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EBWR REACTOR PRESSURE VESSEL REVISIONS FOR
INSTRUMENTATION AND INCREASED STEAM OUTPUT

by

T. L. Kettles and N. Balai

Reactor Engineering Division

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EBWR REACTOR PRESSURE VESSEL REVISIONS FOR INSTRUMENTATION AND INCREASED STEAM OUTPUT

by

T. L. Kettles and N. Balai

I. GENERAL INTRODUCTION

The objective of this report is to document the procedures developed and utilized for the addition of connections to the EBWR pressure vessel after three years (approximately 8000 hr) of intermittent operation at the 20-Mwt design heat output. A unique requirement for these conversions was the practical necessity of modifying the original pressure vessel geometry from within the pressure vessel itself. The reader is referred to ANL-5607⁽¹⁾ for the review of the construction of the reactor facility; from ANL-5607, the proximity of the fixed biological shielding to the pressure vessel is apparent. Major nozzle connections to the pressure vessel were made during two separated periods and under different conditions of vessel content.

The first group of nozzles (2) was installed between February 23, 1959, and March 24, 1959; these nozzles were located in the upper conical ring forging of the pressure vessel which permitted the use of water for shielding against core radiation, that is, the conversion was executed with the original core loading in place. The second group of nozzles (5) was installed between October 1, 1959, and November 24, 1959, and after the EBWR had been operated at the 62-Mwt power level. Prior to the final conversion, the core and control rods were unloaded from within the reactor pressure vessel. Unloading of the core and control rods was dictated by reasons other than the vessel conversion. In the light of later radiation surveys, which are briefly described later in the report, the absence of the core during the second conversion was appreciated.

Table I summarizes the number, size, and functions of the major connections added to the original EBWR pressure vessel. Figure 1 illustrates the working arrangements within the pressure vessel during the second installation period; all vessel changes, with the exception of the northeast instrument nozzle, are shown on the illustration.

The details of the conversion are organized into four main sections:

- II. Nozzle design
- III. Preparations
- IV. Nozzle installation
- Appendices

Verbal descriptions are augmented by numerous selected photographic illustrations for the guidance of future "do-it-yourself" mechanics.

Table I

CONDENSED SUMMARY OF EBWR NOZZLE ADDITIONS

Location in Vessel	Nozzle Identification	Number and Size
<u>February 23, 1959 to March 24, 1959 Additions</u>		
Closure ring forging	East instrument	One 2-in. pipe size with (external) thermal sleeve. Accommodates three $\frac{1}{2}$ -in. and one $\frac{3}{4}$ -in. pipes.
	West instrument	One 2-in. pipe size with thermal sleeve.
<u>October 1, 1959 to November 24, 1959 Additions</u>		
Shell	Steam outlet	One 10-in. pipe size with thermal sleeve.
	Feedwater inlet	One 6-in. pipe size with thermal sleeve.
	Water-level measurement	Two-1 $\frac{1}{2}$ -in. pipe size.
Closure ring forging	Northeast instrument	One 2-in. pipe size with thermal sleeve.

Fig. 1

Working Arrangement in Vessel During Second Nozzle Installation
111-9335-A

II. DESIGN

A. Introduction

The EBWR reactor pressure vessel was originally designed and built in accordance with Section I, "Power Boilers," of the 1956 ASME Boiler and Pressure Vessel Code; the details of the design philosophy and construction are summarized in ANL-5607.⁽¹⁾ Generally, the original philosophy was followed except for the thermal stress relief of welds. It was impracticable to heat the entire vessel and undesirable to stress relieve individual nozzle connections locally because the ring forging and the shell form rigid structures. Local nozzle heating to stress relief temperatures would undoubtedly yield and distort adjacent vessel areas, particularly between ligaments; subsequent cooling might leave unpredictable locked-in stresses in regions adjoining the heat-affected area higher than those relieved in the weld metal. Weld stresses were minimized by three mechanisms: (1) by restricting electrode size to a maximum of $\frac{1}{8}$ -in. diameter; (2) by mechanically peening each weld layer; and (3) by preheating of both the nozzle material and shell plate.

The design of each nozzle installed is described individually. Many of the new features of the nozzle design are minor modifications of the original EBWR nozzle design. Code stress calculations are summarized in Appendix B.

All modifications of the vessel, including boring, torch cutting, weld groove grinding preparations, welding, peening, and fluid penetrant examinations, were made from within the pressure vessel. Metal preheating operations were conducted by heating from the exterior of the pressure vessel. All operations were monitored by Health Physics for air-borne activity.

B. West Instrument Nozzle

The west instrument nozzle is located in the top of the vessel and passes through the wall of the closure ring forging. It incorporates a thermal-sleeved, 2-in. stainless steel pipe connection for a future test of a 900°F superheated steam fuel element; other uses are for in-reactor instrumentation. Its design is shown in Fig. 2.

The required 2-in. pipe connection necessitated the installation of a 3-in. steel nozzle to accommodate all of the cladding and thermal sleeve components. Steel strength welds join the pressure vessel and nozzle materials in order to eliminate the uncertainties of dissimilar metal welds under high restraint conditions. The inside of the 3-in. nozzle is covered with a loose liner of $\frac{1}{8}$ -in.-thick, Type 304 stainless steel corrosion-resistant surface. A stainless steel safe-end was Argonne shop welded to

the dissimilar metal weld between the liner and nozzle material; bare Type 310 stainless steel filler wire was used to make a butt-weld joint which incorporated a consumable backing ring.

Fig. 2

2-in. West Instrument Nozzle
RE-6-32134-D

Three spacers are welded to the 2-in. stainless steel pipe near the inner surface of the ring forging to reduce bending stresses in the connecting weld. An $8\frac{1}{2}$ -in. thermal sleeve length is about the maximum that can be accommodated in the complex reactor geometry; the length is adequate to accommodate the thermal stresses developed by the metal between 900°F superheated steam and forging at 488°F.

Welds in the nozzle assembly were examined by X-ray and dye-penetrant methods. The integrities of welds and components were established by hydrostatic and helium leak detection tests.

The nozzle assembly fitted into a drilled hole in the ring forging prepared for groove-type steel attachment welds and similar to the arrangement shown by Fig. P-36(e-1) of the ASME Power Boiler Code. These strength welds were also examined by dye-penetrant methods prior to the application of cladding. No credit was taken for strength of the Inconel cover weld in the Code stress calculations.

The inner end of the nozzle liner was welded to the ID of a $\frac{1}{8}$ -in.-thick, 8-in.-OD, Type 304 stainless steel diaphragm plate whose OD was welded to the ring-forging cladding. The flex-plate construction (also used in the original EBWR design) accommodates the differential expansion between the steel nozzle and the Type 304 stainless steel liner. Integrity

of construction was established by introducing nitrogen to the weep holes previously drilled through the ring forging and nozzle walls and checking finished welds with liquid soap. The weep holes through the ring forging and nozzle are permanently connected by $\frac{1}{4}$ -in. piping to a pressure gage mounted outside the reactor shielding to detect leaks during operation.

C. East Instrument Nozzle

The east instrument nozzle is located in the closure ring forging at the same elevation as the west nozzle. Its design is similar to that of the west nozzle and functionally provides three $\frac{1}{2}$ -in. and one $\frac{3}{4}$ -in. connections for attenuation of superheated steam and for instrumentation. Socket welding couplings are butt-welded into the 5-in. elliptical head for these external attachments; weld soundness was verified by X-ray and by dye-penetrant examination. The design is illustrated by Fig. 3.

Fig. 3

2-in. East Instrument Nozzle
RE-6-32135-D

D. Northeast Instrument Nozzle

The northeast instrument nozzle is located in the closure ring forging at the same elevation as the west nozzle. The 2-in. pipe connection is terminated above the operating floor level by a short capped length of 6-in. pipe studded with compression-type fittings for tubing connections. The design, as shown in Fig. 4, is also similar to the west nozzle.

Fig. 4

2-in. Northeast Instrument Nozzle
RE-6-32130-C

E. Water-level Measurement Nozzles

Two nozzles were welded into the vessel shell to provide connections for visual gage column observations (with the TV camera) and instrument measurement of the reactor water level. The internal extension of the nozzle offers an opportunity for determining the water level from either side of the shock shield. The design shown in Fig. 5 is similar to the original EBWR water column connections.

