Docket No. 50-029

MEMORANDUM FOR: Richard H. Wessman, Director
Project Directorate I-3
Division of Reactor Projects - I/II
Office of Nuclear Reactor Regulation

FROM: Patrick M. Sears, Project Manager
Project Directorate I-3
Division of Reactor Projects - I/II
Office of Nuclear Reactor Regulation

SUBJECT: SUMMARY OF MEETING WITH YANKEE ROWE CONCERNING REACTOR VESSEL TEST PROGRAM

On November 20, 1990, representatives of Yankee Atomic Electric Company (YAEC) met with the staff to discuss their reactor vessel test and material sampling program. This meeting was part of ongoing discussions regarding the Yankee Rowe reactor vessel and relate to the staff's safety assessment of August 31, 1990. YAEC requested staff concurrence on their test program and furnished the enclosed slides. At the conclusion of the meeting YAEC was requested to provide the following test matrix:

- Number of capsules
- Composition of materials in each capsule
- Number of samples of each material in each capsule
- Irradiation temperature
- Heat treatment conditions (i.e., fine grain vs. coarse grain)
- Fluence

YAEC agreed to provide the above in a letter by November 26, 1990. The staff agreed to respond within 2 weeks of receipt of that letter. The staff stated that based on the information provided by the licensee at the meeting the number of weld material samples to be removed from the reactor vessel should be increased. The licensee indicated that the information was preliminary and a form of submittal regarding the weld sample program would be provided at a later date.

A list of attendees is also enclosed.

Patrick M. Sears, Project Manager
Project Directorate I-3
Division of Reactor Projects - I/II
Office of Nuclear Ractor Regulation

Enclosures: As stated

cc: See next page

*See previous concurrence

LA:PDI-3	PM:PDI-3	RES/EMEB	EMCB*	NRR/DET	D:PDI-3
MRushbrook	PMSears	AHiser	KWichman	JRichardson	RWessman
12/4/90	12/4/90	12/7/90	11/26/90	12/5/90	/ /90

OFFICIAL RECORD COPY: MEETING SUMMARY YR 11/20/90

Docket No. 50-029

MEMORANDUM FOR: Curtis J. Cowgill, III, Acting Director
Project Directorate I-3
Division of Reactor Projects - I/II

FROM: Patrick M. Sears, Project Manager
Project Directorate I-3
Division of Reactor Projects - I/II

SUBJECT: SUMMARY OF MEETING WITH YANKEE ROWE CONCERNING REACTOR VESSEL TEST PROGRAM

On November 20, 1990, representatives of Yankee Atomic Electric Company (YAEC) met with the staff to discuss their reactor vessel test and material sampling program. YAEC furnished the enclosed slides. In addition, YAEC was requested to provide the following test matrix:

- Number of capsules
- Number of samples of each material in each capsule
- What are the materials in each capsule
- Irradiation temperature
- Heat treatment conditions (i.e., fine grain vs. coarse grain)
- Fluence

YAEC agreed to provide the above in a letter by November 26, 1990. After some discussion the staff stated that the number of weld material samples to be removed from the reactor vessel should be increased.

A list of attendees is enclosed.

Patrick M. Sears, Project Manager
Project Directorate I-3
Division of Reactor Projects - I/II

Enclosures:
As stated

cc: See next page

LA:PDI-3	PM:PDI-3	EMCB	PD:PDI-3(A)
MRushbrook	PMSears	KWichman	CJCowgill
11/26/90	11/26/90	11/26/90	/ /90

DISTRIBUTION:

Docket File
NRC & Local PDRs
F. Miraglia
J. Partlow
S. Varga
E. Greenman
PDI-3 R/F
R. Wessman
P. Sears
M. Rushbrook
OGC
ACRS(10)
E. Jordan
K. Wichman
J. Caldwell
J. Johnson, Region I

DF01

Docket No. 50-029 December 11, 1990

MEMORANDUM FOR: Richard H. Wessman, Director
Project Directorate I-3
Division of Reactor Projects - I/II
Office of Nuclear Reactor Regulation

FROM: Patrick M. Sears, Project Manager
Project Directorate I-3
Division of Reactor Projects - I/II
Office of Nuclear Reactor Regulation

SUBJECT: SUMMARY OF MEETING WITH YANKEE ROWE CONCERNING REACTOR VESSEL TEST PROGRAM

On November 20, 1990, representatives of Yankee Atomic Electric Company (YAEC) met with the staff to discuss their reactor vessel test and material sampling program. This meeting was part of ongoing discussions regarding the Yankee Rowe reactor vessel and relate to the staff's safety assessment of August 31, 1990. YAEC requested staff concurrence on their test program and furnished the enclosed slides. At the conclusion of the meeting YAEC was requested to provide the following test matrix:

- Number of capsules
- Composition of materials in each capsule
- Number of samples of each material in each capsule
- Irradiation temperature
- Heat treatment conditions (i.e., fine grain vs. coarse grain)
- Fluence

YAEC agreed to provide the above in a letter by November 26, 1990. The staff agreed to respond within 2 weeks of receipt of that letter. The staff stated that, based on the information provided by the licensee at the meeting, the number of weld material samples to be removed from the reactor vessel should be increased. The licensee indicated that the information was preliminary and a formal submittal regarding the weld sample program would be provided at a later date.

A list of attendees is also enclosed.

Original signed by:
Patrick M. Sears, Project Manager
Project Directorate I-3
Division of Reactor Projects - I/II
Office of Nuclear Ractor Regulation

Enclosures: As stated

cc: See next page

*See previous concurrence

LA:PDI-3	PM:PDI-3*	RES/EMEB*	EMCB*	NRR/DET*	D:PDI-3*
MRushbrook	PMSears	AHiser	KWichman	JRichardson	RWessman
12/04/90	12/04/90	12/07/90	12/25/90	12/05/90	12/11/90

OFFICIAL RECORD COPY: MEETING SUMMARY YR 11/20/90

Enclosure

MEETING CONCERNING YANKEE ROWE REACTOR VESSEL

NOV 20, 1990

LIST OF ATTENDEES

NAME	ORGANIZATION/POSITION	PHONE
PATRICK SEARS	NRR/PD1-3 PROJ. MGR	492-1436
Art Lowe	BWNS	804-385-3276
KEITH WICHMAN	NRR/EMCB	301 492-0752
S. LEE	NRR/LRPD	301-492-0771
FRANK LOSS	MEA	301 577-9490
C. COWGILL	NRR/PD 1-3 Acting Director	301-492-1434
[illegible] BIEMILLER	YAEC	508-865-0121
Randy K. Nanstad	ORNL	615-574-4471
John Haseltine	YAEC	508-779-6711
Steve Fyfitch	BWNS	804-385-3273
Joe McCumber	YAEC	508-779-6711
Norm Snidow	BWNS	804 385 3738
R.J. CACCIAPOUTI	YAEC	508 779-6711
S. E. MAYS	ACRS	301-492-7904
L. PETRUSHA	BWNS	804-385-2584
B. ELLIOT	NRR/EMCB	301 4920709
LAMBROS LOIS	NRR/DST	301-492-3233
AL TABOADA	NRR/RES	301 492 -3938
STAN T ROSINSKI	DOE/SANDIA LABS	505-844-[illegible]
John TSAO	NRR/EMCB	301-492-0713
Allen Hiser	RES/MEB	301-492-3988
ROBERT CARTER	YAEC	508-779-6711
Ron Gamble	Novetech	301-330-1919
Eve Fotopoulos	SERCH Licensing, Bechtel	301-417-3094
Lynn Connor	SAIC	703-827-4957
ANDREW McMINN	FoRA	703-914-1070
JR HAWTHORNE	MEA	301-577-9491

