intergranular attack, stress corrosion cracking, and/or contact corrosion between different materials; and restricted in cobalt content to as low a level as practical with target of 0.02 w/o or less for all stainless steel or nickel base alloy components. Cobalt for components fabricated with stainless steel or nickel base alloy with a large wetted surface area (major piping, clad, etc.) and with operating temperature above 200°F shall be restricted to a maximum content of 0.050 w/o. In addition, components made of stainless steel or NI-base alloy located in, or near, the core where neutron flux is high enough to cause activation of CO to CO in significant amounts, or for components that are expected to release significant quantities of corrosion products in the reactor coolant stream, and for components that are expected to be a significant source of radiation exposure to plant maintenance personnel cobalt content targets (mean values) lower than 0.05 w/o shall be specified by the Plant Designer.

Cobalt-base hardfacing alloys to provide wear resistance shall only be used in those application where no proven alternative exists. Hardfacing alloys to provide wear resistance shall only be used in accordance with the principles of EPRI NP-6737, Cobalt Reduction Guidelines Revision 1. The plant designer shall identify to the plant owner all applications of cobalt-base alloys and provide technical justification for their selection.

The design of the plant shall consider both reduction and attenuating of noise sources to reduce exposure to operation and maintenance personnel. Personnel shall be provided with acoustical environments which will not cause personnel injury, interfere with voice or other communications, cause fatigue or degrade overall system effectiveness. Noise is a major contributor to operator fatigue and ineffectiveness. Plant design decisions such as equipment design and location, arrangement and design of compartments, and interior finishes all can contribute to an unacceptable sound environment.

The ALWR plant design shall enhance maintainability by including human factors considerations and providing adequate space, illumination, platforms, lifting equipment, handling gear, shielding, communications, HVAC, and compressed air supply.

Experience with maintenance problems at existing nuclear plants indicates plant designs provide easy and adequate access for maintenance and inspection requirements will require less time for necessary inspection and repair activities. Factoring access requirements into the ALWR plant design and layout enhances maintainability by promoting high performance, minimizes errors by maintenance personnel, and helps ensure maximum system and component availability and performance. Specific maintenance activities have been the source of major problems in most of the existing nuclear plants because of inadequate design consideration for the maintenance of the particular equipment. This requirement simplifies maintenance activities and promotes plant availability and performance.

Equipment modules shall be used in a way that modules may be removed for maintenance and intercharged. In areas expected to experience high radiation, plant layout shall consider the use if robotics.

The Plant Designer shall provide features to facilitate critical maintenance activities. The plant Designer shall consider providing mockups of critical equipment to facilitate training, minimize the potential for maintenance errors, and reduce personnel exposure to high radiation.

The Plant designer shall select filters from types which: a) Meet the process needs of adequate solids removal and b) Have sufficient capacity for the expected solids loading. For filters of the backwashable type, the designer shall choose those that require minimal time and effort to keep in service, keep personnel radiation exposure ALARA and are economical, considering operational maintenance and solid waste production characteristics. For crossflow filters, the filter shall be automatically backwashable by remote means producing as small a volume of backwash as possible. Air scrubbing shall be provided as part of the backwash operation for hollow fiber filters. The filter shall be designed for element replacement after a final backwashing. The radiation exposure to personnel shall be as low as reasonably achievable by providing quickly replaceable filter elements or remote means of replacing filter elements, or both. The hollow fibers shall be sufficiently radiation resistant that they will retain their filtering function after receiving 10Roentgens of beta-gamma radiation. The hollow fiber filter shall retain its filtering function after operation at 140°F for short periods (of about one day).

The substitution of a leakage control system that directs MSIV leakage to the main condenser in place of current leakage control systems results in a significantly reduced radiation exposure to operating personnel because of reduced maintenance requirements.

Appendix J to 10CFR50 requires that Type C containment leakage rate tests be performed during each reactor shutdown for refueling but, in no case, at intervals greater than two years. This testing interval of two years was established at a time when the traditional refueling interval was 12 months. Accordingly, some time margin was provided between refueling and Type C testing. Section 6.3.2.3 of chapter 5 requires a test interval of 30 months. The ALWR will have an expanded refueling interval of up to 24 months. This is kayed to the fundamental ALWR objective of being economically attractive in comparison to competing power generation options. The improved availability resulting from the longer refueling cycle supports this objective. An additional benefit is reduced personnel radiation exposure, i.e., about 30 man-rem per year (based upon extending the refueling cycle from 12 to 24 months).

The arrangement of sensing instrumentation and impulse lines shall assure that the sensor (transmitter) is located in a low radiation and accessible to minimize personnel radiation exposure during calibration and/or maintenance operations. Isolation valves for each pressure sensor (transmitter)shall be located outside high radiation areas to allow double isolation of the pressure transmitter without entering a high radiation area.

The reactor coolant equipment system arrangement shall facilitate the utilization of robot technology for inspection and maintenance operations to reduce the radiation exposure of plant inspection and maintenance personnel.

The design and arrangement of pressurizer heater sleeves shall permit replacement of heater sleeves without excessive exposure of personnel to radiation. The preferred method of heater sleeve arrangement is by use of horizontal replaceable heater bundles which are attached by bolting to reinforced access openings in the pressurizer shell. Alternatively, the designer may choose a different method of heater sleeve arrangement , such as bottom mounted individual heater sleeves, which can be replaced individually. The choice of any method other than the preferred method shall be justified by the designer

Filters shall be designed for rapid replacement of filter media utilizing remote handling techniques and equipment , thereby reducing personnel exposure consistent with the annual man-rem exposure limits.

Provision shall be made for diluting liquid and gas samples for subsequent radiological analysis. Dilution shall be performed either at the sampling station or in the laboratory, whichever leads to the simpler dilution equipment and lower radiation exposures to personnel . Collection and dilution of the post-accident sample shall be performed remotely. Dilution capability is required to reduce the radioactivity concentration and therefore the radiation exposure to operators. Remote collection will minimize personnel exposure in accordance with ALARA practices.

The general requirements for maintenance concerning provisions for access and minimizing personnel exposure which are applicable to the process sampling system must be met.