Fig. 5

1 1/2-in. Water-level Measurement Nozzle
RE-6-32133-C

The safe-ended shop assembly attached to the vessel shell by welds meets the requirements of Fig. P-36(e-1) of the ASME Power Boiler Code. The strength welds as well as the shop dissimilar metal welds were examined by dye-penetrant, radiographic, and hydrostatic test methods. A $\frac{1}{8}$ -in.-thick, Type 304 stainless steel diaphragm plate was welded to both the cladding and the nozzle to accommodate the differential expansion between the Type 304 stainless steel nozzle liner and the steel nozzle.

F. Steam Outlet Nozzle

This 10-in. nozzle connection replaced the original 6-in. steam outlet for the 100-Mwt output of the reactor. The thermal sleeve design is an adaptation of the original EBWR nozzle design which had functioned satisfactorily. Nozzle details are shown in Fig. 6. The structural requirements of the biological shield design limited the vertical and radial coordinates for the steam-line piping. Measurements inside the removable shielding tunnel revealed that the best arrangement was that which maintained the elevation of the top of the bore of the original 6-in. steam line.

Fig. 6

10-in. Steam Outlet Nozzle
RE-6-32131-C

The bore of the steel nozzle is protected by a loose $\frac{1}{8}$ -in.-thick liner of Type 304 stainless steel. The liner was shop welded to the steel nozzle by the tungsten argon gas arc process with bare Type 310 stainless steel filler wire. Enough additional weld metal was deposited, and subsequently machined, to provide a safe end for the butt-welding of the new, internally concentric, 10-in. steam connection. Three spacers were welded

to the pipe, near the inner surface of the vessel wall, to reduce bending stresses on the dissimilar metal weld. The weld attaching the 10-in. stainless steel pipe to the steel nozzle was examined by the dye-check fluid penetrant method; integrity of construction was verified by helium leak detection tests.

The vessel end of the nozzle was contoured to the inner radius of the vessel shell. The weld root passes were deposited from inside the vessel against a $\frac{1}{4}$ -in.-thick mild steel backup ring which was later removed to permit building up the external fillet portion of the weld. Each weld pass was systematically examined visually prior to peening of the layer. In addition, the root, middle, and the final passes were examined with dye penetrant. The finished welds were radiographed; integrity of construction was demonstrated by the 1200-psi pressure vessel hydrostatic test prior to the reinstallation of vessel insulation and biological shielding.

A $\frac{1}{8}$ -in.-thick, Type 304 stainless steel diaphragm plate was preformed to the inner radius of the vessel shell and welded to both the shell cladding and nozzle liner to complete the cladding of the carbon steel parts of the pressure vessel. This plate accommodates the differential thermal expansion between the stainless steel liner and steel nozzle. Integrity of the cladding construction is continuously monitored during operation. A weep hole bored through the nozzle is permanently connected by a $\frac{1}{4}$ -in. pipe to a pressure gage outside the reactor shielding. This connection was also used to check final cladding integrity. Welds were examined by painting with soap solution while nitrogen gas at 600 psi was maintained behind the cladding.

G. Feedwater Supply Nozzle

This nozzle supplements the capacity of the original 3-in. feedwater supply connection. It provides a thermally sleeved, 6-in. pipe connection feeding a 4-in. internal distribution ring. Its location, well above the core, provides an opportunity for controlling the carryunder of steam bubbles through the reflector region. Except for the size of the distribution ring and strength weld details, the design of the connection is a duplicate of the original 6-in. steam outlet connection. Design details are shown in Fig. 7.

The distribution ring, in two pieces, was assembled inside the bottle-nicked reactor vessel. After welding the internal subsections together, the ring was leveled and the external stainless pipe-to-steel nozzle weld was completed. Nozzle preparations, sealing of carbon steel surfaces by Type 304 stainless steel, and demonstrations of integrity were similar to those described for the 10-in. steam nozzle connection.

Fig. 7

6-in. Feedwater Supply Nozzle
RE-6-32132-C

III. PREPARATION

A. Introduction

Three factors influenced the development of procedures for the installation of the required nozzles into the EBWR pressure vessel:

(1) The geometric relationship of the pressure vessel to its biological shielding (and auxiliary blast shielding). The original design placed virtually all of the desired piping connections along the east face of the biological shielding, which was made removable for possible future maintenance. Access to the work was extremely limited from the exterior. All major contemplated work had to be executed from within the pressure vessel itself.

(2) The limited modification experience gained by the ANL Central Shops during the installation of instrument nozzle connections into the closure flange. Five, widely scattered $\frac{3}{4}$ -in. connections were bored through the 9-in.-thick head with portable, electrically powered and magnetically positioned boring equipment. The results achieved were satisfactory but time consuming, i.e., conventional electrically powered and portable tools were insufficiently powered. Electrically energized tools with adequate power were not portable.

(3) The largely unknown radiation environment. From knowledge gained through operations in removing the head, the radiation from within the pressure vessel was gamma activity. Contributions from (1) the core; (2) activated walls; and (3) deposited particle activity were open to speculation.

The general problem of limiting the radiation exposure was solved by incorporating such "unconventional" machine shop tools as (1) geared air-powered drills, (2) air-powered hand grinders; (3) oxyacetylene flame machining; (4) piloted precision weld bevel grinding; and (5) air-powered peening hammers. A specially mounted Ingersoll-Rand air vane-powered drill proved, as anticipated, to be the work horse for these operations. Many tool improvisations, and improvements, were found necessary during the "dry" runs, which were made against previously prepared steel targets to simulate reactor vessel conditions. Only those who participated in these preliminary operations were permitted to duplicate the operations within the reactor vessel itself. These training missions uncovered a number of material faults (as chisels with inadequate edge-crumbling resistance) which were corrected. The actual work inside the pressure vessel proceeded without a breakdown of tools or equipment.

The problem of stress relief of welds was particularly vexing because in these thicknesses stress relief is a mandatory ASME Code requirement. A general stress-relief heat treatment of the vessel was

impractical for both conversions, i.e., (1) all of the reactor internals would have to be removed, and (2) the uncertainty associated with the embrittlement of the Type 304 cladding and of the dissimilar metal welds between the austenitic stainless steels and carbon steel. A local stress relief of the weldment was more undesirable than the general vessel stress relief for the additional reason that the adjacent areas would be stressed to unpredictable levels by thermal gradients imposed on a rigid and varying geometrical section (as the ring forging). The Code, however, does permit stress relief by mechanical peening. This method was adopted; its effectiveness was verified.

The ensuing commentary describes the detailed development of tools, work procedures, and radiation safety techniques for protection of personnel.

B. Holes in Ring Forging: East, West, and Northeast Instrument Nozzles

Each of these nozzles installed required the boring of a hole, $3\frac{9}{16}$ in. in diameter, and the preparation of a J-groove weld profile whose maximum diameter was $5\frac{11}{16}$ in. The holes were drilled normal to the inner surface of the tapered ring forging at a point where the mean thickness was $5\frac{1}{2}$ in.

The mockup of the machining operation is shown in Fig. 8. The steel block bolted to the table simulates the ring forging. The air-powered drill motor develops 5 hp at 56 rpm with air at 100 psi; the air motor was mounted on a base to slide on an inclined way. Drill bits were fed into the work by turning the tail screw of the drill motor. In this illustration, the hole was bored to the finished size previously; tooling for the preparation of the J-groove, a double-edged fly cutter, supported from a piloted boring bar, is shown.

Fig. 8

Mockup of Hole Machining Operation for Instrument Nozzles
111-7341

C. Holes in Shell: Water Level, Steam, and Feedwater Nozzles

The nozzle additions to the cylindrical EBWR pressure vessel shell were started six months after the installation of the east and west instrument nozzles into the vessel ring forging. Here the $2\frac{7}{16}$ -in.-thick shell plate, about one-half the total thickness of the ring-forging wall, is clad with an intermittently spot-welded $\frac{7}{64}$ -in.-thick, Type 304 stainless steel cladding. The performance of the air-powered drill motor in the prior operations earned its appointment as the prime working tool for the preparation of the large holes in the vessel shell as well.

A 4-ft-high by 8-ft-long section of 2-in.-thick, SA-212B clad boiler plate, rolled to the 84-in. ID of the pressure vessel shell and duplicating the vessel shell cladding, was purchased from the Babcock & Wilcox Company, the fabricators of the EBWR pressure vessel. This test plate is shown in Fig. 9 with the air motor set up to simulate a working position within the reactor vessel.

Fig. 9

Test Plate for Development of Shell
Nozzle Installation Procedures
111-7738

Nozzles for water-level connections required 3-in.-diameter holes with J-groove weld profiles. These holes were machined the same way as the holes in the ring forging had been.

