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# RADIOLOGICAL ASSESSMENT OF STEAM GENERATOR REMOVAL AND REPLACEMENT

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## SUMMARY

Frequent maintenance and inspection of steam generators, due to corrosion product accumulation, is necessary at several power reactors to ensure continued safe operation. This need has led to increasing radiation exposure to the workers who perform these tasks.

The combination of frequent maintenance and inspection needs and increasing occupational exposures has led several power reactor owners to consider replacing the existing steam generators with new ones. This procedure involves a significant amount of radiation exposure, but could save even more by reducing the radiation field and the need for such frequent maintenance and inspection; thus it will also lead to more economic plant operation with fewer power output interruptions.

An analysis of the radiation exposure resulting from the replacement of a single steam generator is given below:

- Post-shutdown preparation. . . . . . . .150-270 man-rem
- Removal of steam generator . . . . . . .350-550 man-rem
- Installation of new steam generator. . .600-1100 man-rem

These doses were arrived at by using standard time-estimating manuals and radiation exposure rate readings taken at several operating power reactors. High exposure rates were chosen to assure a conservative analysis. In some cases, this approach may result in overestimates of the actual exposure, but for radiation protection purposes this is the desirable approach.

One of the objectives of the analysis is to point out tasks that can result in high occupational exposures. The tasks of primary concern and their associated exposures are:

- Installing local control structures. . . . . . . 115 man-rem
- Cutting and removing reactor coolant piping. . . 190 man-rem
- Cutting steam generator wrapper. . . . . . . . . 190 man-rem
- Removing steam generator supports. . . . . . . . 72 man-rem
- Reinstalling reactor coolant piping. . . . . . .1000 man-rem

Liquid, solid and airborne effluents released during the removal and replacement of a steam generator are very small. Total liquid releases to the environs amount to about 190 Ci of $^{3}H$ and 0.23 Ci of other radionuclides. Total radioactive particulates released to the atmosphere are about $3.6 \times 10^{-5}$ Ci.

Disposal of the steam generator after its removal is a separate topic. Several means of disposal are possible, each with an associated radiation exposure:

| Alternatives | Exposure, man-rem |
|---|---|
| · Long-term onsite storage | 10-16 |
| · Interim onsite storage | 60-230 |
| · Immediate cutup and shipment to burial site | 270-580 |
| · Shipment intact to burial site | 2.4-5.0 |

The analysis in this report has been limited to the U-tube type of steam generator, but the analytical technique and radiation exposure levels are applicable to other types of steam generators and perhaps to other reactor system components.

# CONTENTS

# RADIOLOGICAL ASSESSMENT OF STEAM GENERATOR REMOVAL AND REPLACEMENT

## INTRODUCTION

Corrosion problems in steam generators at several nuclear power plants have led to the need for periodic inspection and maintenance of the steam generator tub  tc ensure continued safe operation. Efforts to inspect and repair s  m generators to maintain appropriate safety margins may result in such severe economic and occupational exposure problems that some utilities may chose to replace steam generators. The maintenance and replacement of steam generators involves a complex radiological problem.

A radiation problem is created by corrosion products activated by (n,α) and (n,p) reactions. These activation products are deposited on reactor core surfaces, solubilized or eroded into the reactor coolant, and finally deposited on out-of-core surfaces. These radionuclides form a film on reactor components and systems, such as steam generators. Maintenance and inspection of steam generators, which is necessary for continued safe operation, results in a major fraction of the radiation exposure received by occupational personnel.(1) The radionuclides that contribute most to this exposure have been experimentally verified to be $^{58}Co$ and $^{60}Co$.(2,3) The trend is for $^{60}Co$ to increasingly dominate the radiation field after the plant has operated for a few years.(2-5)

Some affected utilites are proposing, as a solution to this problem, the replacement of corroded and contaminated steam generator U-tubes. This replacement would be accomplished by cutting the steam generator shell below the steam dome, disposing of the lower assembly containing the U-tubes, and welding a new lower assembly to the primary system and the steam dome. While long-term savings may result, potentially high radiation exposures must be controlled during the maintenance activites.

The evaluation of alternatives for steam generator maintenance must include consideration of all related costs. A cost of considerable importance in these evaluations is occupational radiation exposure.

The analysis in this report provides a detailed estimate of occupational exposure received during the removal and replacement of contaminated steam generator U-tube assemblies. For this analysis, the high end of the exposure rate range for each step was chosen to assure a conservative approach in estimating the radiation dose to workers. Where possible, comparisons with utility exposure estimates are made and high-exposure tasks are identified. Alternatives for disposal of the removed U-tube assemblies are examined and estimates of radioactive releases from the removal and replacement operation are made.

This analysis covers U-tube steam generators in particular, but the technique may be adapted to other types of steam generators and other reactor system components that might have to be removed.

## GENERAL PROCEDURE FOR ANALYSIS

The assessment of expected exposures related to the removal and replacement of contaminated steam generator components involved three tasks: 1) detailed breakdown of maintenance activities, 2) estimation of man-hr requirements for each activity, and 3) determination of exposure rate by location and maintenance activity. The combination of these three elements yielded the exposure (man-rem) per maintenance activity, and these exposures were summed for the total exposure related to the project.

Maintenance activities were developed as a composite of Florida Power and Light[6] (Turkey Point) and Virginia Electric and Power Company[7] (Surry) work descriptions. The composite work description is discussed in detail in a later section and is itemized in Tables 13-15.

Man-hr estimates for each activity, as well as a listing of the personnel involved, were developed based on prior experience with similar activities and on standard estimating techniques.[8-10] The man-hr listings in Tables 13-15 represent man-hrs of actual exposure. Time spent traveling to and from the work area and other activities conducted outside the radiation zone are not included.

Exposure rates were based on information contained in NUREG-0395,[10] U.S. Nuclear Regulatory Commission (NRC) Dockets 50-250 and 50-251,[6] Babcock & Wilcox Document Number RDTPL-77-24,[2] Ayers,[4] and Westinghouse Document Number WCAP-88-72.[3] Single exposure rate values were selected usually on the high end of the range, with credit taken for temporary shielding and distance where applicable. For activities involving work crews exposed to several different exposure rates, an average rate for the activity was developed based on estimated time spent in each exposure zone.

The product of maintenance activity man-hrs and exposure rate (R/hr) yielded the activity exposure (man-rem). The individual activity exposures were then summed to obtain the total exposure for the project. The total man power for the project may be estimated by establishing an exposure limit which can be used to divide the total exposure into the necessary man power.

## CHARACTERIZATION OF PLANT FEATURES

The main emphasis of this section is to characterize the radiation fields and contamination levels in and around the steam generators for a typical nuclear power plant after 3 to 6 years of commercial operation. Radiation exposure rates and contamination levels were based on information taken from NUREG-0395,[10] and USNRC Docket Numbers 50-250 and 50-251,[6] Babcock & Wilcox,[2] and Westinghouse.[3] The tables and figures referred to in this section are grouped at the end of the section (pp 9-18) following the text.

### THE STEAM GENERATOR

The steam generator shown in Figures 1 and 2 is a vertical shell and U-tube evaporator with integral moisture-separating equipment. The reactor coolant flows through the inverted U-tubes, entering and leaving through the nozzles located in the hemispherical bottom head of the steam generator. The head is divided into inlet and outlet chambers by a vertical partition plate extending from the head to the tube sheet. Manways are provided for access to both sides of the divided head. Steam is generatred on the shell side and flows upward through the moisture separators to the outlet nozzle at the top of the vessel. The unit is primarily carbon steel. The heat transfer tubes and the divider plate are Inconel and the interior surfaces of the reactor coolant channel heads and nozzles are clad with austenitic stainless steel. The primary side of the tube sheet is weld clad with Inconel. Table 1 provides some data on steam generator design pertinent to this study.

### RADIATION EXPOSURE RATES AND CONTAMINATION LEVELS

Radiation exposure rates were measured[a] during shutdown at several pressurized water reactors (PWRs) that had been operating from 3 to 6 years.[10] Exposure rates did not vary greatly from site to site.[10] Representative radiation exposure rates are presented in Table 2, with the locations of the measurements shown in Figures 3 through 6.

(a) Measurements were taken at the following reactors:
Carolina Power and Light Co. - H. B. Robinson No. 2
Florida Power and Light Co. - Turkey Point No. 2 and 3
Rochester Gas and Electric Co. - R. E. Ginna
Virginia Electric Power Co. - Surry No. 1 and 2

Measured radiation exposure rates for a "typical" steam generator are listed in Table 3, with locations shown in Figure 7.

Experimentation has verified that these exposure rates are caused primarily by the activated corrosion products $^{58}Co$ and $^{60}Co$,[2-5] and has shown that $^{60}Co$ increasingly dominates the radiation field after the plant has been in operation for a few years.[2,3] Measurements at a reactor site indicate that the most notable difference between the end of cycle 1 (EOC 1) and end of cycle 2 (EOC 2) is the increase in the out-of-core $^{60}Co$ activities.[2] The radiation exposure rates on the steam generator tube sheets remained virtually unchanged between EOC 1 and EOC 2, but the $^{60}Co$ contribution to the exposure rate increased significantly.[2] Table 4 shows this effect for the six long-lived radionuclides of primary concern.