Operating panel filter/demineralizer resin makeup/replacement areas and sampling stations shall be always accessible and shall be located in a low radiation area to minimize personnel exposure.

Head flange seals and in-core instrumentation dry tubes (BWR) shall be replaceable. The arrangement and design of seal servicing and in-core instrument tube facilities shall be such that maintenance burden and personnel radiation exposure are consistent with the availability , reliability , and personnel exposure requirements. Industry experience has shown that head seals must be replaced each time the vessel head is lifted to ensure proper performance.

A means shall be provided to remotely perform RPV stud tensioning and removal, and stud hole covering. The Plant Designer shall develop a well engineered system for RPV head removal and installation. The system design shall strike a balance among ALWR design objectives of simplicity , reliability , low personnel exposure to radiation, plant availability and cost. Power-assisted and remotely -controlled equipment shall be employed. This requirements reduces radiation exposure for a routine refueling task and is expected to result in a benefit in reactor disassembly time. A savings of several days of critical path time for each outage can result based on experience with equipment of this type in use overseas.

The reactor systems design shall minimize the operations and time necessary for removal of the RPV head and related components. Any required disconnects shall be of a reliable, quick-disconnect type. Design features for minimizing head removal burden shall be evaluated for consistency with requirements on availability , reliability, personnel exposure , maintainability and cost.

The CRD system pressure boundary shall be designed for a service life of 60 years. Non-pressure boundary parts which may have a service lifetime less than 60 years shall be maintainable and replaceable consistent with requirements for plant availability, maintainability and personnel radiation exposure.

Testing provisions shall minimize the time required to accomplish the tests and the associated degree of exposure to radiation of plant personnel. Test provisions for each isolation valve shall be engineered to ensure that all permanent and temporary equipment required to perform the testing is provided and that the arrangement for accomplishing testing is suitable. The design for test capability shall ensure that:

- Means are provided to drain or vent pipe sections as required for testing. Any associated isolation valves must also meet the low leakage requirements.
- Manually operated test valve are appropriately located in the vicinity of isolation valves to permit single isolation valve testing and to reduce test volume.
- Sufficient access is available for personnel and any required test equipment, including space to perform the actual test.
- Maintenance valves and test connections are installed where necessary to facilitate testing of the isolation valves in the proper direction of anticipated leakage flow.
- Physical arrangement of all valves to be tested and the installation and access space required for testing promotes ease of testing, e.g., all valves should be located so they are accessible from platforms or the floor.

Sometimes, appropriate attention has not been paid to testing provisions during the design process, which has resulted in great difficulties in performing the required tests. It is not intended that all equipment required to accomplish testing be permanently installed in the plant, i.e. portable test equipment is acceptable. However, such equipment should be pre-engineered to ensure that testing is facilitated.

As an accident mitigation measure, the Plant Designer shall evaluate identified leakage paths (with appropriate allowance for unidentified leakage) and capability to meet the performance requirements. The evaluation shall be used to rationally establish allowable leakage rates and details of the systems designs, including size and type of fission product processing to be provided (i.e.,HEPA filters) and HVAC requirements. The analyses should include appropriate radiation source terms, timing of fission product release, behavior of fission products in the release path (e.g.,holdup, plateout, scrubbing, etc.), decontamination provided by processing equipment, release point,etc.

The Plant Designer shall make a study of planned maintenance task manning and time, and expected radiation levels at the work areas to confirm that the target radiation exposure in Chapter 1 is expected to be met. The study shall establish that no cost-effective reduction in personnel exposure can be made by increased shielding or additional equipment maintenance design features or arrangements.

Radioactive piping and equipment shall be segregated from non-radioactive piping so that maintenance can be accomplished on the non-radioactive components with minimum personnel exposure.

Means shall be provided to minimize or eliminated the need for plant personnel to enter areas greater than 100 mrem/h for routine operation, such as reading of gauges or adjustment of valves, or for routine maintenance. The following design methods shall be used to minimize radiation levels where operation and maintenance personnel are required to carry out their functions.

- Provide remote viewing devices for routine visual surveillance.
- Locate valve operators in a low radiation zone.
- Locate instrumentation indicators, solenoid valves, control panels, and **E/P** converters in a lower radiation zone.

- For sensing elements in high radiation areas, locate transmitter readouts in allow radiation zone.
- Locate instrument isolation valves just beyond penetration on the low radiation side of a shield wall to allow maintenance during the plant operation.
- Locate instruments and their isolation valves so that they are accessible for use, calibration, and repair without disassembly or removal of piping, grating or other structures.
- Design instrumentation for long service life and low frequency of maintenance and calibration.
- Provide features which permit periodic calibrations of radiation monitors in high radiation rooms from adjacent low level areas.
- Locate penetrations for piping, HVAC ducts, etc. through shield walls above personnel head height to minimize personnel exposure by streaming effects. Penetrations shall not be located in line of sight between radiation sources and occupied areas.
- Valves shall be located and shielded as necessary to enable maintenance of the valves without significant radiation exposure.
- Piping layout should minimize the existence of highly radioactive pass-through piping (for example, the header pipe of the branch pipe to the equipment within the cubicle being serviced) which could cause high radiation levels even when the cubicle equipment has been flushed.
- Reach rod shafts and associated valves shall be such that the drive shaft does not block or cross access ways or corridors that are necessary for maintenance of equipment.
- Remotely controlled TV cameras shall be strategically located in high radiation areas for remote surveillance of those areas, shall have horizontal and vertical scanning and shall have zoom and iris controls.

In URD a detailed list (tables 1.8.2 to 5 and 2.6D3) is provided with all the operation problems from which the issues to be addressed for personnel dose reduction can be obtained.

Previous experience has shown that in operating LWRs, a large amount of personnel radiation exposure is associated with refueling operations. Several of the operations required to refuel the reactor require personnel to work in relatively high radiation environments. Such operations include removing and installing the reactor head, removing and installing reactor vessel internals, preparing the PWR fuel transfer equipment for operation, and refueling pool wall decontamination. A primary goal of this chapter is to reduce the amount of personnel radiation exposure associated with refueling operations. The primary approach of reducing radiation exposure is including requirements that simplify and speedup operations and that high exposure operations be performed by automatic or remote manual processes. Specific design features, e.g., use of permanent refueling seals and specifying smooth surface conditions on pool walls, have also been included. Total radiation exposure is also reduced by reducing reactor disassembly and assembly operations through the recommended use of integrated head removal features.