Hole diameters required for the steam and feedwater nozzles were $16 - \frac{5}{8}$ in. and $11 - \frac{5}{8}$ in. minimum, respectively; each of the holes required a 10-degree side bevel for welding. They were cut out with an oxyacetylene torch and ground to finished size.

Figure 10 illustrates the peeling of cladding prior to flame cutting the hole for the steam nozzle connection. A 1-in. pilot hole for centering the flame cutting rig and a 1-in. torch cutting starting hole are visible. Cladding between the two concentric $\frac{1}{8}$ -in.-wide grooves, manually ground only to the thickness of the cladding, was removed by an air-powered chipping hammer. (The diameter of the outer groove is the OD of the nozzle diaphragm plate; the inner groove diameter is less than the finished hole size.)

Fig. 10

Removing Cladding for Steam Nozzle Mockup
111-7915

Figure 11 illustrates the flame-cutting operation for the removal of the nozzle hole plug. Before completing the circular flame cut, the plug was tack welded to the adjoining base shell plate to prevent shifting of the center of the flame-cutting fixture. The ring of center punch marks outside the torch tip outline the finished hole size. At least $\frac{3}{16}$ -in. of stock will be removed by the subsequent grinding operations.

Figure 12 shows a diagram of the grinding apparatus used in the preparation of finished hole ready for welding. The grinder was air powered and developed 3 hp at 2500 rpm. Sufficient degrees of freedom were provided the 6-in.-diameter grinding wheel to generate a 20° included angle conical frustrum as the grinder attachment was revolved by the 5-hp air motor.

Fig. 11
Torch Cutting Hole for
Steam Nozzle Mockup
111-7948

Fig. 12
Apparatus for Grinding Steam and Feedwater Nozzle Holes
RE-6-32136-D

The axial wheel travel along the surface of the frustrum was governed by a threaded journal; the wheel ground on both the "in" and "out" parts of the stroke, which was regulated by manipulating the air valves of the 5-hp air motor. Feed into the work was controlled by the transverse feed screw equipped with position locking nuts. Figure 13 is a photograph showing a stage in the grinding of the feedwater nozzle hole. With sufficient practice, the two-man team developed a high proficiency which was demonstrated by the 30-rpm drill motor feed ($3\frac{3}{4}$ in./min) of the wheel axially into the work; one operator controls the radial grinder feed rate while the second controls the axial feed rate.

Fig. 13
Grinding Hole for Feedwater
Nozzle Mockup
111-7796

D. Welding of Water Level, Steam, and Feedwater Nozzles

Extra material for each nozzle size was purchased for welding into the test plate. Welds were deposited while maintaining a 300°F minimum temperature of nozzle and plate; the metal temperature was maintained by a fabricated ring burner attached to the exterior of the nozzle. Welds were examined visually immediately after each bead was laid down; dye-penetrant examinations were made of the root pass and later stages. Figure 14 shows the steam nozzle mockup being heated by the burner jets; bottled propane gas fuel was used for heating. The concentric flat ring, tack welded to the outer plate surface and to the nozzle, is the backing ring for the strength weld between shell plate and nozzle.

Figure 15 illustrates procedures adopted for the strength weld; in this case the feedwater nozzle weldment is shown. Only stringer passes were permitted; each start was preceded by brushing, grinding, or chipping. The groove depth required the use of a pencil-type power-driven wire brush (chucked in a portable drill) to remove the last vestiges of slag.

Fig. 14

Heating Nozzle and Vessel for
Welding Steam Nozzle Mockup
111-8007

Fig. 15

Laying Strength Weld for
Feedwater Nozzle Mockup
111-7892

Fig. 16

Profiling Fillet Weld on Feed-
water Nozzle Mockup
111-7912

Each layer was peened only from the 12 to 6 o'clock position; the other half of the welds were in the as-welded condition. These connections were later used for an evaluation of the welding procedures. An ample weld was required to permit "fairing" into the plate surface near the cladding by grinding to facilitate radiography and fit-up with the diaphragm plate.

The strength weld was then completed from the opposite side of the plate (the vessel OD), which included the removal of the backup ring and the first two deposited root pass weld layers; the resultant groove (in weld metal) was first ground and then examined by dye penetrant for soundness. The groove was then filled flush with the plate surface, ground and again examined; following this, the fillet weld was built up to the required size and ground to the desired profile. Figure 16 shows the blending of the fillet to the plate and nozzle. A uniform fillet angle was attained by comparison with a template; after polishing the fillet surface, the weld (in the EBWR vessel) was ready for radiographic examinations.

Type 304 stainless steel diaphragm plates were installed for the steam and feedwater nozzle mockups to develop procedures for welding them to the vessel cladding. (Their appearance on the profile specimen, Fig. 17, are not indicative of the fitup or connection to nozzle liners that were provided in the EBWR pressure vessel.)

E. Weld Evaluation

The water level, steam, and feedwater nozzle mockups were cut apart to provide specimens for evaluation of welding procedures. Figure 17 is a photograph of the appearance of typical subsize weld tensile, root bend, face bend, side bend, Charpy V-notch, weld profile hardness, and weld profile macroetch specimens after testing.

The results from the all-weld tensile tests are summarized in Table II. Data from specimens which had been stress relieved at 1150°F for $\frac{1}{2}$ hr show no improvement in ductility over their as-welded or peened-only counterparts. The peened specimens, in fact, exhibited higher ultimate strength and elongation properties.

The $\frac{3}{8}$ -in. by $1\frac{1}{2}$ -in. flat specimens were cold bent 180° around a $1\frac{1}{2}$ -in.-diameter mandrel. All specimens passed the Section IX, ASME Code requirements. Visual examinations of macroetched specimens showed good weld penetration at the side walls, no cracking, and minor porosity. Hardness measurements revealed the usual gradient across the heat-affected regions. There were no significant differences between the as-welded and the peened welds. A $\frac{1}{2}$ -hr stress relief at 1150°F caused a minor general softening; a maximum reduction of 8 points on the Rockwell C scale occurred at the fusion line.

Fig. 17

Typical Weld Evaluation Specimens Removed from
Steam, Feedwater, and Water-level Nozzle Mockups
111-9304

Table II

TENSILE TEST DATA FOR WELD SPECIMENS REMOVED FROM NOZZLE MOCKUPS

(from 0.187-in. diameter by 1-in. gage length standard tensile specimens)

Peened	Unpeened	Stress Relieved	Ultimate Tensile Strength (psi)	Yield Point (psi)	Elongation in $\frac{3}{4}$ in. (%)	Reduction in Area (%)
<u>Feedwater Nozzle</u>						
x	-	-	87,000	64,400	29.2	76
x	-	-	82,000	66,000	33.3	76
-	x	-	80,000	65,500	25	71
-	x	-	81,300	68,000	25	83
<u>Steam Nozzle</u>						
x	-	-	76,300	-	28.1	72
x	-	-	75,500	-	21.8	72
-	x	-	74,500	-	6.3*	-
-	x	-	76,000	-	21.8	79
x	-	x	77,400	-	15.6	26
x	-	x	76,000	-	21.8	69
-	x	x	75,600	-	25	69
-	x	x	76,000	-	18.7	68

*weld flaw

F. Radiation Shielding

Radiation in the reactor vessel was expected from the irradiated core structure, as well as contributions from the thermal shielding and the vessel wall. No prior quantitative data were available. Structural parts of the work platforms were designed so shielding could be built up as found to be necessary. The platform shown in Fig. 18, laid across the top flange of the existing thermal shield, can accommodate an 8-in. thickness of lead brick. The deck structure with its cantilever beams and segmental plates are separable from the center section to permit assembly within the bottle-necked reactor vessel.

A cylindrical shield, seen in Fig. 1, open towards the work area, reduced radiation from the surrounding vessel wall substantially. It is $4\frac{1}{2}$ ft in diameter, 6-ft high, and was constructed of $\frac{3}{8}$ -in.-thick aluminum plate in the ANL Central Shops. It can support as much as a 1-in. thickness of lead.

Fig. 18

Top View of Radiation Shield Platform
111-8041

IV. INSTALLATION

A. First Installation, East and West Instrument Nozzles (February 23-March 24, 1959; 6-day week, 8-hr day)

1. Working Arrangement

After removing the head closure, the vessel was filled with demineralized water to provide a 10-ft-deep water shield over the radioactive fuel. Beta-gamma activity as high as 750 mr/hr at 2 in. from the original 6-in. steam dry pipe and up to 150 mr/hr at 2 in. from the vessel wall were found. These activities were reduced to 150 and 25 mr/hr, respectively, by mopping up loose radioactive particular matter with wet rags.