ENCLOSURE

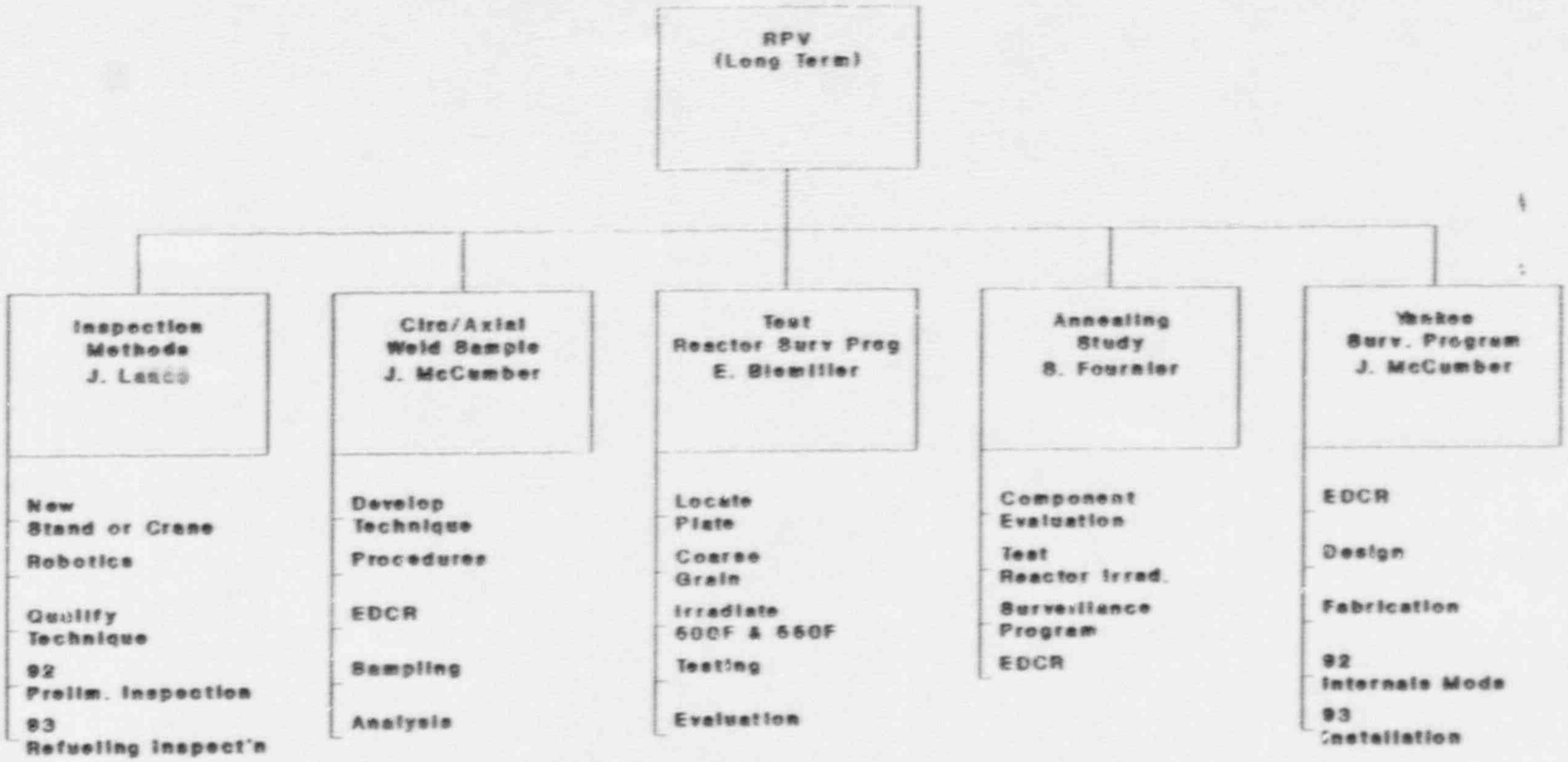
Yankee Reactor Pressure Vessel

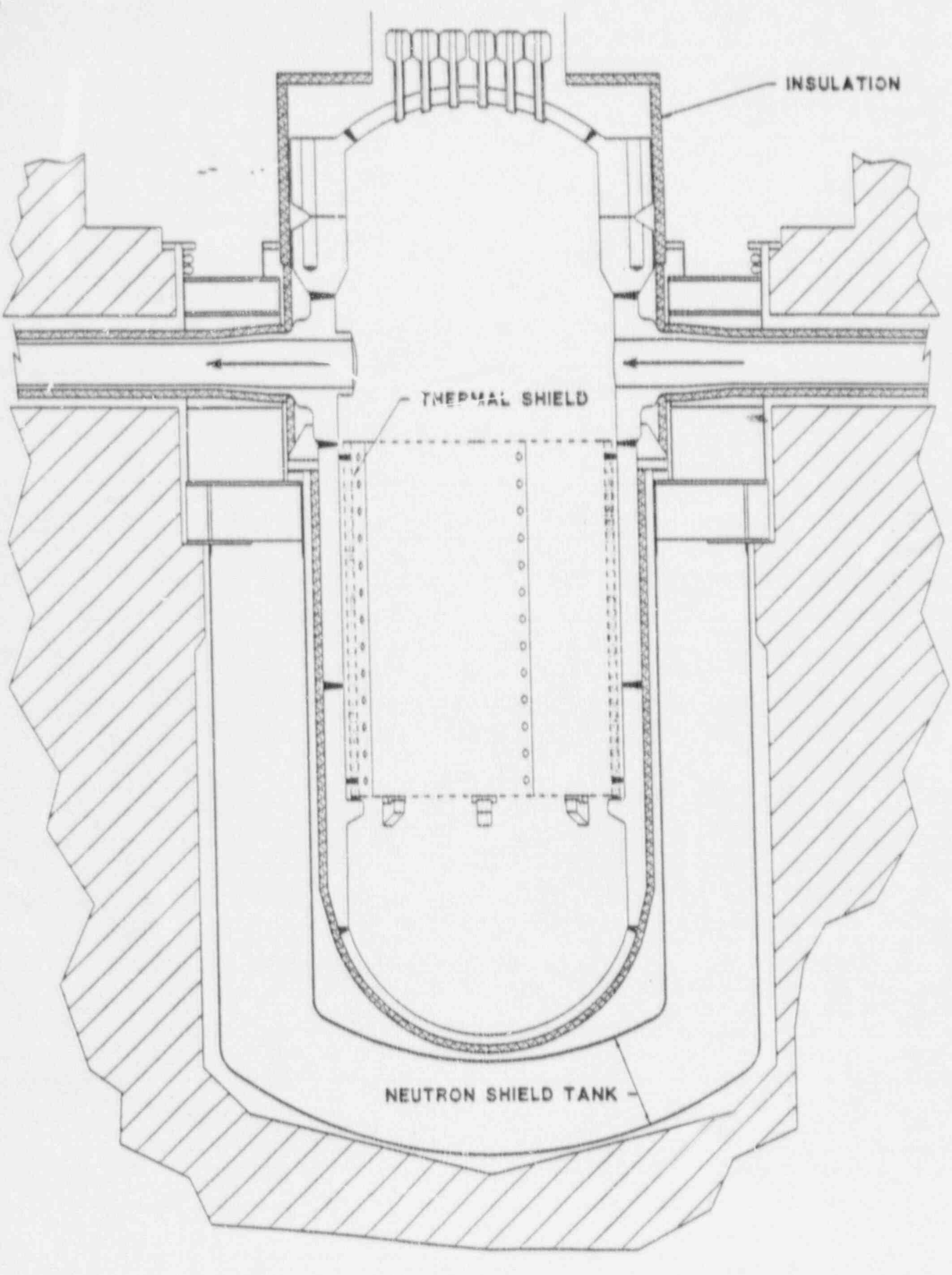
NRC Staff Presentation

November 20, 1990

Presentation Overview

- Introduction
- Test Reactor Program
  - Program Objective
  - Test Material Procurement
  - Plate Heat Treatment Process
  - Baseline (Pre-Irradiation) Tests
  - Proposed Irradiation Matrix
  - Test Reactor
  - Dosimetry for Irradiations
  - Schedule
  - Reporting
  - Additional Tasks
- Weld Sampling Program
  - Program Objective
  - Sampling Considerations
  - Weld Configuration
  - Sample Size/Quantities/Locations


RPV
(Long Term)
Inspection Methods
J. Lasco
New
Stand or Crane
Robotics
Qualify
Technique
92
Prelim. Inspection
93
Refueling Inspect'n
Circ/Axial
Weld Sample
J. McCumber
Develop
Technique
Procedures
EDCR
Sampling
Analysis
Test
Reactor Surv Prog
E. Biemiller
Locate
Plate
Coarse
Grain
Irradiate
500F & 550F
Testing
Evaluation
Annealing
Study
S. Fournier
Component
Evaluation
Test
Reactor Irrad.
Surveillance
Program
EDCR
Yankee
Surv. Program
J. McCumber
EDCR
Design
Fabrication
92
Internals Mods
93
Installation