The normal minimum water depth above the top of the spent fuel assemblies shall be no less than that required for shielding plant personnel. The exposure rate shall be less than 2-1/2 mrem/hr for personnel on the spent fuel pool refueling machine. A radiation alarm shall be provided on the refueling machine.

The fuel storage pool arrangement shall be such that access to an adjacent pool or pit will not result in excessive radiation exposure to operating personnel working in the vicinity of the pool or pit.

The spent fuel pool typically has several pools or pits adjacent to it (for example, cask loading pit or tilt machine pit). It is important that personnel have access to these pits for maintenance without excessive radiation exposure due to unrelated events such as fuel movement.

The average radiation exposure dose rate to personnel during normal cask handling shall be no more than 2,5 mrem/h.

The plant arrangement shall be designed such that all normally removable reactor internals can be removed and stored in the refueling pool or in a adjacent storage pool with the internals always remaining underwater and radiation exposure to personnel remaining below 2,5 mrem/h.

The heating, ventilating and air conditioning system shall be designed to minimize potential exposure of personnel to radioactivity from airborne contamination.

Potential exposure of personnel to airborne radioactivity can be controlled through filtration, differential pressurization, and direction of air flow towards volumes of progressively higher potential airborne radioactivity levels.

The plant support services group M-MIS shall monitor the radiation in those areas of the plant which may have radiation sources and which may be occupied by personnel. This monitoring shall provide local and remote indication and alarming appropriate to the significance and use of the measured radiation levels. The M-MIS shall be integrated and coordinated with the M-MIS for the radiation monitoring of process streams as necessary to support control of personnel exposures, provide indication of equipment malfunctions, and meet applicable regulations. The M-MIS shall provide monitoring during normal, shutdown, and accident conditions.

For lighting fixtures located in high radiation areas , the Plant Designer shall consider special features to minimize personnel radiation exposures during relamping and maintenance activities. These design features may include locating lighting fixtures in low radiation zones , using long-life lighting and providing easy access to lighting fixtures.

The radioactive waste systems shall be designed and constructed such that radiation exposures to plant personnel during operation and maintenance are consistent with requirement of 100 man-rem/year. Features to reach such a goal included are: (1) the design for remote centralized operation to minimize personnel radiation exposure during operation, (2) the selection and design of reliable and easily serviced equipment in order to minimize maintenance , (3) the use of remote handling equipment, especially for solid wastes, to minimize personnel exposure, and (4) the proper arrangement and shielding to make radiation exposure ALARA during operation and maintenance. The use and design for system or component decontamination, wherever practical, is also required.

The Plant Designer shall provide an estimate of personnel radiation exposures for all periodic radwaste operating and maintenance tasks , based upon estimated radiation those rates and occupancy times.

There are many detailed design requirements that in general relate to space for maintenance access, separation of equipment, and use of shielding that current plant experience shows are effective in reducing personnel radiation exposure. There is a potential for these requirements to be compromised by modular construction.

The liquid radwaste system is designed to protect plant personnel from radiation exposure and incorporate the basic "as low as is reasonably achievable" ALARA) objectives by, for example, the use of automated systems, appropriate arrangement, reliable and readily operable and maintainable equipment, shielding, and remotely operated instrumentation and controls.

Valves and instrumentation in lines serving the evaporator package shall be located outside the evaporator enclosure so that maintenance on or operation of these components will be in a lower radiation field. In addition, shielding shall be provided at the sample points associated with evaporator streams to minimize personnel exposure.

The design shall permit hook-up and disengagement of the filling head to the container to be performed to ensure that personnel exposure to radiation exposure is minimized during such operations . The design shall permit these operations to be performed manually or remote manually with long-handled tools. Remote , automatic equipment is permitted if simple and reliable. The design shall be compatible with either unshielded containers follow activity slurries or with shielded containers for high activity slurries. Remote operation minimizes radiation exposure. Hands-on capability to perform these operations, if necessary, is desired in the event any remote operated/automatic equipment malfunctions.

Cleanout connections shall be located for reasonable accessibility with minimal radiation exposure for maintenance personnel.

Means shall be provided to permit obtaining samples periodically for determination and verification of the scaling factors employed for waste classification. Such sampling provisions shall consist of either a sampler for extracting a sample from slurry transfer lines or means for removing a sample from storage tanks using a long-handled tube or scoop. The sampling provision shall minimize radiation exposure to operating personnel.

The design shall include means to transport spent cartridge filters to the Dry Solid Waste packaging station while minimizing personnel exposure and contamination spread. Possible options are an overhead monorail or a transfer vehicle. A standardized method for cartridge removal, shielding, and transport shall be provided. Dedicated and specially designed equipment must be used to lift and transport spent filter cartridges to ensure that personnel exposure is low and that the change for spreading contamination is minimized. The transfer vehicle shall be shielded to maintain radiation exposure to operating personnel ALARA. It shall be possible to transfer the disposable filter assembly into the vehicle remotely without direct visual monitoring.

Means shall be provided for transportation of filled shipping containers to the on-site storage area or to the shipping vehicle. Radiation exposure for personnel operating the transportation equipment shall be kept low through the equipment shielding design.

WASTE MINIMIZATION

EUR

Plant systems shall be designed so that they can be operated to minimize the generation of liquid and solid radwaste. Radwaste systems shall include advanced techniques of waste concentration and volume reduction.

The total final volume of solid radwaste (wet solidified, dry compacted or non compactable) should be no more than 50 m^3 per 1 000 MWe plant-year of Normal Operation.

All staff including Subcontractors, must enter and leave the controlled area at one point which shall be at the entry/exit of the main change room. Entry should be controlled by dosemeter operated turnstiles and exit by monitor operated turnstiles. A guardian operated gate (for trolleys) shall also be provided. A second access point may be accepted for certain circumstances (e.g. maintenance).