The working arrangement in the vessel is shown by Fig. 19. A vented "lower" sheet metal platform, not seen, was suspended above the water level from the closure studs and sealed to the vessel wall with 4-in.-wide Polyken tape. This dual-purpose diaphragm (1) controlled the discharge of reactor gases, and (2) prevented loss of tools, chips, and general junk to the reactor. An "upper" platform, which formed a base for the air drill motor, was bolted to the steam dry pipe. Rigidity of the dry pipe was bolstered by additional slings and compression members, which either absorbed or transmitted vibratory forces generated by the high-torque air motor to the pressure vessel shell. This platform was also sealed, by taping, to prevent the entry of cutting oils, tools, chips, and other debris.

Fig. 19

Machining Hole for West Instrument Nozzle

111-7361

2. Holes Machined for Nozzles

Figure 19 shows a step in the machining of the hole for the west instrument nozzle. Personnel were required to wear dosimeters and film packs; additional dosimeters were strategically taped to the platform supports to augment personnel exposure data from personnel monitors. The usual array of Geiger and alpha counters and area survey meters were provided and used frequently. The maximum radiation level was 15 mr/hr at the working platform floor; no man received a daily body dose exceeding 25 mr/8-hr day.

Self-contained air-mask units were worn during the initial machining stages while building air was monitored for air-borne activity. Air masks were shed as soon as Health Physics established the absence of ingestible radioactive agents. Air was sampled continuously in the work area through the tube which is visible above the head of the machinist. There were no releases of any air-borne activity, gamma or alpha, during the working period within the pressure vessel.

A cutting oil with less than 0.1 w/o chlorine content was used in the metal-cutting operations. Continuous visual checks of the tape seal on the upper platform together with housekeeping prevented the entry of oil, chips, and other debris into the pressure vessel.

3. Nozzles Welded

Figure 20 shows the deposition of the root pass in the east instrument nozzle weld groove. Because previous monitoring established the absence of air-borne activity, neither welder nor inspector are wearing air masks. The root pass, an interim pass, and the ground final pass were examined by dye-penetrant methods.

4. Completion

The completed east instrument nozzle installation as viewed from outside the vessel is shown in Fig. 21. The small bottom pipe is the $\frac{1}{4}$ -in. IPS connection which monitors integrity of the construction of the diaphragm plate and nozzle liner. The horizontal pipe is the original $\frac{3}{4}$ -in. IPS vessel vent line which passes through the reactor shielding along with the new instrument nozzle piping connection. The east nozzle, west nozzle, and associated piping installation consumed 26 eight-hour shifts. A hydrostatic test at 1200 psig and subsequent reactor operations, with saturated steam at 600 psig, proved the integrity of the installation.

Fig. 20

Laying Inner Attachment
Weld for East Instrument
Nozzle

111-7449

Fig. 21

East Instrument Nozzle
as Completed

111-7493

B. Second Installation; Northeast Instrument, Water Level, Steam, and
Feedwater Nozzles (October 1 - November 24, 1959; 7-day week, 24-hr day)

1. Upper Pipe Tunnel Opened

The water level, steam, and feedwater nozzles were placed in the vessel shell and within the accessible upper pipe tunnel (see Fig. 1). This 8-ft-long tunnel is part of the reactor shielding and is a multi-depth concrete block grout-bonded masonry structure. The joints of succeeding layers are suitably broken to eliminate radiation leakage.

Figure 22 shows the steel-lined tunnel with blocks, pipe troughs, and pipe insulation removed. It is $7\frac{1}{3}$ ft high by 8 ft wide at the reactor shield face, and 6 ft high by 4 ft wide at the inner face nearest the reactor pressure vessel. The reactor vessel and vessel insulation are inside a $\frac{3}{4}$ -in.-thick plate steel cylinder which supports the inner lead gamma and ferro-boron neutron shielding and shield-cooling coils.

Fig. 22
Pipe Tunnel Cleared of
Concrete Block
111-7966

The pipes that are visible are (1) the 6-in. steam line that was replaced; and (2) the $1\frac{1}{2}$ -in. poison and water level lines which were retained. The copper tubing, which is visible in Fig. 23, is used to circulate cooling water through the lead shield during reactor operation. It was bent away from the work area to maintain its original seamless and jointless continuity.

Fig. 23
Cutting an Opening in-
to the $\frac{3}{4}$ -in.-thick Plate
Steel Cylinder
111-8030

Figure 23 illustrates an arc-air-gouging technique utilized to outline the opening in $\frac{3}{4}$ -in.-thick steel cylinder following the removal of the ferro-boron and lead. The arc-air gouging was stopped short of complete penetration of the plate in order to prevent the entry of debris into the annulus around the reactor vessel. The plate plug was ultimately parted with a conventional air-powered chipping hammer equipped with a collet-retained cutting chisel.

Figure 24 shows a 6-ft-high by $3\frac{1}{2}$ ft-wide access hole almost completed through the steel cylinder. The right plate section has been removed; the left section is arc-air gouged and ready for final chipping. Bolting lugs were welded on for the later reinstallation of the sections.

Fig. 24

Sections Cut Out for
Access through Steel
Cylinder

111-8121

Neither lead melting nor the arc-air gouging of the steel released any measurable air-borne activity. However, the self-contained breathing masks were worn during both operations for protection against the hot combustion gases released in the close confines of the pipe tunnel.

Figure 25 shows the reactor vessel after the removal of the Type 430 stainless steel wool thermal insulation. A sheet metal "window frame," tack welded to the steel cylinder and sealed to the vessel with furnace iron cement, prevented the entry of debris to the annulus around the vessel in the subsequent operations of nozzle installation. The original 6-in. steam nozzle, whose position is outlined in relief, had been removed earlier by sawing.

Maximum background activity in the pipe tunnel with the vessel full of water prior to the cutting of piping was 10 mr/hr gammas. Maximum background activity with water at the top of the thermal shield and after the nozzle has been sawed was 30 mr/hr gammas.

Fig. 25

Outside Preparations
Completed for Nozzle
Installation

111-8247

2. First Cleanup in Vessel

The interior of the reactor vessel was surveyed for radioactivity after the core had been unloaded and the vessel filled with water to the top of the thermal shield. The measured background was 75 mr/hr at the vessel stud level; the gamma source strength increased to 1000 mr/hr at 6 in. above the core shroud (see Fig. 1). Surface measurements on the shock shield showed up to 1500 mr/hr gamma and beta at 2 in. Wet swab smears from the top of the steam ring revealed that the activity was particulate, which necessitated a scouring of the surfaces most likely to be contaminated.

Men, lowered in a bucket platform slung from the overhead crane, washed particulate matter off surfaces of the exposed vessel and shock shields. A limitation of 80 mr for radiation dose permitted a work period of only 10 min/man. After four swabbings with rags and water, activity on vertical surfaces was reduced by 10%; horizontal surface activity, such as the steam dry pipe, was reduced by 70%. Activity near the core shroud had not been lowered. This was puzzling at the time, but the answer was forthcoming from later activity surveys and later experiences; there had not been sufficient time for the radioactive particulate matter washed down from the vessel walls and shock shield to settle out in the bottom of the pressure vessel. It was demonstrated that agitation of the water, such as by raising and lowering the water level by 6 ft, increased the activity threefold. After a 2-day settling period, the activity dropped to 35 mr/hr at the vessel stud level.

3. Shock Shield Removed

Figure 26 shows a stage in the disassembly of the shock shield. The shock shield was originally made from four longitudinal sections which were assembled together with $\frac{1}{2}$ -in.-diameter cap screws and nuts; the shock shield was bolted to the thermal shield with $\frac{1}{2}$ -in.-diameter cap screws. As a precautionary measure, the nuts and cap screws had been "staked" to the shock shield by tack welds. The assembly screws of the shock shield were unfastened in the quickest manner - by tightening the nuts and shearing the "staking" welds and the screws. Maximum shielding was retained by lowering the water level and bucket platform only enough to work on the next lower circumferential rows of screws. Although lower flange mounting screws are not visible in the illustration, these were readily removed, without galling, from the tapped holes in the harder boron-containing Type 304 stainless steel thermal shield.