Measurements have been performed by Westinghouse to determine the composition of the crud on the steam generator manway at a plant that has been in operation for 5 years. These measurements indicate that $^{58}Co$ and $^{60}Co$ make up from 40 to 64% of the total deposited activity.[3] This activity accounts for approximately 87% of the total dose rate at one meter.[3] Westinghouse has found similar results at other power reactors.[3]

From the viewpoint of the out-of-core radiation fields, $^{58}Co$- and $^{60}Co$-deposited activities need be considered, since these two radionuclides contribute approximately 90% of the radiation fields in steam generators.[2,3] It is evident from Table 5 that the radiation exposure rate is increasingly dominated by $^{60}Co$. By EOC 3, 70% of the exposure rate is attributed solely to $^{60}Co$.[1]

Table 6 lists the gross contamination in the systems and Table 7 gives a breakdown of contamination levels by radionuclide for a steam generator.

## RADIOACTIVE EFFLUENTS

Radiological evaluations of the gaseous and liquid releases of radionuclides attributable to steam generator repair have been performed. The resulting releases are a very small fraction of those associated with the normal operation of a power reactor.

Airborne Releases

The primary airborne releases are due to cutting the reactor coolant (RCS) piping and cutting other system piping. Containment envelopes are used when cutting the RCS piping. These containment envelopes have a HEPA filter in their ventilation system and are exhausted through the plant ventilation system. For other cutting operations, no containment envelopes are required. It is assumed that all HEPA filters are preceeded by a demister which is necessary to retain filter integrity. Segmenting the steam generator at the transition cone and the internal wrapper does not contribute significantly to the airborne releases because the contamination levels on the secondary side are several orders of magnitude below those on the wrapper.

Cutting the reactor coolant system piping:

- 3/8 in. (0.95 cm) kerf
- 34 in. (86 cm) inside diameter
- Four cuts are necessary
- $4 \times 86\pi \times 0.95 = 1030\ cm^2$ of material vaporized
- $86\ \mu Ci/cm^2$ on the interior of the piping
- $1030\ cm^2 \times 86\ \mu Ci/cm^2 = 8.9 \times 10^4\ \mu Ci$ release
- Decontamination factor = $10^4$ (2 HEPA filters preceded by demisters)
- Release to the atmosphere is 8.9 $\mu$Ci

Cutting other system piping (secondary piping):

- 3/8 in. (0.95 cm) kerf
- Six 6-in.-diameter pipes
- Six 2-in.-diameter pipes
- One 30-in.-diameter pipe in two locations (steam lines)
- One 14-in.-diameter pipe in two locations (feedwater)
- $(6 \times 6\pi + 6 \times 2\pi + 2 \times 30\pi + 2 \times 14\pi) \times 0.95 = 430\ cm^2$ of material vaporized
- $6.2\ \mu Ci/cm^2$ on interior of these pipes
- $430\ cm^2 \times 6.2\ \mu Ci/cm^2 = 2.7 \times 10^3$ Ci released
- Decontamination factor = $10^2$ (1 HEPA filter preceded by a demister)
- Release to the atmosphere is 27 $\mu$Ci.

The total airborne release for the cutting operations during removal would be approximately 36 μCi per steam generator. The radionuclide distribution would be very similar to that listed in Table 7.

Liquid Releases

The primary sources of liquid effluent during steam generator removal would be release of the reactor coolant and discharge of laundry waste water.

Release of Reactor Coolant

The reactor coolant system must be drained before removal of the steam generator can proceed. The reactor coolant water would either be discharged or, if enough space is available, stored. Where reactor coolant is discharged, the following calculations and assumptions were used to estimate the waterborne effluents:

- Assume contamination levels as listed in Table 8.
- Reactor coolant will be discharged about 30 days after plant shutdown.
- The decontamination factors for waste-water processing equipment are listed in Table 9 and are in accordance with NUREG-0017.[11]
- There are approximately $1.9 \times 10^8$ g of reactor coolant water ($\sim 4.1 \times 10^5$ lb) in the primary system.[6]

Table 10 lists the estimated liquid release by radionuclide for discharge of reactor coolant.

Release of Laundry Waste Water

Releases of laundry waste water were estimated using the expected activities listed in Table 11, and assuming a discharge of approximately 22,000 gal/day[6] for about 180 days. The decontamination factors that might effect the laundry waste are listed in Table 9. Since processing of the laundry waste water is not anticipated, Table 12 lists the estimated liquid releases from this pathway for both treated and untreated laundry waste water.

SOLID WASTES

The amount of solid waste released (not including the steam generator itself) has also been estimated. Solid wastes generated during removal and replacement of the steam generators will include the plastic (or other material)

and wood used to construct containment envelopes, concrete removed from biological shields, HEPA filters and a small amount of disposable clothing. For each steam generator, approximately 60 $yd^2$ (50 $m^2$) of plastic and 300 ft (91 m) of two-by-fours will be used to construct containment envelopes around the reactor coolant piping. About 20 $yd^3$ (15 $m^3$)[6] of concrete per steam generator will be removed. Several HEPA filters used in the containment envelope will be disposed of following completion of the operation.

Liquid slurry collected during removal of concrete will be solidified and sent to a disposal site. Since the concrete is only slightly radioactive, the slurry will need no special handling.

Most of the clothing will be laundered, but some will be disposed of. Rags and paper used during the operation will also be packaged and disposed of. All this material will be low activity waste and amount to approximately 1000 $yd^3$ (760 $m^3$)[6] of waste per steam generator.

Waste generated during weld and prep operations will also be disposed of as radioactive material. Material used for supporting and moving the steam generator within containment, temporary shielding, scaffolding, the reactor cavity cover, etc., should not become contaminated during the operation and can, therefore, be reused. One exception to this is any temporary shielding used inside of contamination envelopes. This shielding may become contaminated and should either be disposed of or decontaminated.

TABLE 1. Steam Generator Design Data [1,2]

| | | | | | | |
|---|---|---|---|---|---|---|
| Overall Height | ~65 ft | 21 m | | Number of Handholes | 2 | --- |
| | | | | ID of Handholes | 6 in. | 0.15 m |
| Overall Weight | 340 tons | 310 Mg | | Number of U-Tubes | ~3400 | --- |
| Shell OD, Upper | 170 in. | 4.3 m | | U-Tube OD | 0.88 in. | 22 mm |
| Lower | 130 in. | 3.3 m | | Tube Wall Thickness, Nominal | 0.050 in. | 1.3 mm |
| Shell Thickness, Upper | 3.5 in. | 8.9 cm | | Reactor Coolant Water Volume | 945 $ft^3$ | 27,000 ℓ |
| Lower | 2.6 in. | 6.6 cm | | Secondary Side Volume | 4580 $ft^3$ | 130,000 ℓ |
| Number of Manways | 4 | --- | | | | |
| ID of Manways | 16 in. | 0.41 m | | | | |

TABLE 2. Exposure Rates in Containment Building by Location [10]

| Measurement Point[(a)] | Exposure Rate (R/hr) | Location[(b)] | Measurement Point[(a)] | Exposure Rate (R/hr) | Location[(b)] |
|---|---|---|---|---|---|
| 1A-01 | 12-30 | Reactor coolant pump bowl (contact) | 1A-16 | ≤0.5 | Sump, reactor building |
| 1A-02 | 0.5-0.6 | RCS piping, cold leg (contact) | 1A-17 | ≤0.001 | Personnel hatch (outside CV) |
| 1A-03 | 0.05-0.4 | Steam generators (general area) | 2A-01 | ≤0.025 | General area (typical |
| 1A-04 | 0.001-0.012 | Emergency personnel lock | 2A-02 | ≥0.2 | Pressurizer (contact |
| 1A-05 | 0.01-0.6 | Floor drains (contact) | 2A-03 | ≤0.2 | Reactor coolant pump (contact) |
| 1A-06 | 0.01-0.15 | General area (typical) | 2A-04 | 0.1-0.9 | General area (typical) |
| 1A-07 | 0.025-0.1 | RCS pumps (general area) | 2A-05 | 0.01-0.2 | Steam generator area |
| 1A-08 | 0.35-0.8 | SG loop to RCS pump (typical | 3A-01 | 0.005-0.02 | General area (typical) |
| 1A-09 | 18-22 | SG at manway (typical) | 3A-02 | 0.01-0.2 | Steam generator area |
| 1A-10 | 0.5-0.7 | SG at 0.9 m (typical) | 4A-01 | 0.1-1.0 | Reactor cavity (inside edge) |
| 1A-11 | ≤0.3 | SG at 1.5 m (typical) | 4A-02 | ≥0.2 | SG (general area) |
| 1A-12 | ≤0.2 | SG at 1.8 m (typical) | 4A-03 | 0.005-0.05 | General area |
| 1A-13 | 0.05-0.15 | General area (typical) | 4A-04 | 0.005-0.05 | Equipment hatch |
| 1A-14 | ≤0.04 | General area | 4A-05 | ≥0.2 | Above RV on cooling duct (general area) |
| 1A-15 | 0.15-3.0 | Piping (systematic) | 4A-06 | ≥0.6 | RCS piping |

(a) 1A designates 45-ft elevation; 2A designates 61-ft elevation; 3A designates 77-ft elevation; 4A designates elevations ≥93 ft.