Within the controlled area, the extent of contamination controlled areas is reduced ALARA and each contamination area shall be separated from adjacent contamination areas of different levels by the provision of a sub-change room at the point of personnel entry/exit. These sub-change rooms shall define the boundary of each contamination area.

Access to the controlled area for fuel transport flasks, large items of plant, waste drums etc. shall be via an "airlock" type plant handover arrangement which ensures that a contamination controlled area is never directly open to areas where access is uncontrolled.

The access control and main change area shall include entry turnstiles, exit monitors and turnstiles, accommodation for the access guardian, and clothing storage and locker/shower rooms for male and female staff and Subcontractors.

As a design target, main corridors should be uncontaminated and with low dose rates. Where this is impractical the length of personnel routes through radiation and contamination areas shall be minimised to reduce the time spent in transit through such areas. Bulk civil quantities shall not be reduced if this results in a significant increase in operator radiation exposure. The design shall ensure that working times on active components will not be increased by inaccessibility.

To control both the radiation dose incurred by site personnel working in the controlled area, and the spread of contamination, the layout of the controlled area shall be such that personnel should not pass through areas of high radiation to gain access to an area of lower contamination. This design requirement is achieved by identifying at the design stage the access requirements and sources of radiation and contamination that will arise in the installation once it is in operation.

It should not be necessary to cross radiation/contamination controlled areas for the maintenance of equipment in non-controlled areas.

The Designer shall consider the requirement for escape routes. As a basic principle, there should be no emergency exits from non-controlled areas to controlled areas. Where necessary, emergency exits are permitted across control boundaries to corridors of the controlled area.

The main technical features for easy and economical dismantling are, in general, the same as those for achieving easy maintenance. The following features are especially relevant :

1) easy isolation of systems,

2) systems designed with minimum interdependences,
3) easy disassembly allowing heavy component replacement,
4) choice of materials, so as to reduce hazards resulting from dose rate in material vicinity.
5) For instance, the activity of the structural material of the vessel pit should be minimised using one or several of the following means :
6) reduction of the fast neutron fluence out of the vessel,
7) addition of neutron absorbers or moderators in the concrete,
8) limitation of the composition of the elements, the activity from which may be hazardous for Decommissioning, particularly when dealing with concrete and rebar.
9) achievement of good surface condition for potentially contaminated metallic components, thus facilitating subsequent possible decontamination :
    a) to minimise the amount of waste to be stored,
    b) to allow good handling.
10) ready accessibility and easy removal of components and internals in order :
    a) to minimise the radiation exposure to the personnel,
    b) to reduce the required number of personnel for Decommissioning* work.

URD

The use of materials which present a hazard to personnel or equipment (e.g., radioactivity, toxicity, flammability, or corrosively) shall be limited to those applications where no satisfactory alternatives exist. Where use of hazardous materials is required, the Plant Designer shall specify the manner in which the material is to be shipped, stored, handled, and used to minimize the hazards and satisfy applicable regulations and practice. An EPA approved building shall be provided for storage of hazardous and toxic wastes awaiting disposal.

The basic requirements that shall be met to obtain low radiation levels via the design and construction process are:

- "Zero leakage" fuel. Fuel reliability, i.e., zero leakage of fission products over the planned lifetime, is a primary objective.
- Design and proper installation of water treatment and waste processing systems to allow high quality water chemistry standards to be maintained and liquid radioactive waste to be effectively processed.
- Control of materials selection, particularly elimination of cobalt to the extent possible.
- LWR plant surveys show that a large percentage of radiation fields arise from 60. One significant source of radiation exposure to plant maintenance personnel has been wear and corrosion of cobalt-base hardfacing alloys that impact wear resistance to valves. APRI NP-6737, Cobalt Reduction Guidelines, provide detailed information that allows selection of cobalt-free hardfacing alloys for a large number of applications without adversely affecting valve performance.
- Adequate space for maintenance and equipment replacement.

The following consideration apply to the decontamination systems. Decontamination systems and/or facilities provide methods and equipment to remove or reduce radioactive contaminants from plant equipment, protective clothing, and personnel. The major decontamination equipment for the RCS will include the delivery system controller, various spray nozzle assemblies, chemical and/or abrasive supply systems, collection and storage tanks, high pressure pumps, filters, demineralizers and piping connections to waste processors. The decontamination systems include facilities to decontaminate instruments and small tools as well as large tools and large pieces of equipment. All decontamination methods should be evaluated to ensure that the process does not create or at least minimizes any mixed waste.

Also included in the decontamination systems are the hot laundry facilities, hose washdown stations, dikes, curbs around tanks, and special coatings applied to the floors and wall of areas containing radioactive fluids or other potential contaminants.

The personnel decontamination systems include the personnel decontamination sink, hot shower, hot toilet, radiation detection equipment and cleaning supplies needed for personnel decontamination.

The equipment and facilities of the plant decontamination systems shall be designed for effective decontamination of "in place and off-system" plant equipment. In order to meet the ALWR objectives of reduced radwaste and reduced radiation exposure, the most effective methods to decontaminate reactor equipment and facilities will have to be identified and made available for use during plant outages. EPRI studies NP-6433 and NP-2777 have identified several effective "in place" and "off-system" deconcentration techniques that should be considered for use by Plant Designers.

The decontamination system, electropolishing units and degreasing units should be sized to accommodate the plant equipment which may be decontaminated on a routine basis. This would include such equipment items as pump impellers from ECCS pumps, Reactor Coolant Pumps or Recirculation Pumps and valve stems and disks from MSIVs and RHR valves. Larger items which may need to be decontaminated may require special enclosures on an as-needed basis.

The plant decontamination systems' equipment and facilities for the off-system equipment decontamination shall include facilities to decontaminate small tools and instruments as well as large tools and pieces of equipment. The decontamination of small tools and instruments to permit their reuse will provide for a reduction in the amount of dry radioactive waste as well as provide the utility a cost savings on the replacement of such items. The decontamination of large tools and equipment, including pipe, conduit, ladders, etc., will significantly reduce the dry radioactive waste volume for the plant.