YANKEE VESSEL SUPPORT

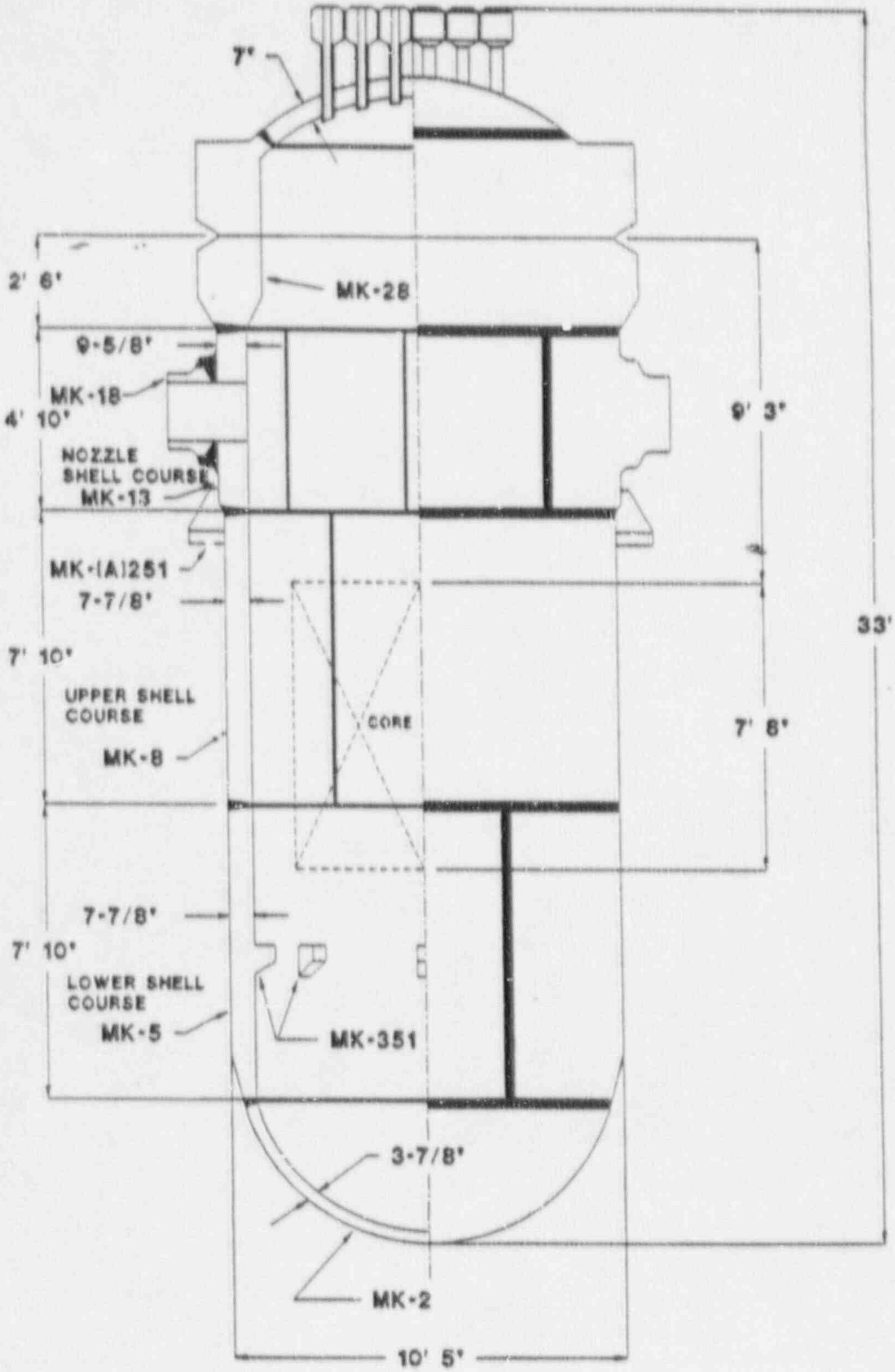


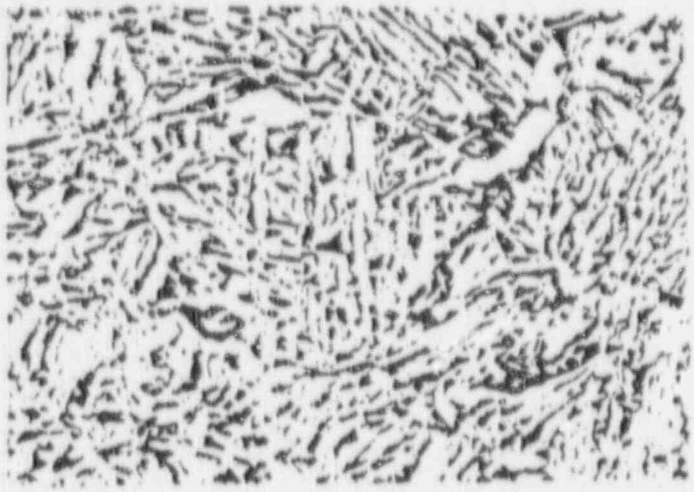
FIGURE 1-2

Weld & Plate Locations

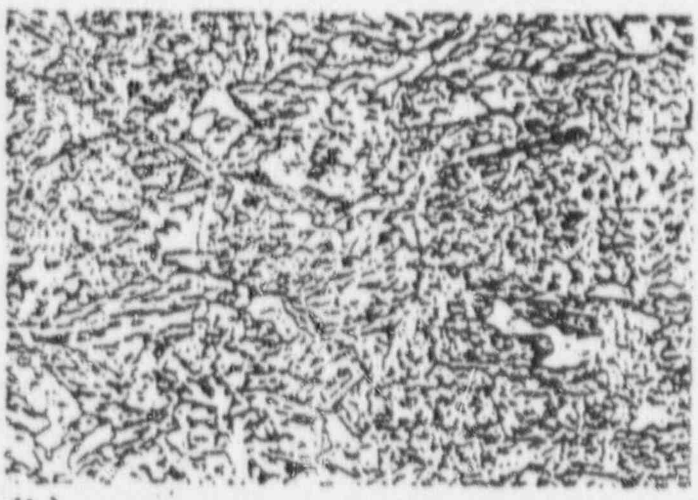
Test Reactor Irradiation Program

Objective

- Verify the irradiation behavior of the Yankee vessel plate materials.
  - Coarse vs. Fine Grain (Austenitized at 1750-1800F vs. 1650F)
  - Effect of Irradiation Temperature (500F vs. 550F)
  - Effect of Nickel
    Lower Plate - 0.63% Ni, 0.20% Cu
    Upper Plate - 0.21% Ni, 0.18% Cu
- The upper plate was included in Yankee and BR3 surveillance studies. The lower plate was not tested.



(a) Yankee pressure-vessel surveillance steel, tempered bainite



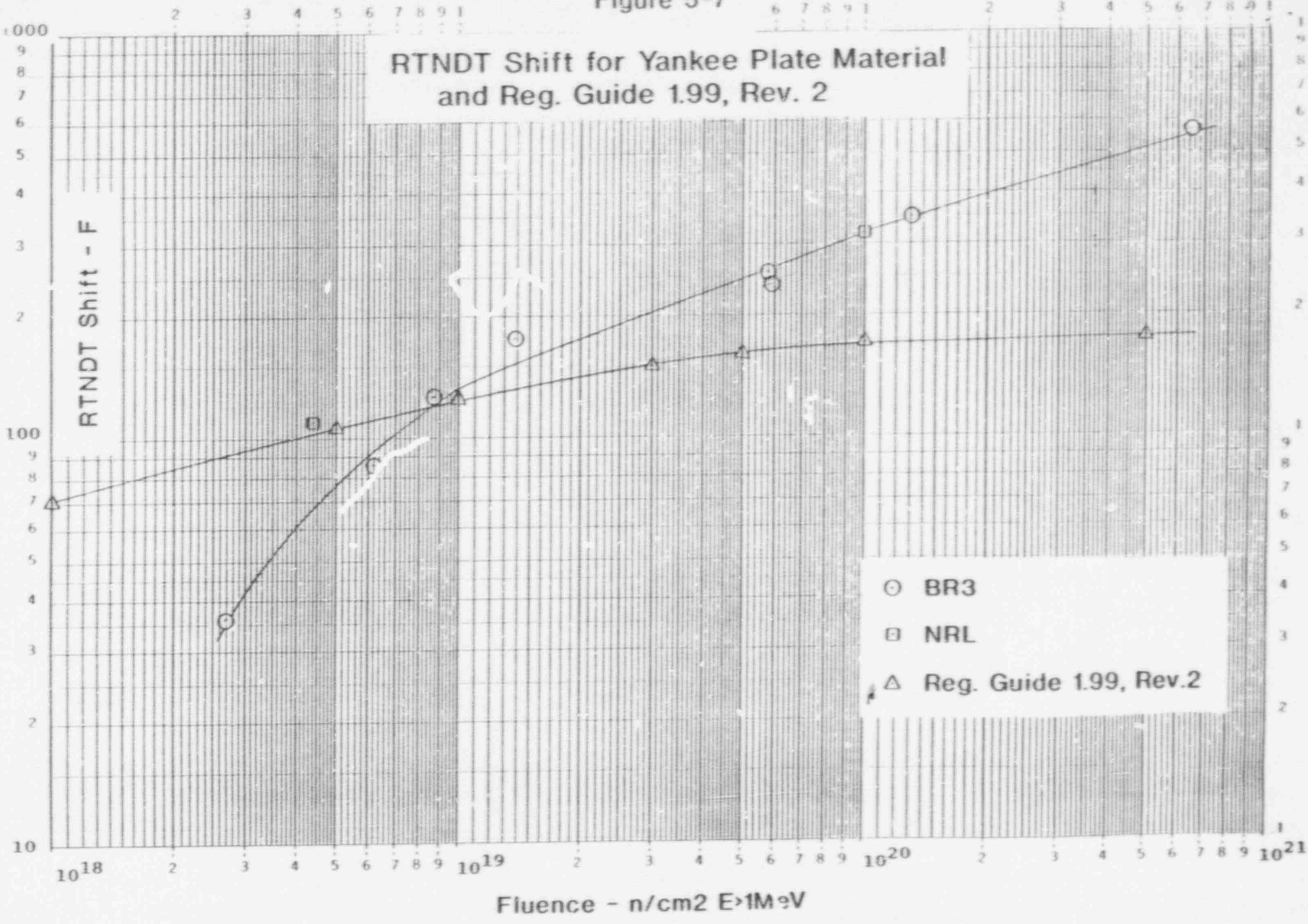
(b). A302B reference steel; tempered upper bainite

FIG. 79—*Microstructures of the Yankee surveillance steel and of the ASTM A302-B reference steel at ×500 (nital-picral etchant) (Ref 11): (a) Yankee pressure-vessel surveillance steel; tempered upper bainite; and (b) ASTM A302-B reference steel; tempered upper bainite.*

FIGURE 5-1

(Reference 9)

Figure 5-7



RTNDT Shift for Yankee Plate Material