(b) RCS = reactor coolant system; SG = steam generator; CV = containment vessel; RV = reactor vessel.

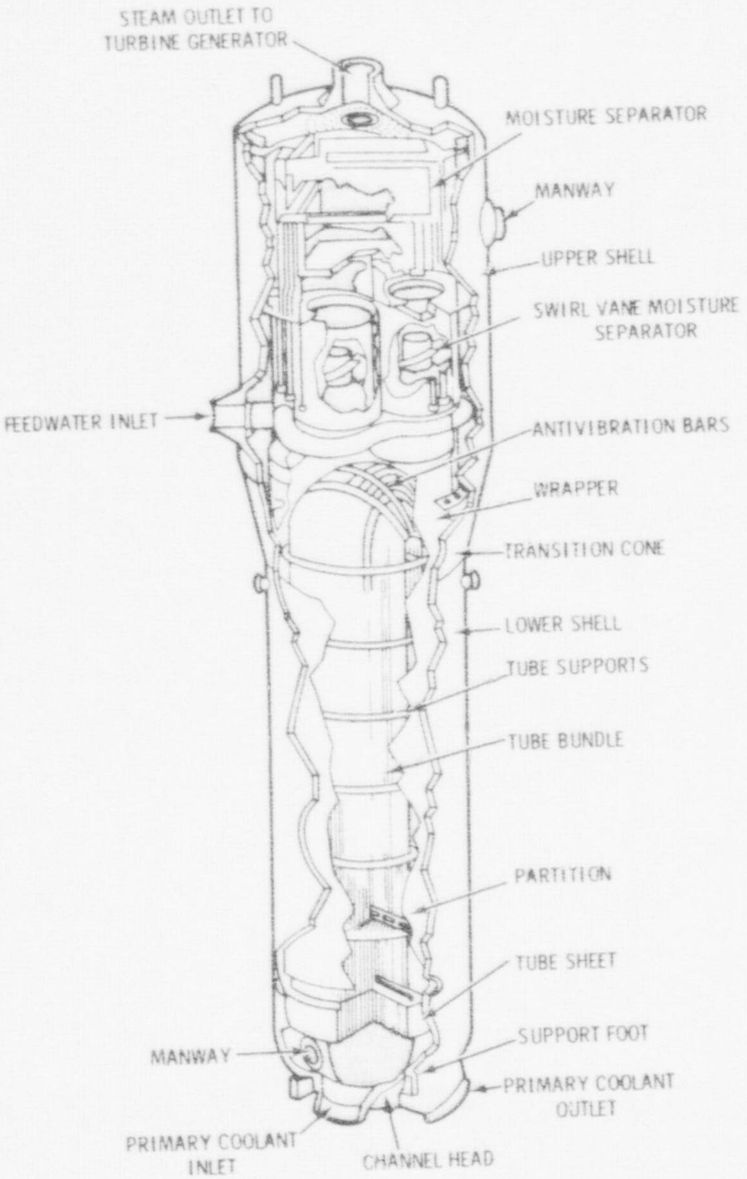


FIGURE 1. Steam Generator (U-Tube Type)

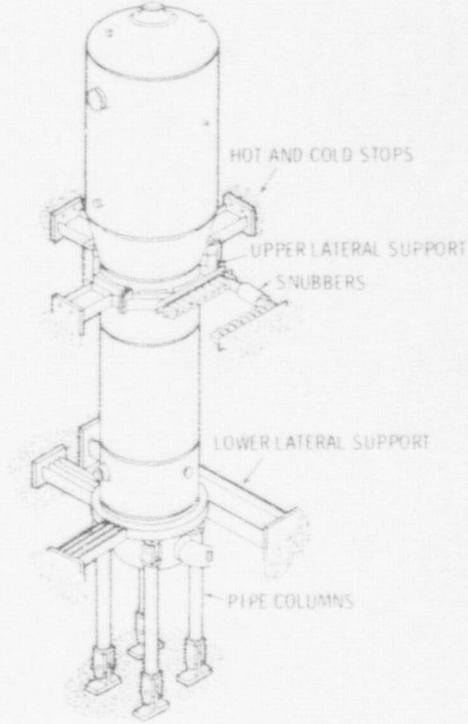


FIGURE 2. Steam Generator Supports

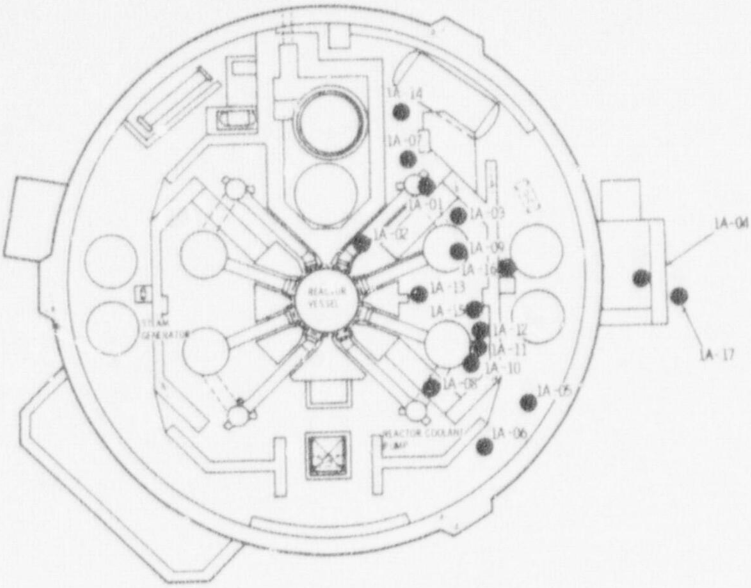


FIGURE 3. Source Locations in Containment Building At 45-Ft Elevation(10)

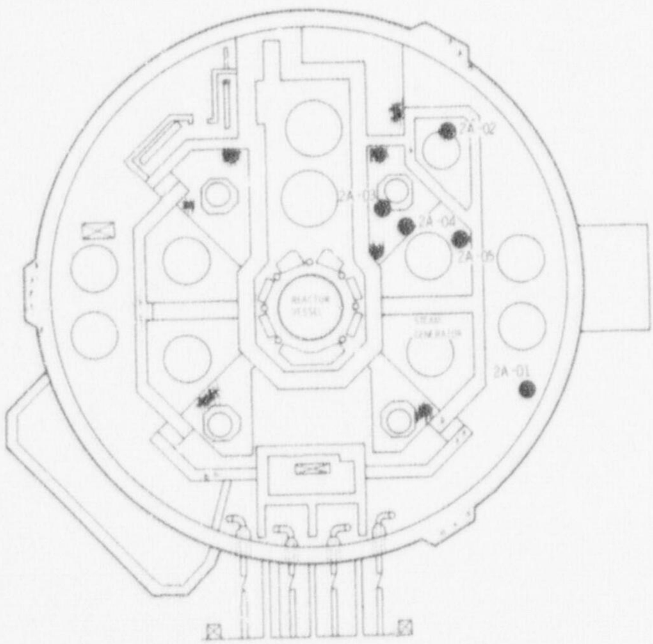


FIGURE 4. Source Locations in Containment Building At 61-Ft Elevation(10)

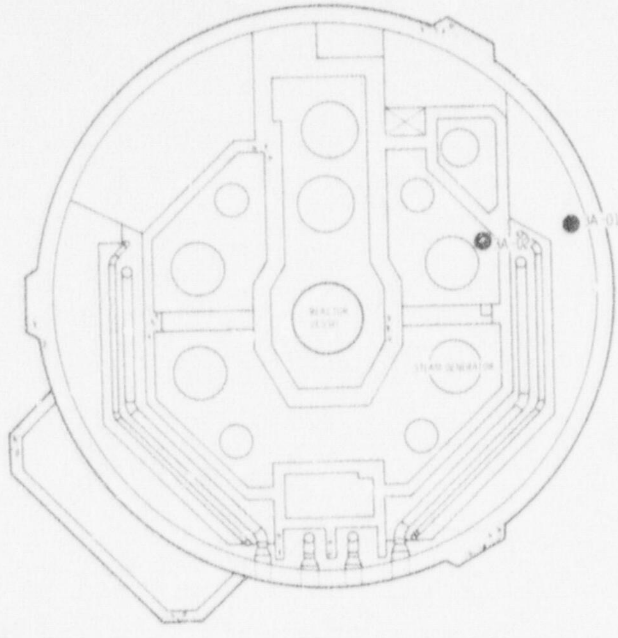

FIGURE 5. Source Locations in Containment Building At 77-Ft Elevation(10)