The latest decontamination methods are described in Source Book for Chemical Decontamination of Nuclear Power Plants, EPRI NP-6433, Aug. 1989.

Some of the ALWR plant's decontamination requirements may be met by use of portable or transportable facilities now available from several vendors on a commercial basis. Candidate decontamination methods shall be evaluated to ensure that they minimize or eliminate mixed waste. The disposal of mixed waste is a problem for plants and should be considered prior to selecting decontamination methods.

Means shall be provided to facilitate the transfer of both chemical and radioactive wastes from the decontamination system to the appropriate radwaste system, taking due account of ALARA requirements.

The Good Neighbor policy as stated in Volume I is that plant be a good neighbor to its surrounding environment and population, and requirements to limit radioactive releases from normal operation shall be defined. The radioactive release limitations will apply to solid waste shipment quantities and radioactive liquid and radioactive gaseous release quantities to the environment.

The ALWR shall be designed and constructed so that amount of radioactive gaseous, liquid, and solid waste release from the plant shall be equal to or better than comparable values for the 10% best plants of the same type (i.e., BWR or PWR) currently operating in the U.S.

In order to specify the design requirements to limit radioactive release of liquids and gases, operating plant data were obtained from the then most recently available (1984 and 1985) annual reports of the radioactive materials releases from nuclear power plants in the U.S. (NUREG7CR-2907). The 10% best PWR and BWR plants were determined for both gaseous and liquid releases. This data base dos not represent the plants operating in the U.S. at the time of these requirements, however, the data chosen present an adequate goal.

This data source gives neither fuel leakage information nor the relative amounts of radioactivity released from gaseous radwaste and from ventilation air sources. It is thus not possible to define the specific basis for the performance of these plants. Nevertheless, on a comparative basis, the 10% best plants were established and are to be used as a reference condition for use in evaluating ALWR design.

It should be realized that the amounts of radioactivity released to the environment via the liquid and gaseous pathway are a measure of the degree of fission product input from fuel defects and of radioactivity input into ventilation air via valve and other radioactive equipment seal leakage. The radioactivity removal mechanisms of the liquid and gaseous radioactive waste processing systems serve to limit and control release of radioactivity. To properly design the systems to meet specific goals beyond the regulatory requirements it is necessary to specify the extend of fuel leakage and input of radioactivity into ventilation air. The ALWR requirements provide a number of features to eliminate or reduce input of radioactive substances into the liquid and gaseous radwaste systems or into the environment. These include valve designs to minimize leakage into ventilation air and into liquids , a goal of zero fuel leakage and minimal fuel manufacturing defects , materials improvements to limit Cobalt 60 production , and the requirements for the radwaste systems.

For the solid wet and dry radioactive wastes volumes were derived from a study by Sargent and Lundy using EPRI reports NP3370 and NP5526 as a foundation.

The norms of performance based upon the best operating plants are:
GASEOUS EFFLUENTS

Policy Basis	BWR	PWR
Total radioactivity , excluding tritium , will be equal to or lower than the 1984-85 10% best plants of the same type in the U.S.	2000 Ci.yr.	200 Ci.yr.

LIQUID EFFLUENTS

Same as above 0.05 Ci./yr.	0.05 Ci./yr.	

SOLID WASTES

Low level dry and wet waste will be equal to or lower than the 10% best plants of the same type in the U.S.	3500 Cu.Ft./yr.	1750 Cu./yr

Dry waste volumes are based on the as-compacted form for the compatible fraction of dry wastes and on the as-shipped form for non-compatible dry wastes. Wet waste are based on the dewatered volume not the as-shipped volume
The ability to achieve the solid waste goals not only requires an appropriate design, but is dependence on (1) how the plant is operated and (2) national and local regulations established by agencies regulating form and concentration of wastes to be shipped and disposed. requirements for shipping and disposal have been established by such agencies independently of how a plant is designs and operated.
The good neighbor policy also includes requirements to limit non-radioactive, hazardous and toxic chemical releases.

The liquid radioactive waste processing system for the ALWR is designed with the approach that all liquid radioactive waste shall be processed through a waste purification system which is based on filtration and ion exchange technology (i.e., does not depend on an evaporator (conditions are given where evaporators may be used): This approach is extended to simplify design and operation , and to minimize shipment of solid wastes. The effluent resulting from this process can be released to the environment , diluted by the cooling tower blowdown and/or dedicated dilution water from another source , or may be recycled back into the plant within the limits of the plant water balance and water chemistry specifications.

The exception to this is in the treatment of PWR reactor coolant wastes wherein the boron is concentrated by evaporation for recycle (or discharge). (The former boron recycle system is relocated to the Liquid Radwaste Processing System LRWPS.) Several sources of undesired input to the LRWPS of operating plants have been identified which can increase LRWPS volumes substantially and/or increase total suspended solids and/or total dissolved solids substantially. Requirements are provided for elimination or minimization of those inputs to LRWPS, e.g., from service water, closed cooling water, and HVAC systems. Application of these requirements will substantially reduce irregular and unplanned leakage inputs which have greatly affected LRWPS performance in the past and have results in large solid waste volumes.

The improvement in valve stem packing thoughout the controlled access portions of the plant will result in less irregular leakage into LRWPS and consequent improved LRWPS performance. Requirements are provided to eliminate leakage and drainage of oil from rotating equipment by using alternatives to oil lubrication or by providing for collection and separate disposal of such leakage. Oil separators are provided in LRWPS to guard against inadvertent releases. The degrading effects of oil on LRWPS processing equipment and consequent increase in solid wates can thus be minimized.

Wet waste sources are the filter sludges and ion exchange resins used in various plant radioactive and LRWPS water treatment processes. Filter cartridges for liquids are in this category based on their process origin. These wastes are minimized by reducing contamination inputs to the various water processing systems. This principally illustrated in the BWR, wherein a tight main condenser will reduce impurity inputs into the condensate demineralizer and into the reactor where the capacity of the RWCU ion exchange resins can also be affected.