Fig. 26

Shock Shield Being
Disassembled Inside
Vessel

111-8251

Previously, the upper 10-in. length of the shield cylinder had been cut off to permit the removal of the remaining lower pieces from behind the poison ring. Cutting was by first grinding a partial groove on the ID of the $\frac{1}{8}$ -in.-thick Type 304 stainless steel shock shield and then slicing through with an air-powered chipping hammer equipped with a collet-retained cutting chisel. Such a procedure was necessary to prevent the entry of grinding debris and tools into the annulus between the shield and wall. Air-borne activity during grinding was negligible.

The light and dark zones which appear on the shock shield apparently developed during the operation of the reactor. The dark zone could not be lightened by vigorous rubbing with wet rags; there were no differences in the activity. The boundary is about 3 ft above the operating water level.

Activity surveys of sections of the shock shield after their removal from the vessel showed source strengths up to 1250 mr/hr at 2 in. Appendix A summarizes the experimental findings concerning the nature of the activity.

4. Second Cleanup in Vessel

An activity survey of the vessel interior following the removal of the shock shield revealed that the activity at 6 in. above the core shroud had been reduced from 1000 to 850 mr/hr. The maximum activity of the exposed vessel wall was 1000 mr/hr at 2 in. These measurements were suspected to be erroneous because there was no practical way to discriminate against the radiation from the core shroud, supports, thermal shield, and other sources below the water line.

Nevertheless, the vessel wall was swabbed another six times with rags and water from the bucket platform. Radiation surveys revealed that these scrubbing operations reduced background, at 6 in. above the core shroud, from 850 to 650 mr/hr. Again all measurements were with unshielded meters; the wall source strength had been reduced an additional 10 to 20%.

The vessel wall laid bare by the removal of the shock shield (see Fig. 27), revealed a fairly uniform scalloped area around the circumference of the vessel. The mean elevation of the bottom of the scallop points is about at the operating water level. It is surmised that the bright-metal, oxide-free areas were caused and maintained by fluid flow conditions existing in the large annulus between shock shield and the pressure vessel.

Fig. 27

Appearance of Reactor
Vessel Cladding Behind
Shock Shield

111-8237

5. Steam Dry-pipe Ring Removed

Figure 28 shows the cutting of the 6-in. steam ring with a reciprocating saw. For this operation, two support brackets for the shadow shield were temporarily removed from the vessel wall to permit the rotation of the dry pipe about the steam nozzle axis for the sawing operation. Air-borne activity during grinding and sawing operations was negligible. Figure 29 shows the steam ring after its removal from within the pressure vessel.

Fig. 28

Sawing 6-in. Steam Dry-
pipe Inside Vessel
111-8258

Fig. 29

Removing 6-in. Steam Dry-pipe
111-8264

The maximum activity on this and on the larger arc section measured 30 mr/hr at 2 in. All holes were taped to prevent the spread of any active particulate material which may have been deposited inside the steam ring.

6. Radiation Shield Platform Installed

The shield platform was partially assembled on the operating floor and lowered onto the thermal shield. The completed deck was then covered with a 3-in. layer of lead brick, as shown in Fig. 30, to reduce radiation from activated components closer to the core. This composite shield, structural steel deck, and a 3-in. layer of lead, with water 2 in. above the core shroud, reduced the activity level to 35 mr/hr at 3 ft above the platform. The maximum vessel wall activity measured 80 mr/hr at 2 in. The before-and-after activity surveys conclusively established that the principal source strength was below the water line. For the subsequent operations, another steel working deck was installed, and this reduced the activity level substantially.

Fig. 30
Radiation Background Being
Measured Over Radiation
Shield Platform and
Lead Brick
111-8273

7. Holes Bored for Nozzles in Shell

The sequence of machining operations was from top to bottom to maintain the maximum depth of water shielding. Figure 31 shows the working platform positioned for machining the upper water level nozzle hole. This platform was a $\frac{3}{4}$ -in.-thick steel plate equipped with sheet metal extension segments to prevent entry of debris to the pressure vessel. The platform was suspended from a structural tension rod system attached to the vessel bolting and to the internal vessel lugs. Lateral rigidity was effected by jack bolts screwed against the vessel wall. The plate was

pre-drilled to provide the required patterns of anchor bolt holes to mount the air drill for the required nozzle orientations. At the highest working level, and with water about 1 ft below the platform, the background radiation on the platform was 8 to 10 mr/hr. The boring of the upper water level nozzle was completed in five working hours.

Fig. 31

Working Platform Being
Assembled for Machining
Upper Water-level Nozzle
Hole

111-8281

Figure 32 illustrates the preliminary flame machining of the hole for the new steam nozzle. The stream of burning metal, issuing from the cut, was caught in a hand-held bucket by a helper stationed in the pipe tunnel. Although the operator of the cutting torch wore an assault mask, the data from air analyses taken during the operation showed negligible air-borne activity. The source strength of the plug removed measured a maximum of 6 mr/hr at 1 in.

Fig. 32

Steam Nozzle Hole
Being Torch Cut
111-8305

Figure 33 is a view from within the vessel showing all holes completed. Dye-penetrant examination of the surface revealed no laminations or grinding cracks. A cladding edge around the lower water level hole is being prepared for welding to its diaphragm plate. The gamma activity at the lowest platform level was 30 mr/hr.

Air-borne activity was negligible during all machining, torch cutting, and grinding operations. The large plug removed for the new 6-in. feedwater nozzle had beta and gamma activity on the clad side, 75 and 25 mr/hr at 2 in., respectively. Figure 34 is a view of the completed holes from the pipe tunnel. The crescent-shaped area above the steam hole outlines the fillet portion of the original 6-in. steam nozzle-to-vessel butt-weld. It was ground flush with the vessel before the new 10-in. nozzle was installed.

Fig. 33

Completed Holes Viewed from
Inside Vessel

111-8329

Fig. 34

Completed Holes Viewed from
Pipe Tunnel

111-8328

8. Hole Machined for Northeast Instrument Nozzle

The decision to install this nozzle was made after the 6-in. and 10-in. nozzle holes had been completed; in consequence, only a limited

water shielding could be provided. However, the background in the working area, illustrated by Fig. 35, was only 10 mr/hr. Machining of the hole, including the preparation of the weld profile, was completed in 7 hr.

9. Nozzles Welded

The lower water level nozzle was installed first. Figure 36 is a view from within the vessel, and shows the as-welded appearance of the connection completed. A surface pyrometer was used to measure the temperatures of nozzle and vessel, which were heated from outside the vessel.

Fig. 35

Northeast Instrument Nozzle Hole
Being Machined
111-8340

Fig. 36

Lower Water Level Nozzle Tem-
perature Being Measured
111-8346

Figure 37 shows a repair operation to remove porosity in an external fillet weld which was visually detected during welding and confirmed by a dye-penetrant examination. The fillet weld for this particular nozzle was the most difficult on account of the welding position. A mirror was required for observation and control of the welding operation. Although all electrodes were previously baked and maintained at 230°F/250°F, five repairs were necessary before a sound fillet weld was made. Two different brands of electrodes were discarded.

Fig. 37

Porosity in Lower Water-level Nozzle Fillet Weld
Being Removed

111-8440

The poor quality of the electrodes was ascribed to the steel strike then in progress, i.e., all commercial low-hydrogen electrode stocks had deteriorated in storage. The accepted weld was made with freshly made Babcock and Wilcox Company Type E-7015 electrodes which were air freighted in hermetically sealed 10-lb containers directly from Barberton. All remaining steel welds were made with these electrodes without further welding difficulties.

Figure 38 is a view of the vessel from the pipe tunnel, which shows an early stage in the welding of the feedwater nozzle. The illustration shows the method of preheating of the vessel and nozzle. The gas-fired ring burner was provided with a temperature-sensing element to stop gas flow on ignition failure.

Fig. 38

Feedwater Nozzle Being
Heated for Strength
Weld

111-8471

In the lower right, the plug removed from the shell for the feedwater nozzle is visible - in the form of a "milk stool." The plug was used as a test weld plate for screening electrodes and to demonstrate that mildly radioactive material has no effect on welding.

Figure 39 is a view looking into the pressure vessel while welding the new feedwater nozzle. For this operation, the aluminum radiation shield cylinder, covered with a $\frac{1}{4}$ -in. thickness of lead, was installed on the working platform to reduce radiation background to 15 mr/hr. Welding was performed on a 24-hr/day basis; the nozzle and adjoining vessel were kept at a minimum temperature of 300°F. The white substance around the nozzle is a compound which was brushed on to prevent contamination of the Type 304 stainless steel cladding by carbon steel weld splatter. Figure 40 shows the new 10-in. steam nozzle in position and ready for pre-heating and welding. The 2-in. pipe support was removed after a substantial root weld had been deposited from the inside of the pressure vessel. Also visible are: the completed 6-in. feedwater nozzle and the upper water level nozzle.