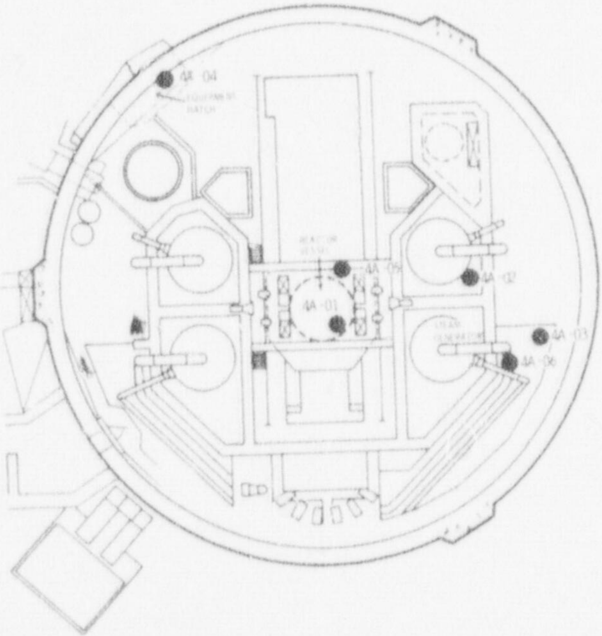

FIGURE 6. Source Locations in Containment Building At Operating Floor and Above (≥93-Ft Elevation)

TABLE 3. Exposure Rates in Steam Generators by Location

| Measurement Point | Exposure Rate (R/hr) | Location |
|---|---|---|
| 1 | 0.05 | Manway |
| 2 | 0.2 | Waist high in center of and next to perforated plates |
| 3 | 0.2 | |
| 4 | 0.2 | |
| 5 | (a) | |
| 6 | 0.5 | 1 ft above deck plate |
| 7 | (a) | |
| 8 | 1 | Feedwater ring |
| 9 | 2 | |
| 10 | 2 | |
| 11 | (a) | |
| 12 | 3.5 | Flow resistance plate |
| 13 | 10.5 | |
| 14 | 10.5 | |
| 15 | (a) | |
| 16 | 10 | Hand hole |
| 17 | 10 | |
| 18 | 30 | Tube sheet |
| 19 | 37 | |
| 20 | 22 | Hot leg |
| 21 | 30 | Cold leg |
| 22 | 18 | Manway |
| 23 | 22 | |
| 24 | 1.2 | Work platform |

(a) No measurement taken.

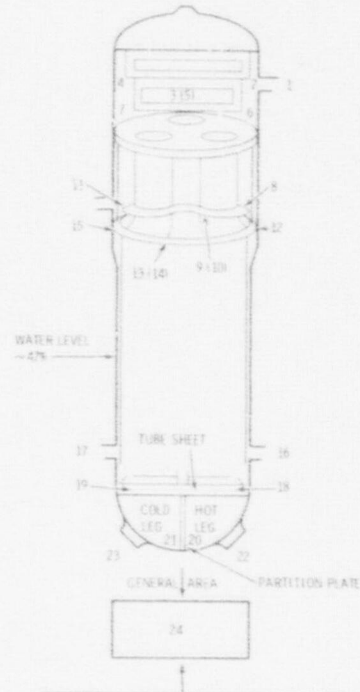


FIGURE 7. Source Locations in Steam Generator[10]

Note: Points in () are located 180° opposite those shown. Steam generator water level is at zero in the primary and at ~47% in the secondary side.

TABLE 4. Sources of Steam Generator Radiation Fields[2]

| Radionuclide | Relative Amount[a] | | Percent of Total Radiation Field | |
|---|---|---|---|---|
| | EOC 1 | EOC 2 | EOC 1 | EOC 2 |
| $^{51}Cr$ | 0.80 | 0.60 | 1.5 | 0.8 |
| $^{54}Mn$ | 0.050 | 0.050 | 2.6 | 2.0 |
| $^{58}Co$ | 1.0 | 1.0 | 65 | 46 |
| $^{59}Fe$ | 0.035 | 0.020 | 2.8 | 1.1 |
| $^{60}Co$ | 0.16 | 0.42 | 26 | 49 |
| $^{95}Zr$ | 0.04 | 0.020 | 2.0 | 0.70 |

(a) Relative to $^{58}Co$.

TABLE 5. Sources of Radiation Fields in Steam Generators As a Function of EFPD[a] [2]

| Radionuclide | 309 EFPD EOC 1 | 604 EFPD EOC 2 | 752 EFPD | 916 EFPD EOC 3 |
|---|---|---|---|---|
| $^{51}Cr$ | 1 | 1 | 0.2 | --- |
| $^{54}Mn$ | 3 | 2 | 1 | 0.8 |
| $^{58}Co$ | 65 | 46 | 28 | 29 |
| $^{59}Fe$ | 3 | 1 | --- | --- |
| $^{60}Co$ | 26 | 49 | 70 | 70 |
| $^{95}Zr$ | 2 | 1 | 0.6 | 0.2 |

(a) Effective full power days.

TABLE 6. Contamination Levels in Piping and Steam Generator

| Component | Contamination Level, $\mu Ci/cm^2$ |
|---|---|
| RCS Piping[10] | 86 |
| Other Piping[10] | 6.2 |
| Steam Generator | |
| Primary Side[6] | 68 |
| Secondary Side | $10^{-3}$ |

TABLE 7. Estimated Activities on Steam Generator Primary Side Surfaces[a,b] [6]

| Radionuclide | Activity, $\mu Ci/cm^2$ | Radionuclide | Activity, $\mu Ci/cm^2$ |
|---|---|---|---|
| $^{58}Co$ | 26.03 | $^{131}I$ | $4.5 \times 10^{-1}$ |
| $^{60}Co$ | 18.1 | $^{132}I$ | $4.5 \times 10^{-1}$ |
| $^{54}Mn$ | 2.03 | $^{137}Te$ | $4.5 \times 10^{-1}$ |
| $^{59}Fe$ | $4.65 \times 10^{-1}$ | $^{140}Cs$ | $6.74 \times 10^{-2}$ |
| $^{51}Cr$ | 1.35 | $^{140}Ba$ | $4.5 \times 10^{-1}$ |
| $^{95}Zr$ | 2.25 | $^{141}La$ | 1.35 |
| $^{95}Nb$ | 3.15 | $^{144}Ce$ | $7.5 \times 10^{-1}$ |
| $^{99}Mo$ | $4.5 \times 10^{-1}$ | $^{239}Ce$ | 3.72 |
| $^{103}Ru$ | 1.5 | Np | 4.8 |
| | | TOTAL | 68 |

(a) The activities are based on actual Turkey Point data.

(b) Activities listed are extrapolated to 7 years of commercial operation.

TABLE 8. Radionuclide Concentrations in Reactor Coolant[11]

| Radionuclide | Half-Life days | Concentration, $\mu$Ci/g | Radionuclide | Half-Life, days | Concentration, $\mu$Ci/g |
|---|---|---|---|---|---|
| $^{3}$H | 4.51E+03[a] | 1.0E+00 | $^{106}$Rh | 3.46E-04 | 1.0E-05 |
| $^{16}$N | 8.22E-05 | 4.0E+01 | $^{125m}$Te | 5.80E+01 | 2.9E-05 |
| $^{51}$Cr | 2.77E+01 | 1.9E-03 | $^{127m}$Te | 1.09E+02 | 2.8E-04 |
| $^{54}$Mn | 3.13E+02 | 3.1E-04 | $^{127}$Te | 3.90E-01 | 8.5E-04 |
| $^{55}$Fe | 9.86E+02 | 1.6E-03 | $^{129m}$Te | 3.36E+01 | 1.4E-03 |
| $^{59}$Fe | 4.46E+01 | 1.0E-03 | $^{129}$Te | 4.83E-02 | 1.6E-03 |
| $^{58}$Co | 7.08E+01 | 1.6E-02 | $^{131m}$Te | 12.5E+0 | 2.5E-03 |
| $^{60}$Co | 1.93E+03 | 2.0E-03 | $^{131}$Te | 1.74E-02 | 1.1E-03 |
| $^{83}$Br | 9.96E-02 | 4.8E-02 | $^{131}$Te | 3.26E+00 | 2.7E-02 |
| $^{84}$Br | 2.21E-02 | 2.6E-03 | $^{130}$I | 5.15E-01 | 2.1E-03 |
| $^{85}$Br | 1.99E-03 | 3.0E-04 | $^{131}$I | 8.04E+0 | 2.7E-01 |
| $^{86}$Rb | 1.87E+01 | 8.5E-05 | $^{131}$I | 9.5E-02 | 1.0E-01 |
| $^{88}$Rb | 1.24E-02 | 2.0E-01 | $^{133}$I | 8.67E-01 | 3.8E-01 |
| $^{89}$Sr | 5.06E+01 | 3.5E-04 | $^{134}$I | 3.65E-02 | 4.7E-02 |
| $^{90}$Sr | 1.04E+04 | 1.0E-05 | $^{135}$I | 2.75E-01 | 1.9E-01 |
| $^{91}$Sr | 3.96E-01 | 6.5E-04 | $^{134}$Cs | 7.53E+02 | 2.5E-02 |
| $^{90}$Y | 2.67E+00 | 1.2E-06 | $^{136}$Cs | 1.31E+01 | 1.3E-02 |
| $^{91m}$Y | 3.45E-02 | 3.6E-04 | $^{137}$Cs | 1.10E+04 | 1.8E-02 |
| $^{91}$Y | 5.81E+01 | 6.4E-05 | $^{137m}$Ba | 1.78E-03 | 1.6E-02 |
| $^{93}$Y | 4.21E-01 | 3.4E-05 | $^{140}$Ba | 1.28E+01 | 2.2E-04 |
| $^{95}$Zr | 6.40E+01 | 6.0E-05 | $^{140}$La | 1.68E+0 | 1.5E-04 |
| $^{95}$Nb | 3.52E+01 | 5.0E-05 | $^{141}$Ce | 3.25E+01 | 7.0E-05 |
| $^{99}$Mo | 2.75E+0 | 8.4E-02 | $^{143}$Ce | 1.38E+0 | 4.0E-05 |
| $^{99m}$Tc | 2.51E-01 | 4.8E-02 | $^{144}$Ce | 2.84E+02 | 3.3E-05 |
| $^{103}$Ru | 3.93E+01 | 4.5E-05 | $^{143}$Pr | 1.36E+01 | 5.0E-05 |
| $^{106}$Ru | 3.68E+02 | 1.0E-05 | $^{144}$Pr | 5.00E-03 | 3.3E-05 |
| $^{103m}$Rh | 3.90E-02 | 4.5E-05 | $^{239}$Np | 2.35E+00 | 1.2E-03 |