Features that contribute to the reduction of radiation exposure to personnel working in the radioactive waste processing areas include: (1) the design for remote centralized operation to minimize personnel radiation exposure during operation, (2) the selection and design of reliable and easily serviced equipment in order to minimize maintenance , (3) the use of remote handling equipment, especially for solid wastes, to minimize personnel exposure, and (4) the proper arrangement and shielding to make radiation exposure ALARA during operation and maintenance. The use and design for system or component decontamination, wherever practical, is also required.

The Plant Designer shall consider where cross connections would prove useful in the event of prolonged equipment outages. Cross connection shutoff shall be leak tight and the design shall minimize the possibility of crud traps where radioactive solids may settle. Cross connecting of similar equipment, such as filters or demineralizers, to provide installed spare capacity without consideration of the consequences of mixing subsystem waste streams may result in degrading system performance. Line blind flanges may be used to prevent cross leakage and minimize inadvertent use. Minimization of crud traps will reduce radiation exposure of personnel.

Sufficient fill, drain, vent and isolation valves and piping shall be included to minimize spills or leaks when connecting and disconnecting mobile equipment. This requirement should reduce radiation exposure and liquid waste. Current designs sometimes have dead spaces holding process fluid. The fluid drains out when the flanges are opened.

Means shall be provided to permit obtaining samples periodically for determination and verification of the scaling factors employed for waste classification. Such sampling provisions shall consist of either a sampler for extracting a sample from slurry transfer lines or means for removing a sample from storage tanks using a long-handled tube or scoop. The sampling provision shall minimize radiation exposure to operating personnel.

Liquid radwaste processing system volume minimization features:
- Employ demineralizers instead of evaporators for waste processing.
- Segregate incoming waste streams in appropriate subsystems, i.e., low conductivity, high conductivity, chemical and detergent.
- Employ selective ion exchange media to remove specific radioactive ion species while allowing non-radioactive species to pass through without exhausting the media.
- Employ improved filtration techniques, i.e. pre-coat filters with body feed and organic polymers.
- Employ condensate processing system spent resin for first stage demineralization (BWR).
- Provide oil separators for incoming streams subject to contamination.
- [Adopt] greatly simplified [systems] (e.g. no evaportators) as compared to typical current systems

Solid radwaste processing system volume minimization features:

- Wet solid wastes processed by dewatering only; no solidification. Avoid volume increase due to solidification additives along with waste generation from solidification equipment flushing/cleaning and maintenance.
- Dry solid waste sorting to permit (1) recycle of usable tools and (2) separation of compactible wastes from non-compactible wastes for improved compaction.
- Exempt from disposal the dry solid waste which may be considered non-radioactive.

Gaseous radwaste processing system volume minimization features:
- Eliminate HEPA exhaust filters.
- Employ ambient temperature charcoal system for reduced vulnerability to charcoal contamination from malfunction of gas conditioning equipment.

Reduce the concentration of radioactivity in reactor coolant to minimize the extent of required liquid waste processing. This involves decreasing both fission product activity and activated corrosion product activity. Fundamentally , these involve:

Improved fuel performance through better fuel designs, greater thermal margins , eliminating known problems (e.g., PWR baffle jetting), and improved water chemistry and other environmental conditions (e.g., reduced hot leg temperatures).

Reduced corrosion product inputs to reactor coolant through major emphasis on high grade corrosion resistant materials and improved water chemistry. Also , reduced cobalt 60 generation through reduced cobalt content materials (e.g., less than 0.020 percent weight for all RCS components, 0.015 percent for PWR SG tubing).

Reduce the volume of liquid waste entering the LRWPS so as to minimize the total volume of waste processed and associated wet solid waste generation .

Reduce the extent of contamination of liquid waste inputs with non-radioactive impurities , such as high conductivity liquids and oil . Such contaminants greatly increase the usage rate of LRWPS process equipment media, i.e.,ion exchange resins and filter materials. This contributes significantly to the total wet solid waste generation , even more so than the input liquid waste volume. The detailed ALWR requirements which minimize liquid waste contamination by impurities are identified in Section B.3 of this appendix.

Reduce the amount of wet solid wastes , such as ion exchange resins , which are generated in various plant systems. This includes , most importantly , the means to obtain extended life for BWR condensate polishing resins as well as the means to minimize solid waste generation in the PWR secondary systems in the event of steam generator tube leakage.

Minimize the extent of area contamination which can occur as a result of equipment leakage and provide features to ease cleanup after such leakage to minimize dry solid waste generation.

Provide capability to decontaminate various equipment so it can be reused rather than shipped to disposal facilities.

Adopt plant management/operating practices which reduce waste generation through management attention and worker awareness directed toward reducing radwaste generation. Such techniques are beyond the scope of the ALWR Requirements Document but, nonetheless, have been shown through experience to have a major impact on both wet and solid waste generation.

Employ volume reduction technologies, such as incineration and supercompaction, for still futher reductions in the volume of processed solid wastes. In fact,the solid waste volume goal was selected so as to not force utilities into procuring volume reduction equipment. nevertheless, these technologies are becoming more widely used, particularly overseas, and developments are under way in the U.S. which could make them viable by the time an ALWR is built. Accordingly, they may be available for use by utilities to reduce shipped waste volume still further.

MINIMIZE LIQUID WATER INPUTS TO RADWASTE

Components containing reactor grade water are designed to minimize leakage and/or collect and return leakage to the originating system without routing to the LRWPS. BWR use sealless recirculation and cleanup system pumps. BWR route condensate pump, feedwater pump, and heater drain pump seal leakage back to the condenser. BWR MSIV drains are routed to the condenser. BWR high purity fluid valve seal and sample drains in the turbine building are routed to the condenser.

PWR reactor coolant pump seal controlled bleedoff flow is returned to the CVCS. PWR RC pump closure shall be designed to detect leakage from the main closure gaskets.

Valves under two inches are packless. i.e., employ bellow or diaphragm stem seals. Larger valves employ "live loaded" packing, with a stuffing box and lantern leak-off provided with leak detection, or are totally enclosed.

RCS instrumentation piping and tubing utilize only welded joints in critical areas that are inaccessible.

BWR recirculation lines and associated valves have been deleted.

The leakage from plant systems which normally contain non-radioactive water is segregated from normally radioactive leakage, monitored, and sent to the LRWPS only if required.