Fig. 39

Feedwater Nozzle
Strength Weld Being
Layed

111-8475

10. Nozzle Welds Radiographed

The water-level nozzle attachment welds were radiographed in one exposure with gamma rays from Ir¹⁹². The source was located in the pipe tunnel on the nozzle centerline, and film and penetrameters were inside the vessel. Feedwater and steam nozzle weld radiographs were also made with an Ir¹⁹² source in accordance with the geometry indicated in Fig. 41. Three different exposures from each of the three selected equidistant circumferential vantage points permitted a 100% radiographic examination of the welds. Film and two penetrameters, one each for the shell and for the fillet weld, were located inside the vessel. Figure 42 shows the taping of the film cassettes to the wall for the radiography of the steam nozzle weld.

Fig. 40

Steam Nozzle Located Ready for
Heating and Welding

111-8526

Fig. 41

Geometry for Radiographing Steam
and Feedwater Strength Welds
RE-6-23836-C

Fig. 42

Steam Nozzle Strength Weld Being
Prepared for Radiography

111-8577

Double-film techniques for single-film viewing were required. A 13-c Ir¹⁹² source was employed. Standard ASME Boiler Code penetrameters were used. A minimum 7 to 1 ratio of S to F was held for resolution of defects. The radiograph film density was approximately 1.5 and clearly reproduced the smallest hole of the penetrameter. Welds were practically defect free; the largest defect was less than that represented by the smallest penetrameter hole. Repairs were not required.

11. Diaphragm Plates and Feedwater Distribution Ring Installed

The feedwater distribution ring was assembled from two pieces within the vessel. The tee section was placed inside the nozzle, rotated, and then welded to the circular section, as shown in Fig. 43. A consumable backing ring was placed into the root of the weld in order to obtain a smooth profile inside the pipe. Later, two equally spaced brackets, were welded to the vessel wall cladding for the support of the distribution ring. After leveling of the welded ring header, the strength weld was made between the tee prolongation of the header and the nozzle safe end on the outside of the vessel in the pipe tunnel. Dye-penetrant examinations established the integrity of the welds.

Fig. 43

Feedwater Distribution Ring
Being Welded in Vessel

111-8600

Type 304 stainless steel diaphragm plates, $\frac{1}{8}$ in. thick, were preformed to expedite a close fit up with the vessel wall. Welds to the vessel cladding and nozzle liners were examined by dye-penetrant methods. Integrity was established by applying nitrogen under pressure behind the plate and testing exterior surfaces with liquid soap. A number of pin holes were found and defects were remedied.

12. Final Cleanup in Vessel

Figure 44 shows the vessel after it had received its final cleaning. Tape used to seal the working platform to the wall left a tenacious deposit that had to be sanded off. This operation produced more airborne contamination than any other, measuring 20% beta-gamma MPL (MPL = 7.7×10^5 d/min/c liter) for Co^{60} at the sander and 5% just outside the vessel. Alpha activity was less than MPL for unknown isotopes at each location.

Fig. 44

Nozzle Installation Completed Inside Vessel
111-8784

13. Pipe Installed through Tunnel

Pipe connections from the new nozzles were temporarily terminated with welded plugs outside the reactor shielding for hydrostatic testing of nozzle welds and tunnel pipe welds. Pipe and fittings ends were pre-matched and assembled with fixtures and on supports, shown in Fig. 45, to maintain close alignment for the critical root welds. These root welds were made with consumable rings by the shielded tungsten arc process; helium blanketing gas within the piping prevented oxidation of the weld.

The illustration shows the completion of a feedwater line weld by arc welding; only stringer beads were deposited. After the desired weld reinforcement had been deposited by the arc welding, the surface of the weld was "washed" by a shielded tungsten arc pass to facilitate grinding.

Inspection of the root welds, from inside the pipe, was facilitated by a predetermined assembly sequence and through the use of mirror arrangements.

Fig. 45
Feedwater Pipe in Tunnel Being Welded
111-8627

Figure 46 is a view of the completed tunnel piping. A number of the piping joints had been previously shop welded and X rayed. All field welds were radiographed in place with a 7-c Ir¹⁹² source. A hydrostatic test at 1200 psig proved the nozzle and pipe welds satisfactory.

Fig. 46
Tunnel Piping Completed
111-8650

14. Pipe Tunnel Closed

Figure 47 is a view showing an early stage in the reinstallation of tunnel shielding materials. The protective sheet metal window frame between the steel shield form and the pressure vessel had been removed; the vessel had been insulated with 3-in.-thick Type 430 stainless steel wool. The $\frac{3}{4}$ -in. steel plate shield form, modified for the new connections, was replaced.

Fig. 47
Lead Shielding Being Poured over
Copper Cooling Tubes
111-8688

The operation depicted is the pouring of the 2-in.-thick lead shield around the $\frac{5}{8}$ -in.-OD, copper cooling coils. The cooling coils were annealed, re-formed to suit the new nozzle arrangement, and tested hydrostatically to ascertain integrity. Figure 48 shows the trowel application of the $\frac{1}{2}$ -in.-thick layer of ferro-boron concrete plaster, supported by expanded metal lath attached to the galvanized sheet metal lead-pouring forms. Pipes were re-insulated with Type 430 stainless steel wool, much of which was salvaged from the original piping insulation.

Fig. 48
Ferro-boron Plaster Being Troweled
against Lead Pouring Forms
111-8682

In Fig. 49, concrete blocks are being laid around protective steel troughs that encase the pipes. This type of construction, with heavy concrete blocks, was continued to the reactor shielding face.

Fig. 49
Concrete Block Being
Layed in Tunnel
111-8686

15. Pipe Installed Outside Reactor Shield

In accordance with prior contractual agreements, Laboratory forces completed the water-level piping to the water column, and terminated the steam and feedwater piping at a point where outside contractor personnel would not be exposed to radiation. The tunnel pipe welding procedures were used on piping outside the biological shield except that welds were not radiographed. Temporary plugs closed off the new connections to permit hydro testing of the completed field modifications. Hydrostatic test plugs were then cut off and new weld ends prepared for subsequent piping welds.

Since the use of consumable welding rings requires closely matched pipe ends with uniform lands, a scarfing tool was built for the preparation of grooves for the $1\frac{1}{2}$ -in. pipes; a grinding rig was built for the preparation of the 6-in. and 10-in. pipe grooves. Figure 50 shows the tooling for grinding of a J-groove on the 10-in. Schedule 80S, Type 304 stainless steel steam pipe. The grinding wheel was preformed to the weld profile; the air-powered grinder was revolved about the pipe manually. Metal removal was controlled by adjustment of the knurled collar.

Figure 51 is a view of the feedwater and steam piping. The 6-in. feedwater line is in the lower left foreground and was the contractor's starting point for piping to the new pumps. In the welding operation the welder is arc welding a 6-in. branch connection to the existing steam drier which supplies dry steam to the turbine.

Fig. 50

Rig for Grinding J-groove on
End of 10-in. Steam Pipe
111-8720

Fig. 51

6-in. Connection from 10-in. Steam Pipe
to Steam Drier Being Welded
111-8765

Figure 52 shows the fusion of a consumable ring in the root weld under the surveillance of the inspector. The 10-in. by 8-in. reducer resting on the support plate was a starting point for the contractor for piping to the new heat exchangers for the production of Laboratory heating steam.

Fig. 52

Consumable Weld Ring Being Fused
in Steam Connection to Heat Ex-
changers and Relief Line
111-8787

V. DISCUSSION AND SUMMARY

Although this documentary report was primarily concerned with the mechanics of the field conversion of the EBWR to future high-power (100-Mw) operations, there were ample opportunities for comparing the performance of the reactor complex with the original designs. The most significant observations are associated with:

- (a) nozzle installation;
- (b) radioactive particulate material transport;
- (c) trapped radioactive particulate matter; and
- (d) future revisions.

Each of these topics is discussed separately below.

A. Nozzle Installation

While in the design stage, the original design of the EBWR pressure vessel incorporated the necessary nozzles to and from future forced-circulation pumps. The required shell nozzle connections, with the exception of the two 12-in. forced-circulation nozzles, were specifically oriented along one face of the biological shield, which was made removable for future maintenance work. No other "spare" vessel nozzles were permitted by the logic which dictated that each additional hole in the shell presented another source of vessel failure.