and Reg. Guide 1.99, Rev. 2
RTNDT Shift - F
Fluence - n/cm2 E>1MeV
BR3
NRL
Reg. Guide 1.99, Rev.2

Material Procurement

- Identify candidate materials for test reactor irradiations.
- Need to match the vessel chemistry as close as possible.
- To date, we have located several materials.

Lower Vessel Shell Material

Chemistry

	Cu	Ni	C	Mn	Si	Mo	S	P	Cr	Al
YA1	.240	.620	.250	1.400	.230	.590	.011	.008	.110	.020
YA2	.170	.560	.230	1.290	.210	.570	.015	.009	.100	.027
Yankee Lower Plate	.200	.630	.190	1.180	.200	.480	.026	.016	.130	-

- YA1 and YA2 materials bracket the Cu, Ni contents of the Yankee vessel lower plate.
- A "coarse grain", 500F irradiation of this material should bound the irradiation behavior of the lower plate.

YA1 and YA2 Materials

- The advantages of using the YA1 and YA2 plates are:
  - YA1 and YA2 have been included in prior test reactor studies.
  - The materials were austenitized at 1600F ("fine grain"). Sections will be grain coarsened.
  - There is pre- and post-irradiation data available (published in ASTM STP-570 by Hawthorne). This material has been irradiated at 550F to fluences of 1.8, 3.2, 5.3, and 5.9E+19 n/cm2.