Leakage and equipment drains from the component cooling water system (CCWS), as well from any other closed cooling water system located in a controlled access area, is routed to the LRWPS only if warranted by radioactivity content.

Process sampling system purge collection headers are routed back to the system of origin, if possible, or to the LRWPS, consistent with process parameters.

PWR turbine building equipment and floor drains are routed to the LRWPS only if warranted by radioactivity content.

Potential sources of clean non-radioactive water which could enter the LRWPS and result in unnecessary processing are minimized:

Plant buildings are adequately waterproofed to prevent ingress of groundwater or rainwater, e.g., through the cork seals between adjacent buildings.

Retaining dikes for outside storage tanks are covered to present precipitation from entering the dike. Water collected in such dikes can be discharged directly After sampling or to the LRWPS, if necessary, by specific operator action such as opening a valve.

Air cooler condensed moisture and cooling water leakage are routed to clean (non-radioactive) sumps.

Separate sumps are provided for clean (non-radioactive) drains.

Means are provided to permit timely detection and source identification of abnormally high inputs to the LRWPS so that appropriate measures can be taken to terminate such inputs, e.g., excessive leakage.

Collection tank levels are recorded in the radwaste control room.

Operation of all sump pumps is indicated in the radwaste control room. The accumulated operating time of each sump pump is determined by a timer.

Hard piped pump and valve seal leakofffs to the LRWPS provide a visual indication of leakage, i.e., a viewing window.

Liquid waste generation from spent fuel cask handling operations may be minimized by permitting a cask loading arrangement in which contaminated spent fuel pool water does not come in contact with the outside surface of the spent fuel cask. This permitted alternative to shipping cask immersion is the shuttle cask method. Both methods are allowed and it is not currently apparent which approach is most beneficial to the ALWR.

MINIMIZE LIQUID WASTE CONTAMINATION BY IMPURITIES

Discard depleted deep bed ion exchange resins rather than regenerate them so that sodium hydroxide and sulfuric acid regenerant solutions do not have to be processed in the LRWPS.

Rather than being regenerated, BWR condensate polisher resins are to be discarded after full use including liquid waste applications. Experience has shown this can be have a major beneficial effect on total BWR wet waste generation.

The deep bed resins in various other plant systems are also to be discarded rather than regenerated, e.g., the PWR CVCS and radwaste ion exchange resins, and the spent fuel pool cleanup system resins.

Minimize inputs to the LRWPS of leakage from systems which contain non-radioactive but high conductivity water.

Service water systems are excluded from controlled access areas. Leakage from service water systems is not routed to the LRWPS.

Drains and leakage from the BWR main condenser circulating water piping, pumps, and the condenser water boxes are collected separately and routed to the LRWPS only if warranted by radioactivity content.

Contamination of the radioactive streams normally entering the LRWPS is minimized.

All equipment drain sumps in controlled access areas are provided with a curb of sufficient height to prevent in-flow from adjacent floors.

The drainage from pump bedplates is collected separately from the leakage from shaft seals and casing drains.

Water chemistry of the component cooling water system and other closed water systems located in a controlled access area is selected to provide the necessary corrosion control and to minimize the impact of leakage upon LRWPS. Closed cooling water system drains are also segregated from radwaste to minimize inputs to radwaste.

Equipment drain and floor drain piping is segregated.

Liquid waste from radioactive or potentially radioactive systems is piped directly to sumps or tanks; open funnels or routing via trenches is not permitted. (This minimizes airborne activity as well as chemical and crud contamination of the liquids.)

Process sampling systems wastes are segregated, i.e., low conductivity samples from high conductivity or high solid samples, radioactive samples from non-radioactive samples. Effluent from analyzers which add chemicals to the samples, e.g., sodium and silica analyzers, are routed to the chemical waste tank.

If bacflushable filters are used for the PWR CVCS, the backflush fluid is to be discharged to LRWPS unmixed with other waste streams.

Means are provided to minimize contamination of liquid waste with oil.

Rotating equipment in controlled access has sealed-for-life bearings, where size permits. Where oil lubrication is used, slinger rings and oil collection devices are used to collect and contain leakage rather than let it drip or spill to base plates or floors.

Hydraulic equipment is provided with means for retaining and collecting oil so it does not escape to floors and floor drains.

Oil containing systems are provided with drains so oil can be collected during maintenance rather than draining to floors and floor drains.

Pipe threaded fittings are prohibited in the oil supply piping for the PWR reactor coolant pump motor bearings.

PWR reactor coolant pump non-welded connections which could be a source of oil are provided with a lube oil collection system.

The turbine generator lube oil system minimizes the potential for oil leakage to ambient and permits oil to be drained and collected during maintenance. Specifically, (1) lube oil supply and drain piping is all welded, with the supply piping provided with guard piping; (2) piping and equipment connections are made either within the oil storage tank or within protective shields, covers, etc,; (3) the lube oil tank is located below the low point drain on the turbine generator bearings, and all oil piping is slopped towards the tank.

MINIMIZE WET SOLID WASTE INPUTS TO RADWASTE

Minimize ionic depletion of BWR condensate processing system demineralizer resins.

Employ a high integrity condenser which minimizes leakage of circulating water into the condensate. Specific features include erosion-corrosion resistant tubing and tube sheets (e.g., titanium tubing and titanium clad carbon steel tube sheets for brackish or salt water applications), double tube sheets or welded tube-to-tube sheet joints, and capability to detect leaks and permit isolation of a portion of the tubes for repair while operating at reduced power.

Employ chemically equivalent resins, i.e., the ratio of anion to cation resin is such that both resin types are depleted at approximately the same time.

Minimize the return of potentially high conductivity fluid from the LRWPS to the BWR condensate system by requiring LRWPS recycle to meet condensate water quality requirements.

Minimize BWR condensate polisher resin contamination by corrosion products.

Employ erosion-corrosion resistant materials for piping and other components which could contribute crud to the ion exchangers. This includes chrome-moly steel for extraction steam piping, various erosion-corrosion resistant materials for the moisture separators reheaters, and stainless steel tubing for the feedwater heater tubes (LP tubes are 304L with 3o4L clad tube sheets; HP tubes are 316L with 316L clad tube sheets).