Soon after the completion of the most urgent experiments in core physics, there arose a demand for communications with the interior of the vessel. These were satisfied by introducing five $\frac{3}{4}$ -in. connections through the flat-plate closure flange. These operations have been excluded from this report although mentioned in the Introduction to Part III; the design and method of attachment were identical with those for the $\frac{3}{4}$ -in. vent line. At a still later time, results from the reactor experiments created demands for still more nozzle connections. The addition of these later nozzles were the major changes which were described herein.

B. Radioactive Particulate Material Transport

Over the operating period preceding the conversion to permit operation at 100 Mw, the closure had been removed on numerous occasions (about two dozen times), which permitted an assessment of the "hot crud" problem. On all occasions, except the last one, which included the demonstration of the stability when producing 62-Mw power, the "skyshine" from the reactor vessel, flooded with water, presented no problem. Other check points in the system, the activities from the steam separator (cooler-dryer) and from the condenser hotwell, confirmed the low rates of carryover of radioactive solids. The activity problem at conversion time was quite different and was

solved practically by a parade of manpower; each man absorbed 100-mr gammas in 15 min during the initial washing and shock shield-removal operations.

C. Trapped Radioactive Particulate Matter

In the design stage, the pressure vessel was jokingly referred to as the sump of the sewer system. The operating history between December 1956 and June 1959 amply verifies the jest, although filters and ion exchangers have given yeoman service. Although the source of the accumulated crud is unknown, its presence has manifested itself continuously in the form of high activity at the control rod thimbles. Gamma activity as high as 50 r/hr has, with difficulties, been sluiced, which included rodding, from the thimbles on a number of occasions. The original $\frac{1}{2}$ -in. thimble connections have also been enlarged to permit future higher velocities of wash water to get rid of this crud. Thus, the time-honored boiler blow-down connection has a similar useful function in a nuclear reactor application, and was incorporated into the EBWR during this shutdown as described above.

D. Future Revisions

The problems encountered in the conversion of the upper portion of the EBWR pressure vessel have been readily solved. Additional major nozzles in the upper half of the shell can be provided, but in areas other than along the face of the removable biological shielding. The installation of such additional nozzles would necessitate excavations in the monolithic 8-ft-thick biological shield itself.

The problems associated with the installation of nozzles in the lower half of the vessel would require the removal of the internals (core shroud, grid plate, thermal shield, and thimble shielding). Indications of these problems were manifested after the core was removed from the shroud structure and the vessel drained. The "skyshine" from the coreless vessel was 15 r/hr. Such future operations would require the development of remotely operated tools working through at least 15 ft of water shielding.

Appendix A

RADIOACTIVITY

Radiation encountered during the period of second nozzle installation was produced by induced activity of reactor parts and of particulate matter. Most of the gammas came from the bottom 11 ft of the reactor. Radiation at the vessel top measured 35 mr/hr after completion of the nozzle installation, with lead brick shielding and platform removed and water just above the thermal shield. The gamma level increased to 15,000 mr/hr when the vessel was drained.

Loose particulate matter on vertical surfaces accounted for 10% to 20% of the total activity in the upper vessel. The balance was a tenacious radioactive deposit. A 48-hr chemical decontamination experiment on a section of the shock shield by a mixture of 10% H_3PO_4 + 4% EDTH at room temperature, followed by additions of 2% HCl, Rustaway 77 (a proprietary compound), and agitation with steam resulted only in a negligible reduction in activity. Another shock shield section from the most active region was surveyed. Gamma activity on the side which faced the center of the reactor was 25% higher than the surface which faced the vessel wall. Beta activity on the reactor side was six times that of gamma. Beta activity on the vessel side was 25% of the gamma activity.

Experiments in shock shield decontamination by surface grinding revealed that a 60% reduction of both beta and gamma activity was achieved by removing 0.00075 in. from each surface. The removal of 0.003 in. from each surface removed all beta activity and reduced gamma activity by 90%.

Analyses of smear samples, ground material, and machine chips identified the activity as the long-lived radioisotopes Co^{58} and Co^{60} . Calculations indicate that, at reactor shutdown, 85% to 90% of the total activity was due to Co^{58} . No short-lived nuclides were detected five months after reactor shutdown.

Appendix B

ASME CODE NOZZLE CALCULATIONS

Supporting calculations show that the strength of the connections meet the requirements of the 1959 Edition of the ASME Boiler and Pressure Vessel Code. These calculations follow:

1. West Instrument Nozzle

Design condition: 800 psig at 650°F (900°F at end of superheated steam connection)

a. Nozzle Wall Thickness [Section I, Par. P-268 (e)(4)(a)]

$$t_{rn} = \frac{800 \times 1.45}{15,000 \times 1 - 0.6 \times 800} + 0 = 0.080 \text{ in.}$$

Minimum wall provided = $0.875 \times 0.3 = 0.26 \text{ in.}$

b. Reinforcement [Section I, Par. P-268 (c)]

t_r ring forging [Section VIII, Par. UG-32 (g)]

$$t_r = \frac{800 \times 75.375 \text{ in.}}{2 \times 0.889 (17,500 \times 1 - 0.6 \times 800)} = 1.99 \text{ in.}$$

$$A_r = 2.9 \times 1.99 = 5.77 \text{ in.}^2$$

Area provided in forging alone = $2(5.06 - 1.99)(5.06) = 31 \text{ in.}^2$

c. Nozzle Welds [Section I, Par. P-268 (h)(2)(d)]

$t_{\min} = 0.3 \text{ in.}$, $1.25 t_{\min} = 0.375 \text{ in.}$, $t_1 = 0.5 \text{ in.}$, $t_2 = 0.5 \text{ in.}$

Load on weld (pushout) = $\pi \times 1.75^2 \times 800 = 7700 \text{ lb}$

Strength of fillet weld alone = $\pi \times 3.5 \times \frac{1}{2} \times 0.49 \times 17,500 = 47,200 \text{ lb}$

d. Pipe Penetration Wall Thickness [Section I, Par. 23]

$$t_r = \frac{800 \times 2.375}{2 \times 9400 \times 1 + 0.8 \times 800} + 0 = 0.098 \text{ in.}$$

Minimum wall provided = $0.875 \times 0.218 \text{ in.} = 0.19 \text{ in.}$

- e. Conical End of Transition [Section VIII, Par. UG-32 (g)] (for Type 316 Stainless Steel Material)

$$t_r = \frac{800 \times 2.77}{2 \times 0.866 (16,000 \times 1 - 0.8 \times 800)} = 0.083 \text{ in.}$$

Minimum thickness provided = 0.30 in. (measured)

$$\text{Load on weld (pushout)} = \pi/4 \times (2.375)^2 \times 800 = 3500 \text{ lb}$$

$$\begin{aligned} \text{Strength of fillet weld alone} &= \pi \times 2.375 \times 0.35 \times 0.49 \times 9400 \\ &= 12,000 \text{ lb} \end{aligned}$$

2. East Instrument Nozzle

Design condition: 800 psig at 650°F

a., b., & c. Same as for West Instrument Nozzle (Item 1 above).

- d. Head Thickness [Section I, Par. 195 (g)]

$$t_r = \frac{800 \times 2.406}{0.8 \times 11,200 \times 1 - 0.6 \times 800} = 0.227 \text{ in.}$$

Minimum wall provided = $0.875 \times 0.375 = 0.328 \text{ in.}$

- e. Coupling Thickness [Section I, Par. P-268 (e)(4)(a)]

$$t_{rn}(\frac{3}{4} \text{ in.}) = \frac{800 \times 0.53}{0.8 \times 11,200 \times 1 - 0.6 \times 800} = 0.050 \text{ in.}$$

Minimum wall provided = $0.193 - 0.06 = 0.133 \text{ in.}$

- f. Reinforcement [Section I, Par. P-268 (c)]

$$A_r = 1.06 \times 0.227 = 0.24 \text{ in.}^2$$

Area provided:

$$\text{Head} = (0.375 - 0.227) \times 1.06 = 0.157$$

$$\text{Coupling} = 2(0.133 - 0.050) \times 2.5 \times 0.193 = 0.138$$

$$\text{Coupling land} = (1.05 - 0.742) \times 0.375 = 0.116$$

$$\text{Total} \quad 0.411 \text{ in.}^2$$

g. Coupling Weld

$$\text{Load on Weld} = [(1.45 \times 0.227) - (2.125 - 1.45)(0.375 - 0.227)]$$

$$\times 11,200 = 2550 \text{ lb}$$

$$\text{Strength of groove weld alone} = \frac{1}{2} \times \pi \times 1.45 \times 0.375 \times 0.74$$

$$\times 11,200 = 7100 \text{ lb}$$

3. Northeast Instrument Nozzle

Design condition: 800 psig at 650°F

a., b., c., & f. Same as for West Instrument Nozzle (Item 1 above).