Additional Materials Located

- Plate

	Cu	Ni	P	S
YA3	.13	.48	.013	.014
YA4	.13	.82	.015	.015
YA5	.13	.58	.012	.015
YA6	.14	.48	.008	.015
YA7	.14	.57	.006	.015

- The copper is too low to represent the vessel lower shell plate.
- YA3 and YA4 may be of use to determine a nickel effect.

Upper Vessel Shell Material

	Cu	Ni	C	Mn	Si	Mo	S	P	Cr	Al
YA8	.140	.200	.210	1.150	.250	.600	.017	.015	.220	<0.01
YA9 (not obtained)	.240	.190	.170	1.280	.220	.500	.022	.026	.160	-
Yankee Upper Plate	.180	.210	.200	1.270	.210	.480	.028	.020	.060	-

- YA8 material has low copper compared to the Yankee vessel upper plate.
- YA9 is located but has not been obtained.
- We are still looking for A 302-B material in the .18% - .22% copper range.

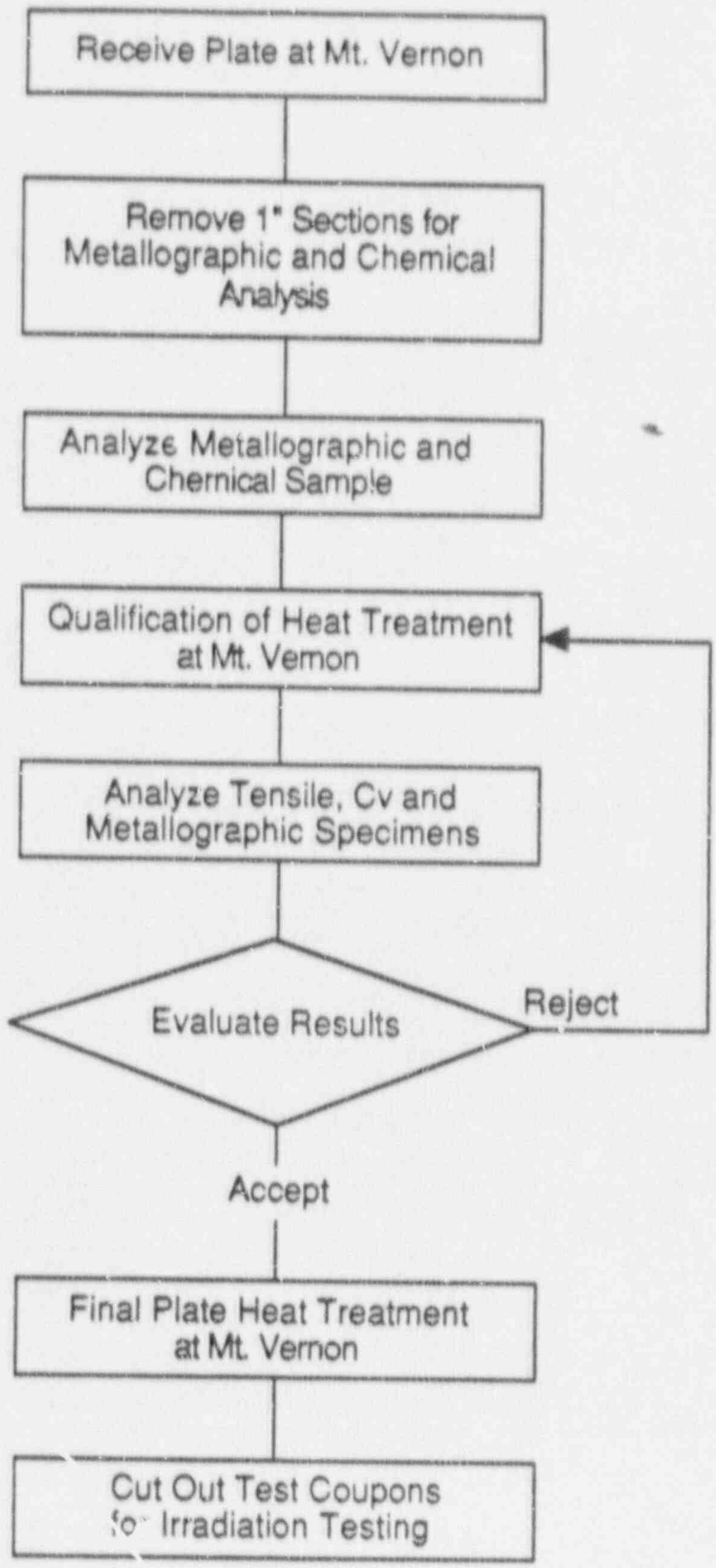
Standard Material

- A "standard reference material" which has been used in previous irradiation studies will be included to benchmark the tests.
- This reference material will be "fine grain" material and will be irradiated at 550F.
- We believe plates YA1 and YA2 can double as a reference material because of its prior irradiation history.
- We are still investigating the use of other reference material such as HSST plates.

Heat Treatment Process

- The plate will be heat treated at B&W.
- The test material will have additional material welded to it to provide mass to duplicate the cooling rates.
- The plates will be austenitized at 1750F to 1800F and spray quenched.
- The microstructure will be characterized through the thickness.

Heat Treatment Qualification

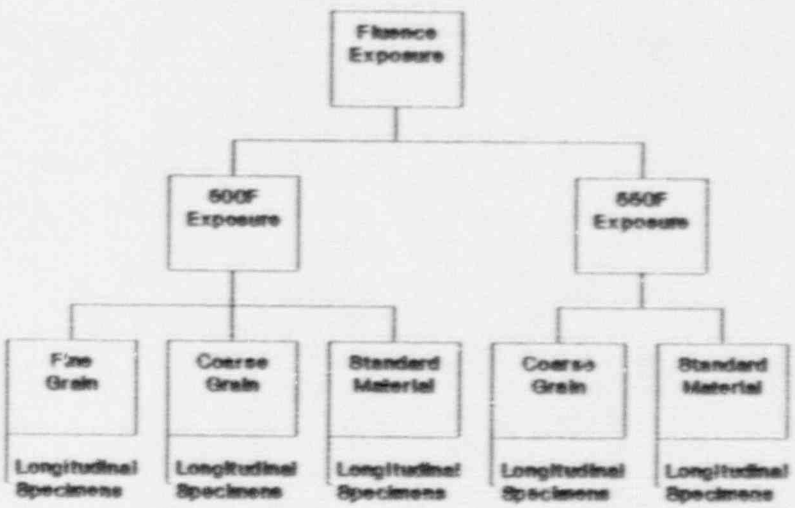


Baseline Test
Pre-Irradiation

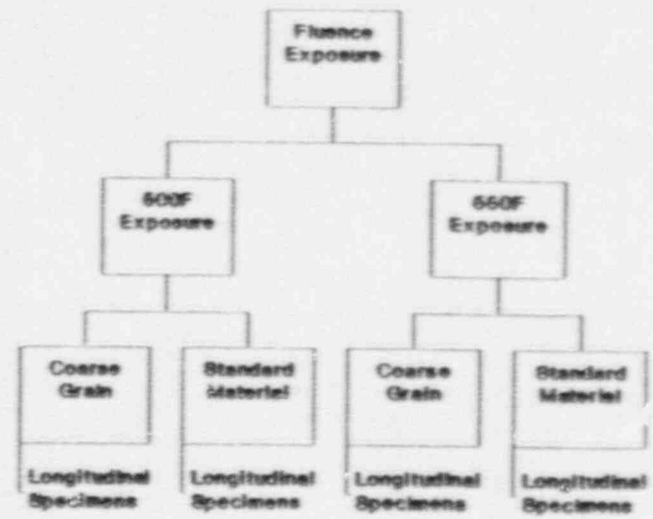
- Vickers Hardness (DPH)
- Tension Tests (Tensile Specimens)
- Instrumented Charpy
  - Longitudinal Direction
  - Compares to existing data in the longitudinal direction.

