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<Review> Today's Nuclear Challenge: Maintenance and Radiation Exposure

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Abstract

The Nuclear power industry today faces a serious and rapidly emerging problem in reactor maintenance and occupational radiation exposure control. The basic problem is the need for much maintenance on nuclear power plants. The problem is seriously compounded by radiation exposure control requirements. Many studies are underway seeking solutions but the industry is developing rapidly and new plants will not await the results of such studies. It is essential that attention be given to maintenance and exposure control in all phases of plant design, construction and operation.

1. Introduction

Control of radiation exposure has been a major consideration in the nuclear power program since its inception. Consequently during normal operations, exposures are small for both the workens and the public. In recent years special attention to protection of the environment has resulted in stringent limitations on release of radioactivity to the environment so that public exposure from reactors is a small fraction of the exposure from natural radiation. There is a desire in many quarters to make similar reductions in doses to workers but this has not been found practicable.

Concern about possible accidents has been another omnipresent factor in the development of nuclear power. Consequently serious accidents are rare. The industry has compiled on excellent safety record.

Despite the good provisions for normal operations and for accidents, experience makes it manifest that provisions for maintenance could have been better. More maintence has been necessary than was generally expected. This is evidenced by the assumption of capacity factors on the order of 85% in cost estimate studies for plants where the actual value has been more nearly 70%. Furthermore, some of the maintenance requirements were quite unexpected. There seemed littly likelihood of having to do any significant work on steam generator downcommers, for example.

To date, nuclear power plants have been built for contact maintenance. That is, if something must be repaired, people are expected to work on it directly. Consequently maintenance and radiation exposure are closely connected. Radiation exposure control requirements have seriously compounded maintenance problems and maintenance work has led to high personnel exposures. This situation could be further complicated by changes in the exposure limits that today appear probable.

2. Maintenance Problems

Every type of reactor plant has experienced a variety of difficulties. It has been estimated that over half the unscheduled downtime is due to the inability to perform maintenance during operations.

The most widely discussed maintenance problems are those with steam generators but they are far from the only maintenance problems.

It is often noted that the major problems have been with "conventional" rather than "nuclear" systems. While there is much truth in the implication of significant differences in quality, it is also true that most of the equipment in a power plant is conventional. Further, nuclear systems, particularly cladding and control rod drives, have experienced their share of difficulties. See Table 1.

3. Steam Generator Maintenance

Almost every PWR has experienced steam generator failure in its first few years of operation. Most commonly holes develop in some of the tubes permitting primary coolant to leak into the secondary side. This causes radioactive contamination of the secondary side, including the turbine, and releases to the atmosphere which may exceed "as low as practicable" guides. With 1% failed fuel and a 1 gallon per minute leak rate, on the order of 40 curies of nonvolatile fission and corrosion products are expected to enter the secondary system each day. About 1.5 mCi of I-131 might be released through condenser off-gassing. Clearly, a blowdown treatment system is needed if operation is to continue under such conditions.

The introduction of primary system boron into the secondary system creates problems

Table 1. Maintenance Operation at PWRs in the USA Causing Significant Outages in 1973[*]

- Yankee Rowe (575 MWe, Commercial Operation Feb. '61)
  - Control rod shroud replacement
- Indian Point-1 (265 MWe, Commercial Operation, Oct. '62)
  - Superheating system repairs
  - Stuck control rod
  - Steam generator downcomer cracks
- Connecticut Yankee (575 MWe, Commercial Operation Jan. '68)
  - LP turbine blade failures (twice)
  - LP turbine rotors replacement
  - Turbine major overhaul
  - Feedwater cintrol valve repair
  - Moisture separator/reheater repair
- San Onofre-1 (430 MWe, Commercial Operation Jan. '68)
  - Steam generator tube leaks
  - LP turbine blade failure
  - HP turbine flange leak
  - Pressurizer safety valve leak
  - Reactor coolant Pump overhaul
- Ginna (472 MWe, Commercial Operation March '70)
  - Condenser tube leaks
  - Feedwater valve
  - Charging pump discharge filter system weld leaks
- Point Beach-1 (497 MWe, Commercial Operation Dec. '70)
  - Moisture separator/reheater repairs
  - Primary coolant system valve leaks
  - Steam generator tuble leaks
  - Turbine-generator overhaul
- Robinson (700 MWe, Commercial Operation Dec. '71)
  - Steam generator tube leaks
  - Moisture separator/reheater repairs
  - Reactor internals modification (vibration)