(a) 4.51E+03 = $4.51 \times 10^{3}$

TABLE 9. Decontamination Factors Used to Calculate Liquid Effluents

| Process Equipment | Decontamination Factors | | | |
|---|---|---|---|---|
| | $^{3}$H | Iodines | Cs & Rb | Others |
| Mixed Bed Demineralizer | 1 | 10 | 2 | 10 |
| Radwaste Evaporator | 1 | $10^{3}$ | $10^{4}$ | $10^{4}$ |
| Evaporator for Laundry Wastes | 1 | $10^{2}$ | $10^{2}$ | $10^{2}$ |

TABLE 10. Estimated Releases Due to Discharge of Reactor Coolant Water [(a)]

| Radionuclide | Release, Ci |
|---|---|
| $^{3}H$ | 1.9E+02[(b)] |
| $^{51}Cr$ | 1.7E-06 |
| $^{54}Mn$ | 5.5E-07 |
| $^{55}Fe$ | 3.0E-06 |
| $^{59}Fe$ | 1.2E-06 |
| $^{58}Co$ | 2.3E-05 |
| $^{60}Co$ | 3.8E-06 |
| $^{86}Rb$ | 2.6E-07 |
| $^{89}Sr$ | 4.4E-07 |
| $^{90}Sr$ | 1.9E-08 |
| $^{90}Y$ | 1.9E-08 |
| $^{91}Y$ | 8.5E-08 |
| $^{95}Zr$ | 8.2E-08 |
| $^{95}Nb$ | 5.3E-08 |
| $^{99}Mo$ | 8.3E-08 |
| $^{103}Ru$ | 5.0E-08 |
| $^{106}Ru$ | 1.8E-08 |
| $^{125m}Te$ | 3.8E-08 |
| $^{127m}Te$ | 4.4E-07 |
| $^{129m}Te$ | 1.4E-06 |
| $^{131m}Te$ | 2.8E-13 |
| $^{132}Te$ | 8.7E-08 |
| $^{131}I$ | 3.9E-04 |
| $^{133}I$ | 2.7E-13 |
| $^{134}Cs$ | 2.3E-04 |
| $^{136}Cs$ | 2.5E-05 |
| $^{137}Cs$ | 1.7E-04 |
| $^{140}Ba$ | 8.2E-08 |
| $^{140}La$ | 1.2E-12 |
| $^{141}Ce$ | 7.0E-08 |
| $^{143}Ce$ | 2.1E-14 |
| $^{144}Ce$ | 5.8E-08 |
| $^{143}Pr$ | 2.0E-08 |
| $^{239}Np$ | 3.3E-10 |

(a) For a three steam generator power plant.

(b) 1.9 E+02 = $1.9 \times 10^{2}$.

TABLE 11. Estimated Activities in Laundry Waste Water[6]

| Radionuclide | Concentration, μCi/cm$^3$ |
|---|---|
| $^{58}$Co | 6.7E-6[a] |
| $^{60}$Co | 5.0E-6 |
| $^{137}$Cs | 5.4E-6 |
| $^{134}$Cs | 6.5E-7 |
| $^{54}$Mn | 7.3E-7 |
| $^{131}$I | 1.1E-7 |

(a) 6.7E-6 = $6.7 \times 10^{-6}$

TABLE 12. Estimated Liquid Release Due to Discharge of Laundry Waste Water (per unit[a])

| Radionuclide | Release, Ci | |
|---|---|---|
| | With Processing | No Processing |
| $^{54}$Mn | 1.1E-4 | 1.1E-2 |
| $^{58}$Co | 1.0E-3 | 1.0E-1 |
| $^{60}$Co | 7.5E-4 | 7.5E-2 |
| $^{131}$I | 1.7E-5 | 1.7E-3 |
| $^{134}$Cs | 9.8E-5 | 9.8E-3 |
| $^{137}$Cs | 3.1E-4 | 3.1E-2 |

(a) It is assumed that a unit consists of three steam generators.

## STEAM GENERATOR REMOVAL AND REPLACEMENT PROCEDURES

Maintenance activities considered in assessing worker exposures from the removal of contaminated steam generator components have been grouped into three categories: post-shutdown preparation, removal, and installation.

### POST-SHUTDOWN PREPARATION

Following reactor shutdown, removal of fuel to the spent fuel storage pool, and primary system drainage, containment work areas are surveyed and generally decontaminated as necessary. Where required, temporary shielding is installed. Working areas are prepared with the assembly of prefabricated scaffolding and the installation of a cover over the reactor cavity. A portion of the biological shield wall and insulation on the steam generator and associated piping are removed. Contamination control structures and filtration systems are installed in areas where activities may generate airborne contamination. The containment polar crane is inspected and tested, and equipment for transporting the lower steam generator section out of the containment is prepared.

### REMOVAL

Piping associated with the steam generator is cut at the nozzle and a distance away to allow clearance for lifting the steam generator out of position (see Figure 8). This piping includes the steam line, feed-water, reactor coolant inlet and outlet, and miscellaneous small pipes. The steam generator wrapper is cut to disconnect upper and lower steam generator internals. Access to the wrapper is through the steam dome manway. The steam generator shell is cut at the transition cone (see Figure 8) and the steam dome is lifted clear and set down horizontally. Primary system pipe ends and steam generator pipe ends are plugged to prevent the spread of contamination and to reduce the radiation field. The steam dome internals are inspected and repaired or replaced as necessary. Following removal of steam generator supports and snubbers, the unit is lifted clear with the polar crane, set down on a special transfer cart near the equipment hatch, and transported to an interim storage location (see the Appendix). Following steam generator removal, cut-away pipe sections and contaminated wastes are removed from the containment. General and working areas are maintained in a clean condition.

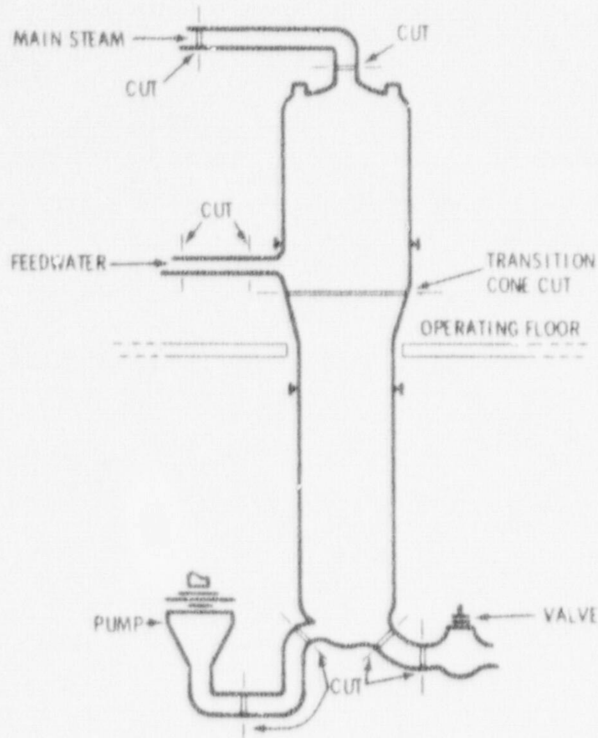


FIGURE 8. Cut Locations

## INSTALLATION

The replacement steam generator lower assembly is delivered to the site and transported to the containment equipment hatch. The assembly is lifted onto the equipment hatch platform, moved into the containment, lifted vertically, and lowered into position over the steam generator supports. The steam generator support system is reassembled and/or reinstalled. The pipe ends and other surfaces to be welded are prepared for rewelding prior to bringing the steam generator into the containment building. The steam dome is lifted into place and held in alignment with positioning devices. The shell is rewelded, stress-relieved, and inspected. With access through the steam dome manway, the steam generator wrapper is welded and inspected. Steam generator piping is positioned and welded. The biological shield wall is reconstructed and concrete surfaces are inspected and repaired. Insulation is reinstalled. The scaffolding and reactor cover are removed. Following cleanup of affected areas and systems, startup tests are performed.