Irradiation Test Matrix for A 302-B Material

A302-B Low Cu, Low Ni



A302-B Low Cu, Mod. Ni



Target Fluences

- *1.0 E19*
- *3.0 E19* *n/cm-2 >1 MeV*
- *5.0 E19*

Proposed First Irradiation Test

- The first irradiation will include:
  - Coarse grain material with nickel.
  - Fine grain material with nickel.
  - Standard reference material.
- Irradiation temperatures will be 500F and 550F.
- Target fluence is 3E+19 n/cm2 (E>1MeV).

Test Reactor

- We plan to use the Ford Reactor at the University of Michigan.
- Materials Engineering Associates, Inc. (MEA) will encapsulate the test specimens and conduct the irradiations.
- Charpy and tensile test specimens will be irradiated.
- The neutron flux is $\sim$ 9E+12 n/cm2/sec.
- Two capsules can be irradiated simultaneously at different temperatures. Temperature is monitored using thermocouples. Temperature control will be verified in a dummy capsule test prior to the first irradiation.
- The capsules can hold 40 and 50 Charpy equivalents each.

Dosimetry

- The irradiation position used in the Ford Reactor will be characterized with a steel block containing dosimetry wires in place. Characterization will include determination of axial flux profile and the neutron spectrum.
- The following dosimeter wires will be used in each capsule containing test specimens:

Dosimeter Wire	90% Response Range
Ni	2.1 - 7.6 MeV
Fe	2.5 - 7.8 MeV
Co/Al	Thermal
Ag/Al	Thermal
Nb	0.6 - 6.0 MeV
* U-238	1.5 - 6.7 MeV

* subject to availability

Dosimetry
Continued

- B&W will perform the fluence analysis using the DOT4.3 two-dimensional neutron transport theory code with the following parameters:
  - S8 quadrature
  - P3 scattering
  - ENDF/B4 cross-section library
  - BUGLE-80 energy group structure
- Laboratory analysis of dosimetry will be done by EG&G.

Schedule

- 1st irradiation should start in March 1991 with a duration of about 3 months.
- 2nd irradiation will start in June 1991 and has a duration of about 4 months.
- 3rd irradiation has not been scheduled.
- The Buffalo test reactor may become available in July 1991.
- Final report is scheduled for late January 1992.

Irradiation Test Report

- Capsule inspection and disassembly
- Specimen inspection
- Experimental results
  - Neutron dosimetry
  - Thermal monitors
  - Tensile tests
  - Instrumented Cv tests
  - Hardness tests
- Discussion
  - Neutron dosimetry (analytical results)
  - Cv impact properties
  - RTNDT shifts (test and SRM materials)
  - Tensile properties
  - Hardness properties
  - SRM investigation (flux effects)
- Conclusions

Additional Tasks

- Yankee is still searching for a .18% Cu, .21% Ni A 302-B material.
- We need to know if the Oak Ridge "Sugarman" cask is available for shipping irradiated specimens.
  - Drawing: ORNL-DWG-80-8706R.
- U238 dosimetry is desired for the tests; however, it is no longer available from Oak Ridge. We are looking for sources of the material.

WELD SAMPLING PROGRAM

OBJECTIVE

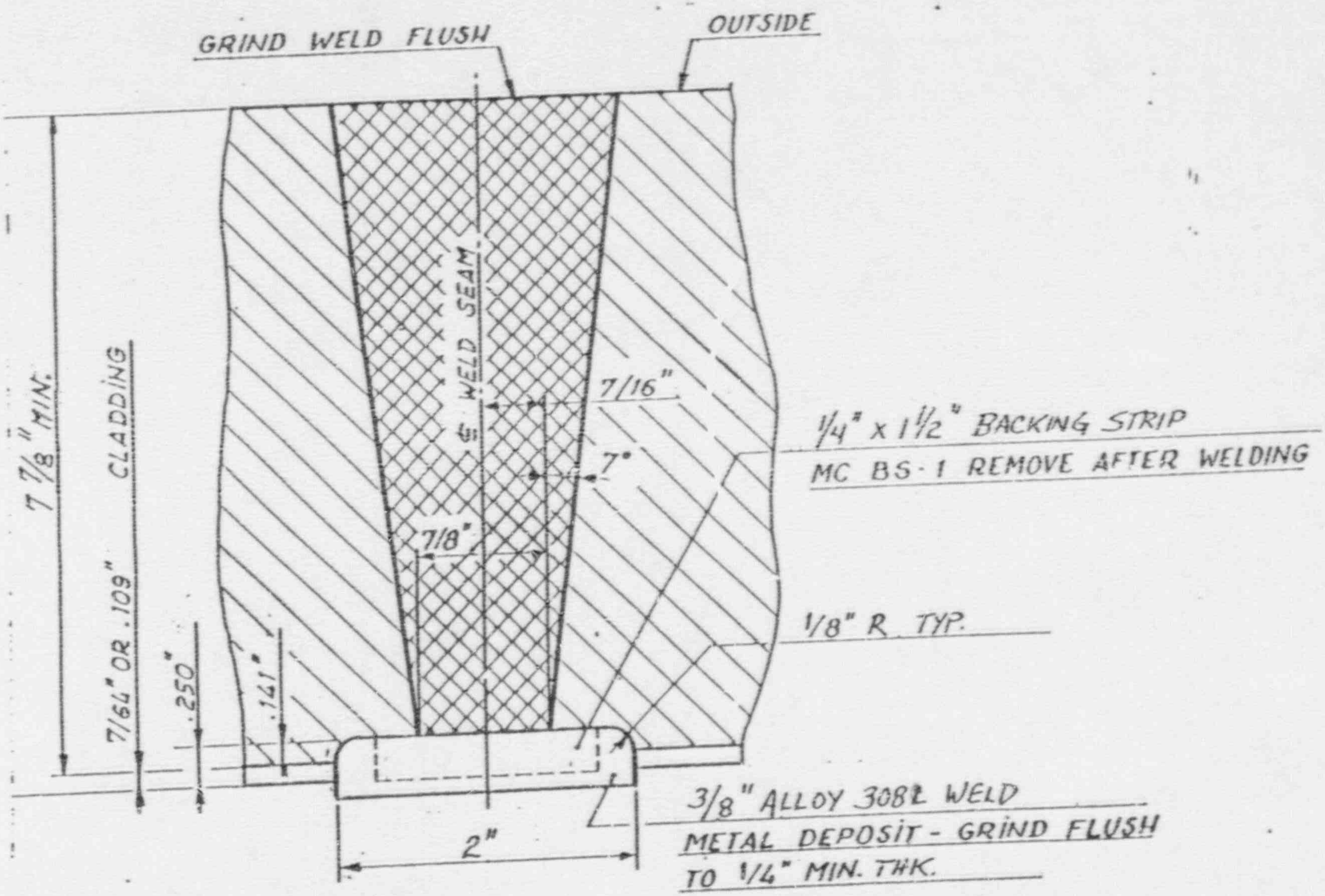
DETERMINE THE CHEMISTRY (Cu, Ni) OF THE YANKEE BELTLINE CIRCUMFERENTIAL AND LONGITUDINAL WELDS