Palisades (700 MWe, Commercial Operation Dec. '71)
- Steam generator tube leaks
- Moisture separator/reheater repairs
- Reactor internals modification (vibration)

Surryy-1(788 MWe, Commercial Operation Dec. '72)
- Reactor coolant pump replacement (shaft failure)
- Primary coolant loop bypass valve repair
- Steam line leak
- Main steam trip valves
- Steam generator swirl vanes modifications

Maine Yankee (790 MWe, Commercial Operation, Dec. '72)
- Reactor coolant pump vibrations
- Condenser tuve damage
- Lp turbine blades missing

Turkey Point-3 (693 MWe, Commercial Operation, Dec. '72)
- Condenser steam dump valves inoperable
- Feedwater bypass control valve leak
- Seismic restraint repair

Point Beach-2 (497 MWe, Commercial Operation, April '73)
- Equipment deficiencies discovered during check-out
- Main steam stop valve

Surry-2 (788 MWe,) Commercial Operation, May '73)
- Main steam trip valve repair
- Feedwater bypass control valve leak

Oconnee (886 MWe, Commercial Operation, July '73)
- Equipment deficiencies discovered in checkout
- Control rod drive stator

Ft. Calhoun (457 MWe, Commercial Operation Aug. '73)
- Safety injection tank repair
- Condenser cleaning
- Main steam line leak

Turkey Point-4 (693 MWe, Commercial Operation Sept. '73)
- Condensate pump repair
- Seismic restraint repair

quite apart form the radioactivity. Specifically, PH must be controlled by the addition of chemicals to the secondary water. Various systems have been used, especially "balanced phosphate" and "all volatile", but none has been proven effective in controlling further damage to the steam generator.

The industrial effort to reduce exposures from work on steam generators is an example of an effort that should be expanded to reduce all kinds of exposures. The need for such efforts on steam generators was manifest because PWR exposures have been dominated by the steam generators. The perfect solution, of course, would be the elimination of failures, but even in theory this is not attainable. For example, a "target" failure rate of 10^{-9} defects/tube-hr for steam generators was set for Pickering; even this high reliability amounts to a rate of one defect per year for the 2000 MWe plant.

When a tube fails the reactor must be shutdown to permit plugging of the defective tube. This entails plant shutdown and cool-down, draining the primary system, removal of manway covers, tube plugging, replacing manway covers, refilling the primary system and plant startup and heatup. The reactor is off-line for at least 70 hours.

Tube plugging involves work in radiation fields as high as 25 R/hr. Conventionally, tube plugging is accomplished by counter-boring the defective tube to remove the tube end and the tube-to-tube plate weld. A tapered plug is then driven into the prepared tube end and manually welded using the gas tungsten process. Long residence times for maintenance personnel result in large doses, especially where a number of tubes are to be plugged.

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* Many plants operated at reduced power because of fuel densification.

The NSSS vendors have developed a much more rapid plugging technique. Typically, an explosive-containing-plug is placed in the defective tube, and the charge is electrically detonated prducing a metallurgical bond between the plug and the defective tube. In addition to the speed of the operation, further exposure reduction can be achieved by inserting the plugs with a handling tool. Westinghouse reports plugging 4 tubes in one instance with a dose of only 3.5 man-rem, and even more impressively, 840 tubes were plugged at another plant with a dose of only 13 man-rem.

The importance of dose reduction in tube plugging is indicated by the numbers of tubes involved. A plant may have 10 to 50 thousand tubes per GWe. This typically includes some 20% spares to compensate for those that may be plugged. That is, a plant may still deliver rated power after 2 to 10 thousand tubes have been plugged. Several planst have already used up most of this 20% margin and a few have seriously exceeded it, so planning to plug this number or more over the life of the plant is not unduly pessimistic.