Provide hollow fiber filters ahead of the condensate polishers to improve reactor water quality and preclude the need for cleaning of polisher resins.

Provide design features for layup, both short-term (less than four days) and long-term.

The extent of PWR secondary systems wet solid wastes requiring disposal as radioactive waste is minimized.

Steam generator tube leakage is minimized through high grade materials, improved water chemistry (both primary and secondary sides), improved environmemtal conditions (e.g., reduced hot leg temperature), and various steam generator design features such as tube supports.

The steam generator blowdown system permits continuous blowdown flow through dedicated blowdown ion exchangers and the re-use of the blowdown fluid. In the event of steam generator tube leakage, this minimizes the extent of condensate polisher contamination and concentrates the activity on smaller volume blowdown demineralizers.

A high integrity condenser,with features equivalent to those for the BWR condenser, would minimize condensate polisher depletion and the need for frequent resin disposal during operation with steam generator tube leakage.

PWR load follow operations are accomplished using grey control rods instead of reactor coolant boration/dilution cycles. This reduce consumption of ion exchange resin in the borated waste processing subsystem.

MINIMIZE AREA CONTAMINATION AND EASE CLEANUP

Many of the requirements which minimize liquid waste generation will also minimize area contamination. e.g., use of low leakage components, hard-piped leakoffs, leak detection capability, etc.

Means are provided to minimize the extent of area contamination as a result of equipment leakage. Cubicles which contain radioactive tanks employ curbs to retain the entire contents of the tank within the cubicle. Sloped floors within cubicles promote drainage via floor drains. Main access floor spaces employ multiple floor drains with floors sloped towards the drains. Means are provided to ease cleanup of contaminated areas. Water supply connections are provided within cubicles to facilitate wash down of cubicle walls and floors. Concrete surfaces with the potential for contamination are protected with a smooth surface epoxy coating.

EQUIPMENT DECONTAMINATION CAPABILITY

The dry solid waste system permits sorting contaminated tools from other dry wastes. Means are provided for de contaminating such tools and other small equipment by chemical, ultrasonic, or abrasive action of a material such as sand.

Means are provided to decontaminate the larger pieces of equipment which represent a significant fraction of the contaminated equipment which has typically been cut up and shipped as radwaste, such as pip, staging ladders, etc.

PLANT MANAGEMENT PRACTICES

Studies by EPRI reported in EPRI NP-3370 and its update, EPRI NP-5526 , have indicated that various plant management practices and specific operating techniques have a major impact on total waste generation. These are not within the ALWR scope , but , nevertheless , such techniques will be necessary, in addition to the numerous design practices included in the ALWR Requirement Document, to achieve the ALWR yearly solid waste volume goal. Accordingly, techniques identified in the EPRI studies are summarized below.

The summarized techniques include the key attributes of successful waste minimization programs identified in EPRI NP-5526, along with specific techniques. The summary includes only the 20 techniques originally identified in EPRI-3370 which the subsequent report showed are most commonly employed at current BWRs and PWRs. Some of the "top 20" techniques are design techniques which have been incorporated in previous sections and tables and are not repeated. A few new techniques were also identified in EPRI NP-5526, and they are included.

Finally , it should be noted that no single technique is employed at all plants, nor does any plant employ all of the listed techniques. Accordingly , the following summary identifies the most common current practices , but it is not intended to imply that any specific technique must be followed to achieve successful waste minimization.

Plant operators have identified several key attributes of successful waste volume minimization programs. It was concluded from the EPRI effort that, to be successful , any waste minimization program must include these attributes as a minimum (EPRI NP-5526 , Volumes 1 and 2 , Section 6 , Waste Minimization Techniques).

Radwaste minimization and control is the responsibility of the entire plant not just that of the Radwaste or Health Physics departments.

Total management commitment and continual involvement with the program is absolutely necessary.

Comprehensive worker training and awareness of waste reduction efforts are imperative.

Formally established waste minimization programs and procedures , as opposed to informally implemented techniques , are required.

Formal goals , established at the plant manager level with a dedicated commitment to achieve the goals, are required.

Specific training practices for minimizing waste volume include the following:

Radwaste training programs are used to instruct plant workers in the need for waste reduction techniques , etc.(GA-9)2.

Signs are posted at control points and other "high traffic" areas to alert personnel to reduce radwaste , particularly dry waste , and to emphasize individual worker responsibilities(GA-10).

Annual radwaste generation trends are displayed for all workers to see plant performance (GA-14).

Memos are circulated to all plant personnel on radwaste related items, e.g., current plant projects that are resulting in large quantities of radwaste (GA-12).

Dry active waste is traced to the place in that plant where it was generated (GA-4).

Housekeeping inspections by a fire marshal are used to increase plant emphasis on keeping radiological areas clear of trash and unnecessary combustible material through 10CFR5O, Appendix R regulations (ga-20) .

The same dedicated operators are used to operate DAW compactors on a regular basis (GA-8).

Dedicated individuals or groups are assigned to do all plant decontamination work---area cleanup---(GA-11).

One plant keeps records of the volume of waste generated for each specific maintenance activity and uses the records to predict waste generation for subsequent comparable activities (new technique - EPRI NP-5526).

4. Conclusions

Improvements are possible in reducing personnel exposures and, in particular, collective doses.

Currently cost- benefit analysis do not allow to further reduce these collective doses below the already very low levels reached in the best operating plants. It must be recognized that also the utility requirements ask for the best performances of the current plants, i.e. in the range of 1 manSv/year average in the plant life.

However in the medium-long term it is possible that R&D in the areas mentioned in the text could make economically viable a further reduction of the collective doses.

It can be underlined that plant safety is also related to accurate maintenance and visual inspections. These shall be achieved in conjunction with a collective dose reduction.

However, according to current understanding most of the actions indicated in text would be more justified in the framework of waste reduction and decommissioning facilitation than in the framework of collective dose reduction, which are already very low.

Efforts may be justified, however, in dose monitoring system, which shall be as accurate as possible. This is, however, more a goal of the industry than of R&D.