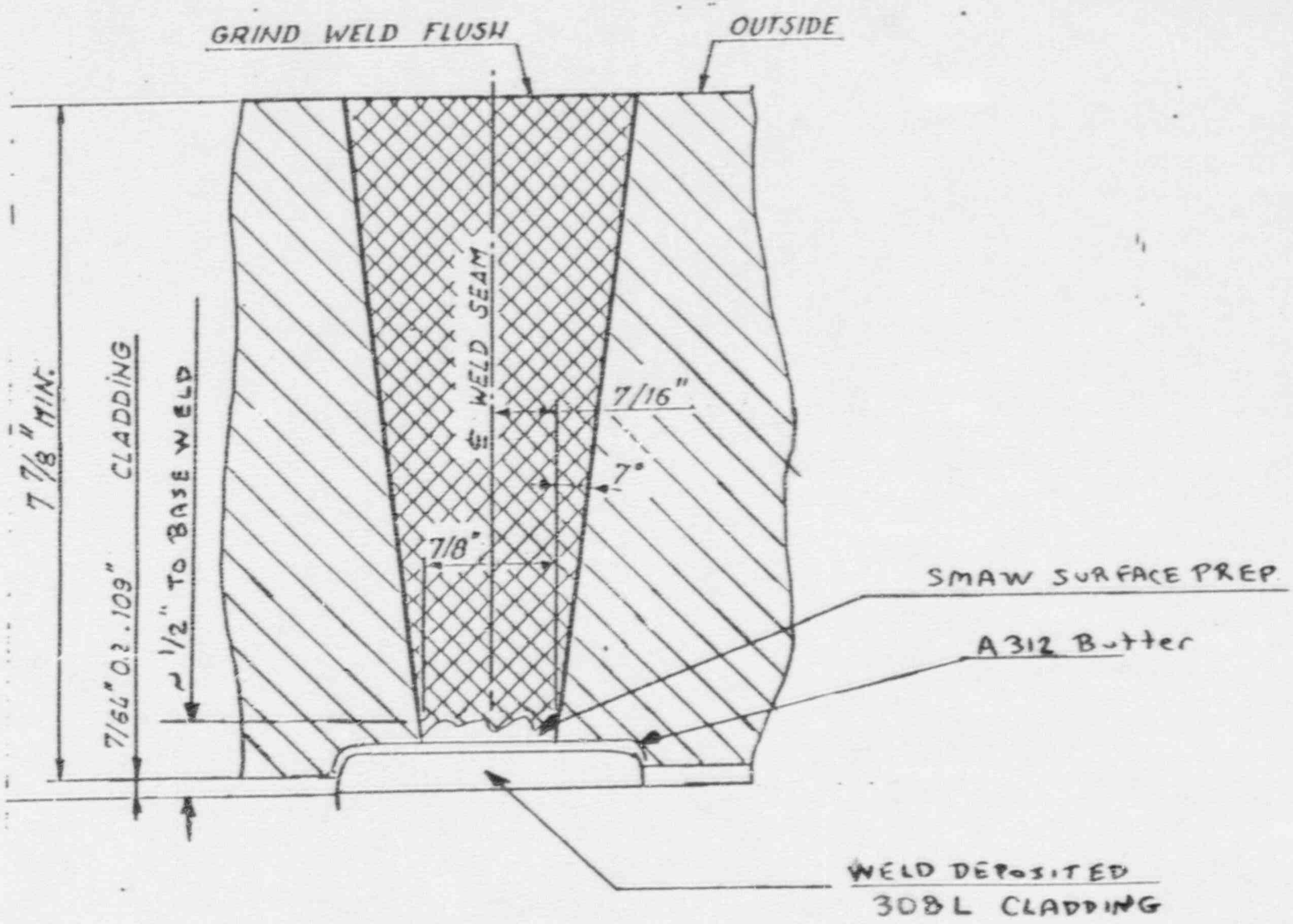
WELD SAMPLING PROGRAM CONSIDERATIONS

- WELD CONFIGURATION
- SAMPLE SIZE
- NUMBER AND LOCATIONS OF SAMPLES

WELD SAMPLING PROGRAM
WELD CONFIGURATION

- FABRICATION PROCESS, BASED ON SHOP RECORDS
  - PLATES WERE WELDED WITH A 1/4" THICK BACKING RING ON I.D.
  - FOLLOWING WELDING, THE BACKING RING WAS CHIPPED OUT AND SURFACE PREPARED BY GRINDING AND MANUAL WELDING
  - AN A-312 BUTTER WAS APPLIED
  - A-308L CLADDING WAS THEN DEPOSITED AND GROUND FLUSH
- RESULT
  - BULK WELD CHEMISTRY IS NOT REACHED UNTIL APPROXIMATELY 1/2" BELOW SURFACE, NOT INCLUDING DILUTION ZONE


GRIND WELD FLUSH
OUTSIDE
7 7/8" MIN.
CLADDING
7/64" OR .109"
.250"
.141"
℄ WELD SEAM
7/16"
7°
7/8"
1/4" x 1 1/2" BACKING STRIP
MC BS-1 REMOVE AFTER WELDING
1/8" R. TYP.
3/8" ALLOY 308L WELD
METAL DEPOSIT - GRIND FLUSH
TO 1/4" MIN. THK.
2"