It would be impractical to plug the tubes individually with a, 70-hour outage each time. As a ludicrous example, 5000 outages of 70 hours each would give a total of some 35 years of down time. Thus the tubes are inspected so that incipient leakers can be plugged during normal outages. Eddy current devices are available that can detect incipient failures. Inspection involves inserting the probe into the tube in question and looking for anomalies. Higher frequencies are used for finding tube defects, and lower frequencies to locate sludge deposits.

Manually inserting the probe in each tube would result in high exposures. Fortunately, remotely operated, automatic systems are being developed. These devices are manually attached to the tube sheet. The operator then leaves the radiation area, and the device examines the tubes in a predetermined order. The data are recorded remotely. Some such devices require manual repositioning to complete the job. A periodic (18-month) examination normally includes at least 3% of the tubes. It is expected that devices that eliminate the need for repositioning will soon be in use.

4. Design Considerations For Radiation Exposure Control.

Occupational exposure control requires special design efforts. Specifically, designs should be reviewed by a qualified health physicist to ensure that exposure control requirements are included. The following design guides are offered to assist in this review. (These guides are derived from work done while with the USAEC.)

Proper design of facilities and equipment for systems which contain, collect, store, or transport radioactive liquids, gases and solids will contribute to assuting that occupational radition exposures will be ALAP. These systems include: The turbine system; the nuclear steam supply system (including the reactor); storage and cleanup system; and radioactive waste treatment, handling and storage system.

Practical experience in designing and operating nuclear power plants has shown that occupational radiation exposures may be reduced by simplifying systems and components and by eliminating equipment which is not absolutely necessary. Conventional non-nulear equipment and piping design generally must be changed to reduce the potential for exposure to radiation. Every effort should be made to reduce the impact of potential sources of radiation exposure.

The following design features, to the extent practicable, should be incorporated in plant designs to redece occupational radiation exposures.

1) All major radioactivity containing components in a system should be isolated and shielded from other major components of a system and they should be separated for ease of maintenance. Major components include tanks, demineralizers, pumps, filters and large valves.
2) Facilities should be designed so that access to a given component of a radioactive system does not require exposure to other major radioactive components.
3) As far as practicable each major component should be capable of being removed from its cubicle without major structural changes to the facility for ease of decommissioning or equipment replacement. In particula, items like evaporators or waste drumming equipment should be readily removable.
4) Systems which are used to store or transport resins require special considerations, such as the following;
   a) All lines conveying resins should be gradually sloped downward (at least 1″ drop/20 running ft.)
   b) Y-valves, strainer valves, check valves, and orifices should not be used in resin lines.
   c) Ball valves with cylindrical openings the same size as the process line are preferrable for spent resin lines.
   d) Long sweep (5" diameter) elbows should be used.
   e) Butt welding is preferred on resin lines because it produces a smoother interior for the flow stream.
   f) Tees should not be used in the process lines which normally convey resins except that tees may be used to introduce clean service (as water or nitrogen) into a resin carrying process line.
   g) Provisions should be made to pressurize resin lines with either nitrogen or water to "blow out" any plugged lines. The water or nitrogen should introduced at a tee downstream of each valve; the leg of the tee should be placed on the top of the resin line in order to prevent settling into and clogging of the clean service inlet.
   h) Nitrogen or water should be used to fluidize the tank from which resin is being transported.
   i) Overflows from a resin tank should not pass directly to the floor drains without first passing thru a collection device which will retain any resins in the overflow. The collection device should be instumented to detect any significant quantity of resin on the device and should be located in the same radiation area as the resin tank it serves.
   j) The design velocity used to transport spent resins should be such that build up material on pipe walls and at other locations will be minimized.
   k) Filters or screens should be located down-stream from each demineralizer in order to minimize the consequences of a demineralizer bed break.
5) Isolation of all process lines should be possible.
6) Each cubicle housing a component carrying radioactivity should have floor-to-ceiling walls and a labyrinth, roofed entrance

way, arranged so that a line of sight viewing of the components is not possible from other cubicles or from a low radiation zone.