## ANALYSIS OF EXPOSURE

The radiation exposure from the removal and replacement of a steam generator lower assembly is analyzed in this section. As discussed previously, worker exposures were estimated by individual maintenance activity within the general categories of post-shutdown preparation, removal, and installation. Tables 13-15 list estimated worker exposures by maintenance activity for the three general categories. The total estimated exposures for each category are:

| | Man-Rem |
|---|---|
| Post-Shutdown Preparation | 270 |
| Removal | 550 |
| Installation | 1100 |
| Total | 1900 |

This represents the total estimated worker exposure from the removal and installation of a single steam generator lower assembly.

When choosing exposure rates to be used in estimating occupational doses, a conservative approach was taken. In some cases, this may result in an overestimate of the actual exposure to be encountered, but for radiation protection purposes this is the desirable approach.

For the estimates made here, we assumed that during all cutting and welding personnel remained in the work area. However, devices for remote cutting and welding are available and their use could substantially reduce the man-rem estimates for some operations. An additional reduction in dose could be achieved by keeping the water level on the secondary side of the steam generator as high as possible. Table 16 illustrates the amount of radiation exposure that might be saved by employing these techniques.

TABLE 13. Post-Shutdown Preparation (per Steam Generator)

| Event Description | Exposure Rate, R/hr | Personnel Involved | Event Duration, man-hr | Exposure, man-rem | Comments |
|---|---|---|---|---|---|
| 1. Unload entire core. | 0.03 | Operators<br>Laborers | 650 | 20 | |
| 2. Survey containment work areas, perform local decontamination, and shield areas where necessary. | 0.2 | Laborers | 240 | 48 | |
| 3. Install cover over the reactor cavity to provide protection to the reactor vessel and associated equipment and to provide a contiguous work area. | 0.05 | Boilmakers | 120 | 6 | Heavy duty steel for laydown area. |
| 4. Assemble special prefabricated scaffolding to permit access to all work areas. | 0.2 | Carpenters | 80 | 16 | |
| 5. Remove biological shield wall and transport debris from the containment | 0.1 | Laborers | 240 | 24 | 25% of biological shields removed - all reinforced concrete. |
| 6. Remove insulation from steam generators, feedwater piping, steam line piping, reactor coolant piping, and other components and transport debris from the containment. | 0.1 | Pipe Fitters | 320 | 32 | |
| 7. Install local control structures, such as tents, ducting, temporary filters, etc. | 0.2 | Carpenters | 576 | 115 | Around reactor coolant piping. 60 $yd^2$ of plastic; 300 ft of 2 x 4 |
| 8. Install the steam generator transport system, e.g., rails, inside the containment and on equipment hatch. | 0.01 | | 500 | 5 | |
| 9. Enlarge and/or reinforce equipment hatch platform outside of the containment. | 0.01 | | 100 | 1 | |
| 10. Inspect and test containment polar crane. | 0.01 | Mill Wrights<br>Operators<br>Laborers | 128 | 1.3 | |

TABLE 14. Removal (per steam generator)

| Event Description | Exposure Rate, R/hr | Personnel Involved | Event Duration, man-hr | Exposure man-rem | Comments |
|---|---|---|---|---|---|
| 1. Remove miscellaneous small piping, such as blowdown piping, and instruments and controls, such as level transmitters, to facilitate removal of the steam generator. | 0.1 | Pipe Fitters | 160 | 16 | Cut six 6-in pipes and six 2-in pipes. |
| 2. Cut steam line piping at the steam nozzle on the upper shell and downstream to allow a section of the piping to be removed so that the upper and lower shells can be fitted. | 0.1 | Pipe Fitters | 128 | 13 | [illegible] in.-thick piping. |
| 3. Cut feedwater piping at its junction with the upper shell and upstream from the junction to allow a section of the piping to be removed so that the upper and lower shell can be removed. | 0.1 | Pipe Fitters | 100 | 10 | |
| 4. Cut and remove reactor coolant inlet and outlet piping. A section of the hot leg (inlet) piping (an elbow) will be removed by cutting the pipe at the steam generator nozzle and on the outlet side of the reactor coolant system isolation valve. A larger section of cold leg (outlet) piping, consisting of two elbows and two straight sections, will be removed by cutting the pipe at the steam generator nozzle and upstream from the reactor coolant pump. | 0.5 | Pipe Fitters | 384 | 190 | Pipe end preparation not included. Shielding on reactor coolant pump and channel head. |
| 5. Cut steam generator wrapper and internal blowdown piping to facilitate lifting of the upper shell. | 2.0 | Pipe Fitters | 96 | 190 | Access through upper shell manway. |
| 6. Cut steam generator shell on the transition cone. | 0.1 | Pipe Fitters | 192 | 19 | |
| 7. Lift off the upper shell of the steam generator with the polar crane and store in the containment. | 0.1 | Iron Workers | 40 | 4 | |

TABLE 14 (Cont'd)

| Event Description | Exposure Rate, R/hr | Personnel Involved | Event Duration, man-hr | Exposure man-rem | Comments |
|---|---|---|---|---|---|
| 8. Inspect and remove moisture separation equipment, feedring, and other associated equipment. | 0.05 | Pipe Fitters | 400 | 20 | Inspection and equipment removal. |
| 9. Disassemble and/or remove the steam generator supports to allow the lower steam generator assembly to be lifted by the polar crane. | 0.2 | Pipe Fitters | 360 | 72 | Minimal cutting. |
| 10. Lift the steam generator lower assembly from its supports using the polar crane | 0.03 | Mill Wrights<br>Laborers<br>Iron Workers<br>Operators | 80 | 2.4 | |
| 11. Remove the steam generator lower shell assembly from the containment through the equipment hatch. | 0.03 | Mill Wrights<br>Laborers<br>Iron Workers<br>Operators | 80 | 2.4 | |
| 12. During removal and thereafter, clean and decontaminate the containment work area to the extent practicable. | 0.05 | Laborers | 240 | 12 | |
| 13. Following the transport of the steam generator lower assemblies through the equipment hatch, remove them from the equipment hatch platform by means of mobile cranes and transport them to an interim storage location. | 0.03 | Iron Workers<br>Operators<br>Laborers | 80 | 2.4 | |
| 14. Remove cutaway pipe sections from containment. | 0.03 | Laborers | 40 | 1.2 | |
| 15. Dispose of steam generator (see Appendix). | | | | | |

TABLE 15. Installation

| Event Description | Exposure Rate, R/hr | Personnel Involved | Event Duration, man-hr | Exposure man-rem | Comments |
|---|---|---|---|---|---|
| 1. Deliver replacement steam generator lower assembly by barge. | 0 | | | --- | |
| 2. Lift the steam generator lower assembly from the transporter onto the equipment hatch platform by means of mobile cranes. Move it through the equipment hatch and into the containment using the containment transport system. | 0 | | | --- | |
| 3. Transport the assembly to a designated location within the containment and upend it using the polar crane. Lift the assembly vertically and move it to a position over the steam generator supports. Lower the assembly into place in the supports. Temporary positioning devices (e.g., jacks) may be installed to facilitate the positioning of the lower assembly without the use of the polar crane. | 0.04 | Mill Wrights<br>Laborers<br>Operators<br>Iron Workers | 160 | 6.4 | |
| 4. Reassemble and/or reinstall the steam generator support system. | 0.05 | Pipe Fitters | 540 | 27 | Supports generally in place. |
| 5. Install new moisture separation equipment, feedring, and other internal components in the upper shell. Prepare mating surface of upper shell for welding to lower assembly. | 0.01 | Pipe Fitters | 600 | 6 | |
| 6. Lift upper steam generator shell into place and align with lower assembly. Temporary positioning devices may be used to facilitate alignment without the use of the polar crane. | 0.01 | Iron Workers<br>Mill Wrights<br>Operators | 120 | 1.2 | |
| 7. Weld the upper and lower assemblies together, stress-relieve, and inspect. | 0.01 | Iron Workers | 2,500 | 25 | |

TABLE 15 (Cont'd)

| Event Description | Exposure Rate, R/hr | Personnel Involved | Event Duration, man-hr | Exposure, man-rem | Comments |
|---|---|---|---|---|---|
| 8. Weld the steam generator wrapper to the upper internals and inspect. | 0.01 | Pipe Fitters | 2,000 | 20 | |
| 9. Install the reactor coolant piping. | 0.25 | Pipe Fitters<br>Radiographers | 4,000 | 1,000 | Pipe end preparation included. |
| 10. Fitup, weld, and inspect the main steam piping. | 0.01 | Pipe Fitters | 192 | 1.9 | |
| 11. Fitup, weld, and inspect the feedwater piping. | 0.01 | Pipe Fitters | 150 | 1.5 | |
| 12. Install miscellaneous piping (e.g., blowdown) instrumentation and controls which were removed. | 0.01 | Pipe Fitters | 200 | 2 | |
| 13. Construct biological shield wall, repair crane wall and other concrete structures which were chipped. | 0.01 | Carpenters<br>Cement Finishers | 500 | 5 | |
| 14. Clean affected systems and work areas. | 0.01 | Laborers | 70 | 0.7 | |
| 15. Install insulation. | 0.01 | Pipe Fitters | 450 | 4.5 | |
| 16. Remove scaffolding. | 0.05 | Carpenters | 80 | 4 | |
| 17. Remove cavity cover | 0.05 | Carpenters | 32 | 1.6 | |
| 18. Reload core. | 0.01 | Operators<br>Laborers | 500 | 5 | |