d. Pipe Penetration Wall Thickness [Section I, Par. P-23]

$$t_r = \frac{800 \times 2.375}{2 \times 11,200 \times 1 + 0.8 \times 800} + 0 = 0.083 \text{ in.}$$

$$\text{Minimum wall provided} = 0.875 \times 0.218 = 0.19 \text{ in.}$$

e. Conical End of Transition [Section VIII, Par. UG-32 (g)] (for Type 304 Stainless Steel Material)

$$t_r = \frac{800 \times 2.77}{2 \times 0.866 (11,200 \times 1 - 0.8 \times 800)} = 0.12 \text{ in.}$$

$$\text{Minimum thickness provided} = 0.30 \text{ in. (measured)}$$

4. Water Level Nozzle

Design Condition: 800 psig at 650°F

a. Pipe Wall Thickness [Section I, Par. P-23]

$$t_r = \frac{800 \times 1.9}{2 \times 11,200 \times 1 + 0.8 \times 800} + 0 = 0.066 \text{ in.}$$

$$\text{Minimum wall provided} = 0.875 \times 0.200 = 0.175 \text{ in.}$$

b. Reinforcement [Section I, Par. P-268 (c)]

$$t_r \text{ vessel shell} = \frac{800 \times 42}{17,500 \times 1 - 0.6 \times 800} + 0.1 = 2.07 \text{ in.}$$

Minimum wall thickness provided = 2.41 in. (measured)

$$A_r = 1.9 \times 2.07 = 3.94 \text{ in.}^2$$

Area provided:

$$\text{Vessel shell} = 2(2.41)(2.41 - 2.07) = 1.64$$

$$\text{Nozzle} = (3 - 1.9)(0.34 + 2.5 \times 0.56) = 1.91$$

$$\begin{aligned} \text{Pipe} &= 2[0.200(2.41 + 0.5) + (0.200 - 0.066)(2.5 \times 0.200)] \\ &\quad \times 11,200 / 17,500 = 0.83 \end{aligned}$$

$$\text{Fillet weld} = 2 \times \frac{1}{2} \left(\frac{1}{2} \times \frac{1}{2} \right) = 0.25$$

$$\text{Total} \quad \underline{\quad\quad\quad} \quad 4.63 \text{ in.}^2$$

c. Nozzle Welds [Section I, Par. P-268 (h)(2)(d)]

$$t_{\min} = 0.55 \text{ in.}, 1.25 t_{\min} = 0.69 \text{ in.}, t_1 = 0.5 \text{ in.}, t_2 = 0.625 \text{ in.}$$

$$\text{Load on welds} = (3.94 - 1.64) \times 17,500 = 40,300 \text{ lb}$$

$$\begin{aligned} \text{Strength of fillet weld in shear} &= \frac{1}{2} \times \pi \times 3 \times 0.5 \\ &\quad \times 0.49 \times 17,500 = 20,200 \end{aligned}$$

$$\begin{aligned} \text{Strength of groove weld in tension} &= \frac{1}{2} \times \pi \times 3 \\ &\quad \times 0.74 \times 17,500 = 38,000 \end{aligned}$$

$$\text{Total} \quad \underline{\quad\quad\quad} \quad 58,200 \text{ lb}$$

d. Pipe Welds [Section I, Par. P-268 (h)(2)(d)]

$$t_{\min} = 0.200 \text{ in.}, 1.25 t_{\min} = 0.25 \text{ in.}, t_1 = 0.56 \text{ in.}, t_2 = 0.25 \text{ in.}$$

$$\text{Load on welds} = (3.94 - 1.64 + 1.91) \times 17,500 = 6800 \text{ lb}$$

$$\begin{aligned} \text{Strength of top fillet weld alone} &= 0.5 \times \pi \times 1.9 \times 0.56 \\ &\quad \times 0.49 \times 11,200 = 9400 \text{ lb} \end{aligned}$$

5. Steam Nozzle

Design condition: 800 psig at 650°F

a. Pipe Wall Thickness [Section I, Par. 23]

$$t_r = \frac{800 \times 10.75}{2 \times 11,200 \times 1 + 0.8 \times 800} + 0 = 0.373 \text{ in.}$$

Minimum wall provided = $0.875 \times 0.5 = 0.438 \text{ in.}$

b. Nozzle Wall Thickness [Section I, Par. P-268 (3)(4)(a)]

$$t_{rn} = \frac{800 \times 5.625}{17,500 \times 1 - 0.6 \times 800} + 0 = 0.264 \text{ in.}$$

Minimum wall provided = 2.09 in. (measured)

c. Reinforcement [Section I, Par. 268 (c)]

$$A_r = 11.25 \times 2.07 = 23.3 \text{ in.}^2$$

Area provided:

$$\text{Vessel wall} = (11.25 - 4.18)(2.41 - 2.07) = 2.4$$

$$\text{Nozzle} = 2(2.09 - 0.26)(0.34 + 2.5 \times 2.09) = 20.4$$

$$\text{Fillet weld} = 2 \times 0.5(1 \times 1) = \underline{1.0}$$

$$\text{Total} \quad 23.8 \text{ in.}^2$$

d. Pipe Attachment Weld

$$\text{Load on weld (pushout)} = \pi \times 5.5^2 \times 800 = 76,200 \text{ lb}$$

$$\text{Strength of fillet weld in shear} = \frac{1}{2} \times \pi \times 11 \times 1.06$$

$$\times 0.49 \times 11,200 = 96,000 \text{ lb}$$

6. Feedwater Nozzle

Design condition: 800 psig at 650°F

a. Pipe Wall Thickness [Section I, Par. P-23]

$$t_r = \frac{800 \times 6.625}{2 \times 11,200 \times 1 + 0.8 \times 800} + 0 = 0.23 \text{ in.}$$

$$\text{Minimum wall provided} = 0.875 \times 0.432 = 0.377 \text{ in.}$$

- b. Nozzle Wall Thickness [Section I, Par. P-268 (e)(4)(a)]

$$t_{rn} = \frac{800 \times 3.56}{17,000 \times 1 - 0.6 \times 800} + 0 = 0.167 \text{ in.}$$

$$\text{Minimum wall provided} = 1.625 \text{ in. (measured)}$$

- c. Reinforcement [Section I, Par. 268 (c)]

$$A_r = 7.125 \times 2.07 = 14.75 \text{ in.}^2$$

Area provided:

$$\text{Vessel wall} = (7.125 - 3.25)(2.41 - 2.07) = 1.32$$

$$\text{Nozzle} = 2(1.625 - 0.17)(0.34 + 2.5 \times 1.625) = 12.80$$

$$\text{Fillet weld} = 2 \times 0.5 (1 \times 1) = 1.00$$

$$15.12 \text{ in.}^2$$

- d. Nozzle Attachment Weld

$$\text{Load on weld (pushout)} = \pi \times 3.31^2 \times 800 = 27,600 \text{ lb}$$

$$\text{Strength of fillet weld in shear} = \frac{1}{2} \times \pi \times 6.625 \times 1$$

$$\times 0.49 \times 11,200 = 53,500 \text{ lb}$$

BIBLIOGRAPHY

1. The Experimental Boiling Water Reactor, ANL-5607 (May 1957).
2. E. A. Wimunc and J. M. Harrer, Hazards Evaluation Report Associated with the Operation of EBWR at 100 Mw, ANL-5781 -Addendum (Dec 1960).
3. EBWR 100-Mw Design Report, ANL-5607 -Supplement (to be published).
4. ASME Boiler and Pressure Vessel Code - 1959 Edition
 - (a) Section I - Power Boilers
 - (b) Section VIII - Unfired Pressure Vessels
 - (c) Section IX - Welding Qualifications

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Over seventy persons were intimately responsible for successful revision of the EBWR reactor pressure vessel.

The Industrial Hygiene and Safety Division provided continuous health-physics representation. They maintained a control point at the vessel entrance to supervise use and disposition of toe rubbers, protective clothing, and radioactive materials. They also tabulated individual radiation doses to assure no man exceeded 300 mr/wk or 100 mr in any one day.

Plant Services provided services such as removing and replacing concrete reactor shielding.

The Laboratory Shops fabricated the parts and installed them in the reactor. They also built and tested the tools developed for the job.