7) Pipe penetrations thru walls should be designed to minimize radiation streaming.
8) Pipe chases should be designed for separation of pipes carrying redioactive material. Equipment cubicles should not have unshielded radioactive material pipe chases running thru them. Pipe spares should be located in radioactive fluid pipe chases where piping is not expected to last the life of the plant.
9) Clean services (air, water, nitrogen, etc.) should be in their own pipe chases, or in radioactive fluid pipe chases only if they are designed for the life of the plant and contain no valving or instrumentation.
10) Each cubicle containing radioactive equipment and components should have the concrete surfaces treated in a manner which keeps radioactivity from penetrating into the concrete.
11) Adequate lighting should be provided for each cubicle. Design of lighting for radiation are as should ensure ease and speed of servicing for reduction of exposure.
12) Drains should be supplied for each cubicle in which radioactive fluids can be released. All drain lines from cubicles should run in the concrete floors or in columns or radwaste pipe chases. Local loop seals should not be used on redwaste floor drains; provisions should be made to prevent backgassing thru the drains (as drain lines entering below the level of a sump). Floors should be sloped to the drains.
13) Interconnections between components should be provided to permit continued operation while one component has to be out of service.
14) Provisions should be made to drain and clean sumps remotely on a periodic basis.
15) Instrumentation. readouts and controls should be installed in a low radiation zone (<1 mrem/hr) if no radioactive fluid is carried by the instrument. Instrumentation which contains minimal radioactivity (such as pressure transducers instead of pressure gages) is preferred.
16) Components, instrumentation, and valves should be designed, specified and selected on the bases of longevity of service and ease of maintenance.
17) Process equipment should be capable of being isolated, drained, purged and cleaned. Auxiliary ventilation, filtered or connected to the plant ventilation system should be provided where processes equipment must be opened to room atmosphere.
18) If a single failure of a critical component could prevent carrying out cleaning or purgingor a radwaste system, then an additional permanently availble scheme should be employed to complete the cleaning operation. Such schemes may consist of redundant outlet valves or pumps on tanks.
19) All processes should be operated either by remote manual or automatic initiation from a control panel in a radiation zone designated for continuous occupancy.
20) Filters located in liquid streams should be designed for removal and changing of filter elements. The liquid filters should be capable of being drained and purged prior to removal of filted elements.
21) Local sampling stations should be located

in their own cubicle. The piping in the cubicle should be minimal. The cubicle should be accessable from a low radiation zone. Provisions should be made to flush the sampling lines in the cubicle after use. Sampling the primary and secondary systems should be accomplished from outside the primary containment.

22) Adequate spacing should be provided between units of air filtration systems and between elements within a unit for ease of maintenance. Regulatory Guide 1.52, Sections 3.e and 4 may be used as criteria. Consideration should be given to the remote removal of charcoal from filters. Filter housings should be separated and shielded from each other.

23) Steps should be taken to assure that field run process piping that may carry radioactive materials is designed and routed with appropriate regard for minimizing radiation exposures to plant personnel.

24) A-41 production should be minimized in PWR containments. Reduction in the volume of air used to cool the reactor cavity is one means to reduce this exposure.

25) For multiple unit sites, there should be piping and layout provisions which minimize exposure of construction workers working on the unfinished unit from the operating unit. For BWR plants, N-16 should be particularly considered.

26) Fuel pool cleanup systems should be provided that will permit zone II designatios for the fuel pool area.

27) The air flow rate of room air should be such that airborne radioactivity is kept below MPC levels where personnel are expected to work for periods greater than one hour.

28) Radiation zones should be established for all plant areas. For consistency with the AEC "Standard Format for SARs" the following zone designations should be used: Maximum Design Dose Rate

Zone I—Uncontrolled
No restrictions on occupancy
<1.0 mrem/hr

Zone II—Controlled
Unlimited access, 40 hrs/week
<2.5 mrem/hr

Zone III—Controlled
Limited access 6 to 40 hrs/week <15.0 mrem/hr

Zone IV—Controlled
Limited access for short periods <100 mren/hr

Zone V—Controlled, high radiation area
Occupancy averages less than one hour per week
>100 mrem/hr

Conclusion

Preparations must be made for maintenance. These include training personnel, obtaining equipment and especially appropriate plant dseign. This is important for every plant but it is even more important in Korea.