TABLE 16. Reduced Man-Rem Estimates

| Event[a] | Man-Rem Saving Technique | Exposure, man-rem With Technique | Without |
|---|---|---|---|
| Post-Shutdown Preparation (from Table 13) | | | |
| 2. Survey, clean and shield work areas. | Water level remains high. Reduce dose rate from 0.2 to 0.1 R/hr. | 24 | 48 |
| 4. Assemble scaffolding. | Water level remains high. Reduce dose rate from 0.2 to 0.05 R/hr. | 4 | 16 |
| 5. Remove biological shield. | Water level remains high. Reduce dose rate from 0.1 to 0.05 R/hr. | 12 | 24 |
| 6. Remove insulation. | Water level remains high. Reduce dose rate from 0.1 to 0.05 R/hr. | 16 | 32 |
| 7. Install local control structures. | Water level remains high. Reduce dose rate from 0.2 to 0.1 R/hr. | 60 | 115 |
| | Man-rem savings | 120 | |
| Removal (from Table 14) | | | |
| 1. Remove miscellaneous small piping. | Water level remains high. Reduce dose rate from 0.1 to 0.03 R/hr. | 5 | 16 |
| 2. Cut steamline piping. | Water level remains high. Reduce dose rate from 0.1 to 0.05 R/hr. | 4 | 13 |
| 3. Cut feedwater piping. | Water level remains high. Reduce dose rate from 0.1 to 0.03 R/hr. | 5 | 10 |
| 4. Cut and remove reactor coolant inlet and outlet piping. | Use remote cutting device. Reduce number of man-hr in radiation zone. | 70 | 190 |
| 6. Cut steam generator shell. | Same as 4. | 10 | 19 |
| 9. Disassemble steam generator supports and remove lower assemblies. | Water level remains high during support disassembly. Reduce dose rate from 0.2 to 0.05 R/hr. | 18 | 72 |
| | Man-rem savings | 200 | |
| Installation (from Table 15) | | | |
| 9. Install reactor coolant piping. | Use remote welding device. Reduce number of man-hr in radiation zone. | 500 | 1,000 |
| | Man-rem savings | 500 | |
| | Total man-rem savings | ~820 | |

(a) Event numbers correspond to those on Tables 13-15.

## COMPARISON OF ANALYSES WITH UTILITY EXPOSURE ESTIMATES

Worker exposure estimates from the Virginia Electric and Power Company (VEPCO) Surry Power Station(7) and the Florida Power and Light (FPL) Turkey Point Power Station(6) are compared with the results of these analyses in Table 17. Although comparison is hampered by the varying levels of detail between the estimates, it is readily apparent that the utilies' exposure estimates are consistently lower than those presented in this report.

High-exposure activities are generally those involving work in the vicinity of reactor coolant piping and the U-tube section of the steam generator. Specific high-exposure activities include the following:

- Cut and remove reactor coolant piping
- Cut steam generator wrapper
- Remove steam generator supports
- Install reactor coolant piping.

Certain activities in relatively low-radiation zones result in large exposures due to the large number of man-hours involved.

TABLE 17. Comparison of Exposure Estimates

| Event | This Report Per Generator | This Report Per Unit[a] | VEPCO[7] Surry Per Unit[a,b] | FPL[6] Turkey Point Per Unit[a] |
|---|---|---|---|---|
| PREPARATION - Total | 150-270 | 450-810 | 640 | 155 |
| Containment preparation | 130-240 | | 600 | 92 |
| Remove insulation | 15-30 | | 42 | 63 |
| REMOVAL - Total | 350-550 | 1100-1700 | 470 | 480 |
| Cut steam generator shell | 10-19 | | 37 | |
| Cut steam generator wrapper | 190 | | | 93 |
| Cut reactor coolant piping | 70-190 | | 150 | 103 |
| Cut main steam feedwater, and miscellaneous piping | 17-39 | | 13 | |
| Lift off steam dome | 4 | | | |
| Remove steam generator supports | 18-72 | | 16 | |
| Remove steam generator lower shell | 7 | | 32 | 39 |
| Remove moisture separation equipment | 20 | | 2 | 103 |
| Miscellaneous | 13 | | 220 | 140 |
| INSTALLATION - Total | 600-1100 | 1800-3300 | 490 | 470 |
| Install lower steam generator shell | 33 | | 10 | |
| Install reactor coolant piping | 500-1000 | | 68 | |
| Install new moisture separation equipment | 6 | | 46 | |
| Lift steam dome into place | 1 | | | |
| Weld steam generator | 25 | | 27 | |
| Weld steam generator wrapper | 20 | | | |
| Install main steam, feedwater, and miscellaneous piping | 5 | | 63 | |
| Install insulation | 5 | | 58 | |
| Miscellaneous | 21 | | 220 | |
| OTHER MISCELLANEOUS ACTIVITIES | | --- | 430[c] | 200 |
| TOTAL | | 3300-5800 | 2000 | 1300 |

(a) Assumes a three-loop unit.

(b) Rounded to two significant digits.

(c) Estimate for post-installation and startup activities.

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# APPENDIX

## STEAM GENERATOR DISPOSAL

The steam generator lower assemblies, when removed, represent the largest source of radioactive waste to be disposed of following repair operations. This disposal effort should be thought of as independent of the repair effort and will be evaluated as such. Actual data gathered at Turkey Point[7] and data presented in NUREG-0395[10] indicate that each lower assembly will contain approximately 1000 Ci consisting primarily of $^{58}Co$ and $^{60}Co$.

### THE OPTIONS

Several options exist for disposal of the old steam generators. The options include, but are not limited to:

- Long-term onsite storage
- Interim onsite storage
- Immediate cut-up and shipment
  (a) with no decontamination
  (b) with decontamination
- Shipment intact

Each of these options will be addressed briefly in the following discussion. In all cases, when the steam generator lower assemblies are removed from containment, they are sealed to prevent release of radioactive material. The external contamination on the steam generators is less than limits of acceptable surface contamination as outlined in Regulatory Guide 1.86.[12]

### Long-Term Onsite Storage

A temporary onsite facility can be constructed for storage of the lower assemblies until shipment to a licensed land-burial site can be arranged, the plant is decommissioned, or sufficient time has passed for the radioactivity to decay to levels that would make cut-up and shipment easier.

Since the steam generators are sealed prior to removal from containment, the only radiological problem associated with onsite storage is direct radiation. Shielding can be provided to ensure acceptable exposure rates external to the storage facility.

Although total enclosure of the sealed steam generators may not be required, it might be prudent and advisable to provide it. A structure that does not provide full enclosure of the stored steam generators will require certain precautionary measures to ensure the integrity of the sealed steam generators. Measures which will be used are fenced and locked or guarded perimeter, maintenance of the steam generator shells (painting to prevent rust), monitoring of the seals to ensure no loss of integrity, drains with radiation monitors for rain water, and smear tests to ensure external contamination remains below that designated in Regulatory Guide 1.86.[12] This list is by no means exhaustive. All measures necessary to prevent release of radioactive material to the environs and intrusion by people or animals into the storage area should be taken. A complete enclosure would reduce the chance of tampering and decrease the need for security guards. Access should be provided for surveillance of the steam generator seal integrity, either by in-place monitoring equipment or by periodic surveys through ports provided for this purpose.

The radioactive material within the steam generators is immobile. Therefore, if seal integrity is lost, a release to the environment is unlikely. Nevertheless, a surveillance program will be necessary and should include visual inspections of the lower assemblies, radiation surveys of the area, and swipes of the welds sealing the openings, depending on the design of the storage facility.

## Interim Onsite Storage

Several options for future disposal may be available if onsite storage is chosen initially. It might at some time become a viable and competitive option to ship steam generators intact to an offsite disposal facility. Moreover, radioactive decay during long-term storage will reduce activity levels to less than 1% of those expected when the steam generators are first removed. These reduced levels will allow the steam generators to be segmented with a minimum of radiation exposure.

## Immediate Cut-Up and Shipment

At present, lower assemblies can be disposed of at a licensed land-burial site if they have been segmented prior to shipment. Currently, rail or truck transport or a combination of the two are viable alternatives for shipment.

The lower assemblies can be cut into segments suitably sized for the chosen method of shipment. Since the expected curie content of the lower assemblies is about 1000 Ci, and the weight of an assembly is over 200 tons, the cut-up sections can be packaged in strong, tight packages and shipped as low specific activity (LSA) material.

Cutting operations on the steam generators should be performed in enclosure envelopes to minimize the spread of airborne activity. These enclosures should be provided with a HEPA filtration system to reduce any potential releases to the environment and should be designed to allow the use of remote cutting techniques to reduce personnel exposure. Temporary shielding should also be available to further reduce personnel radiation exposure.

If truck transport is used, a larger number of packages would be required to accommodate the lower limit.

At the present time, the most probable means of shipment is a combination of truck and rail transport. Rail can be used to transport the channel head and tube sheets, and truck to transport other pieces.

### Shipment Intact

The only means of shipping steam generator lower assemblies intact is via barge. This method involves the least amount of handling onsite. At the present time, however, receipt capabilities at a licensed burial facility are not available. This may become a viable option in the future. This means of shipment is also available if a steam generator vendor or a research organization should purchase the component for use in a materials study.

## RADIATION EXPOSURE ESTIMATES

The radiation exposure to workers from various operations during steam generator disposal are presented in Table A-1. These operations are applied to the appropriate disposal options and the resultant man-rem estimates listed in Table A-2. The man-rem estimates should not be taken at face value, but rather used as a guide for the various options listed.

If steam generators are cut up for disposal, a significant benefit is derived from short-term storage of the components. Within 5 years of removal, the exposure rate has been reduced to 40% of the initial value. At 10 and 15 years, the exposure rate has been reduced to 20% and 10%, respectively, of the initial value.

Once the steam generators are removed, they can be much more easily decontaminated. This decontamination process can result in significant man-rem savings during the segmenting process.

Table A-3 shows a comparison of the man-rem exposures calculated in this section with those calculated by Florida Power and Light.

## RADIOACTIVE EFFLUENTS

The presence and amount of effluents will vary depending on the disposal option chosen. If onsite long-term storage is chosen, there will be no release of radioactive material. If, at any time, the steam generators are shipped intact to another location, there will be no release. For other options, the amount of radioactive material released will depend on the holding time or the decontamination level. Table A-4 lists the potential airborne effluents for various disposal options. (It is assumed that there will be no liquid effluent. The only option that would lead to a waterborne release is cut-up of the generator, combined with chemical decontamination. In this case, however, it is assumed that all contaminated liquid will be solidified, packaged, and shipped to a disposal site.)

### Calculation of Airborne Effluents

The following calculations are for cut-up of steam generators, with no decay and no chemical decontamination. Other airborne releases are fractions of those listed here. The total release to the environment should be about $4.2 \times 10^{-2}$ Ci.

Cutting the U-tubes for packaging:

- 3/8-inch (0.95-cm) kerf
- 21-mm diameter
- 3400 tubes
- $3400 \times 2.1 \text{ cm} \times \pi \times 0.95 \text{ cm} = 2.1 \times 10^4 \text{ cm}^2$ of material vaporized per cut
- 68 $\mu$Ci/cm$^2$ on the interior of the tubes
- $2.1 \times 10^4 \text{ cm}^2 \times 68\ \mu\text{Ci/cm}^2 = 1.4 \times 10^6\ \mu\text{Ci}$ released
- It is likely that two such cuts will be made to facilitiate packaging.
- Decontamination factor = $10^2$ (1 HEPA filter preceded by a demister)
- Release to the atmosphere is $2.8 \times 10^4\ \mu$Ci.

Cutting out the channel head and tubesheet:

(1) Cut around circumference of channel head

- 3/8-inch (0.95-cm) kerf
- 220-cm inside diameter
- 220 x 0.95 = 660 $cm^2$ of material vaporized
- 68 $Ci/cm^2$ on the interior surfaces
- 660 $cm^2$ x 68 $Ci/cm^2$ = 4.5 x $10^4$ μCi released
- Decontamination factor = $10^2$ (1 HEPA filter preceded by a demister)
- Release to atmosphere is 450 μCi.

(2) Separate tubes from tube sheet by cutting

- Same release as calculated for cutting tubes
- One cut necessary
- Release to atmosphere is 1.4 x $10^4$ μCi.

## CONCLUSION

Currently, the options for steam generator disposal under serious consideration are onsite long-term storage and immediate cut-up and shipment to a licensed disposal site. Of these two, long-term storage offers the greatest man-rem savings, but may also be the option least desirable to legislators and the general public. Immediate cut-up and shipment is costly with respect to radiation exposure and from a purely economic standpoint. If chemical decontamination is used prior to cut-up, a significant savings in radiation exposure results. This option, however, with its associated waste handling problems and liquid radwaste treatment requirements, could add a significant additional cost to an already expensive option.

Especially from an exposure standpoint, temporary onsite storage of the steam generators results in a significant savings. The additional possibility of future intact shipment to a disposal site makes temporary onsite storage an option well worth considering.

TABLE A-1. Exposure, Time, and Man-Rem Estimates for Various Operations During Disposal of Steam Generators

| Operation | Exposure Rate, R/hr[(a)] | Time Estimate, man-hr | Dose, man-rem[(a)] | Comments |
| --- | --- | --- | --- | --- |
| Move steam generator to storage or cut-up facility, deposit and seal facility | 0.03 | 80 | 2.4 | |
| Monitoring of steam generator in sealed storage facility for about 30 years | 0.005 | 50 per/yr | 7.5 | |
| Move steam generator to barge, deposit on barge and ready for departure (no storage period) | 0.03 | 80 | 2.4 | |
| Decontaminate exterior of steam generator and remove insulation | ---(0.2) | 50 | 10 | |
| Connect piping and equipment for decontamination of interior of steam generator U-tubes | ---(0.5) | 50 | ---(12) | About 24 of the 50 man-hr will be spent in radiation zone where welders will connect flange. |
| Decontaminate interior of steam generator. Treat radwaste with mobil system and package waste for shipment | ---(0.1) | 100 | ---(10) | Most of this operation will be done remotely. Some hands-on work may, however, be required |
| Disconnect installed piping | ---(0.1) | 20 | ---(2) | |
| Segment shell of steam generator. Package for shipment | 0.2(0.1) | 500 | 100 (50) | |
| Cut out channel head and tube sheets. Package for shipment | 3 (0.6) | 65 | 195 (40) | |
| Cut out U-tubes and package | 1 (0.5) | 250 | 250 (125) | |
| Clean up area within cut-up facility | 0.5(0.25) | 50 | 25 (13) | |

(a) Numbers in parentheses apply to a disposal option including chemical decontamination of steam generator.

TABLE A-2. Comparison of Man-Rem Estimates for Steam Generator Disposal Alternatives

| Option | Approximate Man-Rem per Steam Generator |
|---|---|
| Long-term storage with intact shipment | 10 |
| Long-term storage with cut-up and shipment | 16 |
| Shorter-term storage with cut-up - at 5 yr | 230 |
| - at 15 yr | 60 |
| Immediate intact shipment[a] | 2.4 |
| Immediate cut-up and shipment by rail/truck - no decontamination | 580 |
| Immediate cut-up and shipment by rail/truck - with chemical decontamination | 270 |

(a) Estimates for short-term storage followed by intact shipment would be only slightly larger than this, perhaps 5 man-rem.

TABLE A-3. Comparioson of Estimated Occupation Exposure for Steam Generator Disposal (for three steam generators)

| Option | Man-Rem | |
|---|---|---|
| | This Report | FPL[6] |
| Long-term storage with intact shipment | 30 | 0.5-1.5 |
| Long-term storage with cut-up and shipment | 50 | 10 -20 |
| Shorter-term storage with cut-up - at 5 yr | 690 | --- |
| - at 15 yr | 180 | --- |
| Immediate intact shipment | 7 | --- |
| Immediate cut-up and shipment by rail/truck - no decontamination | 1700 | 750-1500 |
| Immediate cut-up and shipment by rail/truck - with chemical decontamination | 810 | 125-550 |

TABLE A-4. Comparison of Airborne Effluents for Steam Generator Disposal Alternatives

| Option | Approximate Airborne Release, Ci |
|---|---|
| Long-term storage with intact shipment | Negligible[a] |
| Long-term storage with cut-up and shipment | 0.005 |
| Shorter-term storage with cut up - at 5 yr | 0.026 |
| - at 15 yr | 0.015 |
| Immediate intact shipment | Negligible[a] |
| Immediate cut-up and shipment - no decontamination | 0.042 |
| Immediate cut-up and shipment with decontamination | 0.010 |

(a) Since the steam generator will be sealed before it is removed from containment, no release of radioactive material is expected during these operations.

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16. ABSTRACT (200 words or less)
Frequent maintenance and inspection of steam generators, due to corrosion product accumulation, is necessary at several power reactors to ensure continued safe operation. This need has lead to increased radiation exposure to the workers who perform these tasks.

The combination of frequent maintenance and inspection needs and increased occupational exposures has led several power reactor owners to consider replacing the existing steam generators. This procedure involves a significant amount of radiation exposure, but could save even more by reducing the radiation field and the need for such frequent maintenance and inspection; thus it will also lead to more economic plant operation with fewer power output interruptions. This report presents an analysis of the radiation exposure resulting from the replacement of steam generators.

Liquid, solid and airborne effluents released during the removal and replacement of a steam generator are presented.

Disposal of the steam generator after its removal is a separate topic. Several means of disposal, each with an associated radiation exposure, have been evaluated.

The analysis has been limited to the U-tube type of steam generator, but the analytical technique and radiation exposure levels are applicable to other types of steam generators and perhaps to other reactor system components.

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