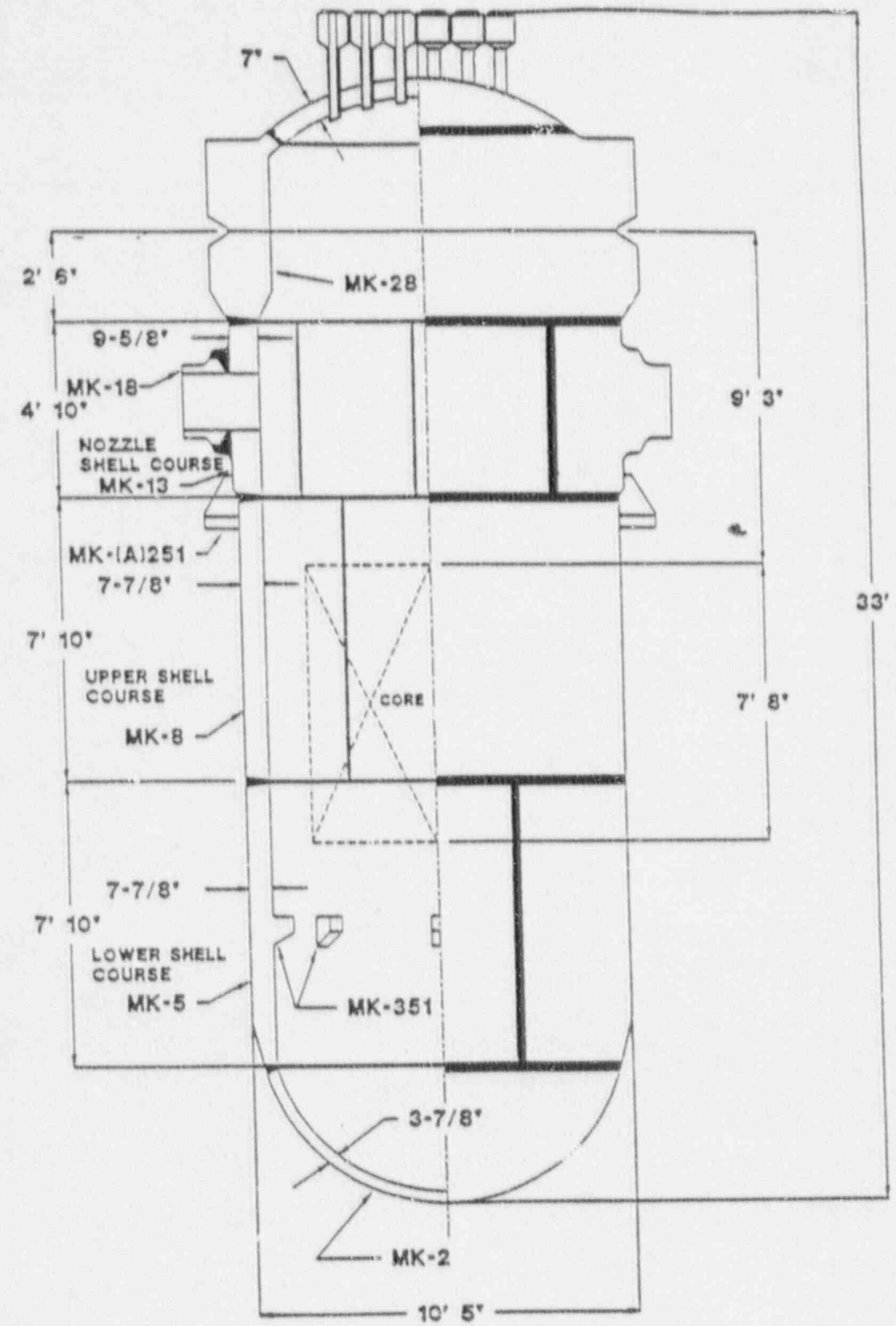

GRIND WELD FLUSH
OUTSIDE
7 7/8" MIN.
7/64" O.2 .109"
CLADDING
~ 1/2" TO BASE WELD
℄ WELD SEAM
7/16"
7°
7/8"
SMAW SURFACE PREP
A312 Butter
WELD DEPOSITED
308L CLADDING

WELD SAMPLING PROGRAM
SAMPLE SIZE

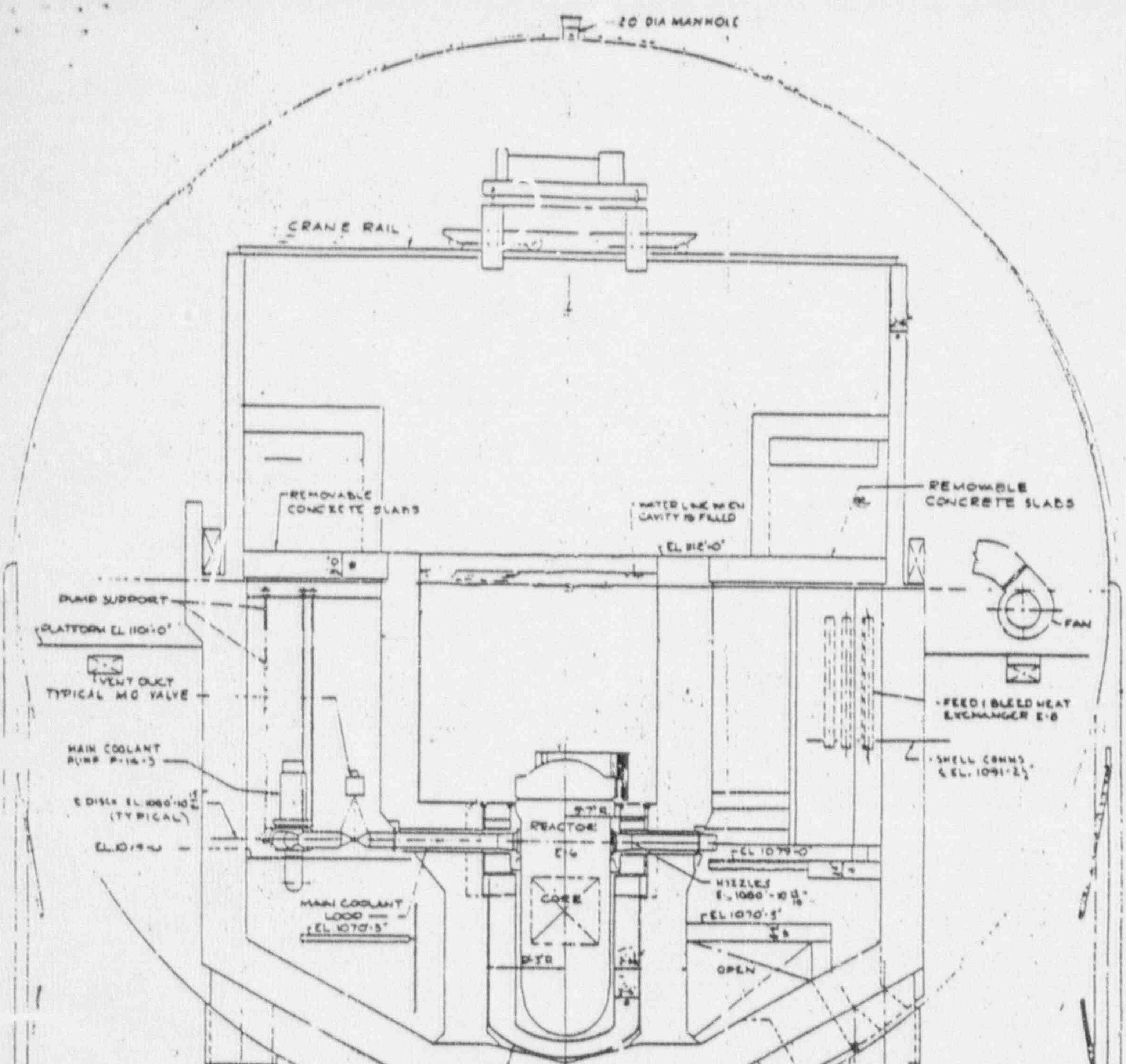
- SAMPLE SIZE AND SHAPE ARE DICTATED BY:
  - WELD CONFIGURATION
  - CODE LIMITATIONS
  - ABILITY TO OBTAIN
- PRELIMINARY PLANS ARE TO REMOVE CYLINDRICAL OR CUBE SHAPED SAMPLES, LEAVING ROUNDED BOTTOM CYLINDRICAL DEPRESSIONS (< 2" Dia. and < 1" deep)

WELD SAMPLING PROGRAM
SAMPLE LOCATIONS

- THE BELTLINE CIRCUMFERENTIAL AND BOTH LONGITUDINAL WELDS WILL BE SAMPLED
- WORK MUST BE PERFORMED REMOTELY, 50 FT. BELOW THE WATER SURFACE
- HOLES MUST BE CUT IN THE THERMAL SHIELD TO ALLOW ACCESS FOR TAKING SAMPLES



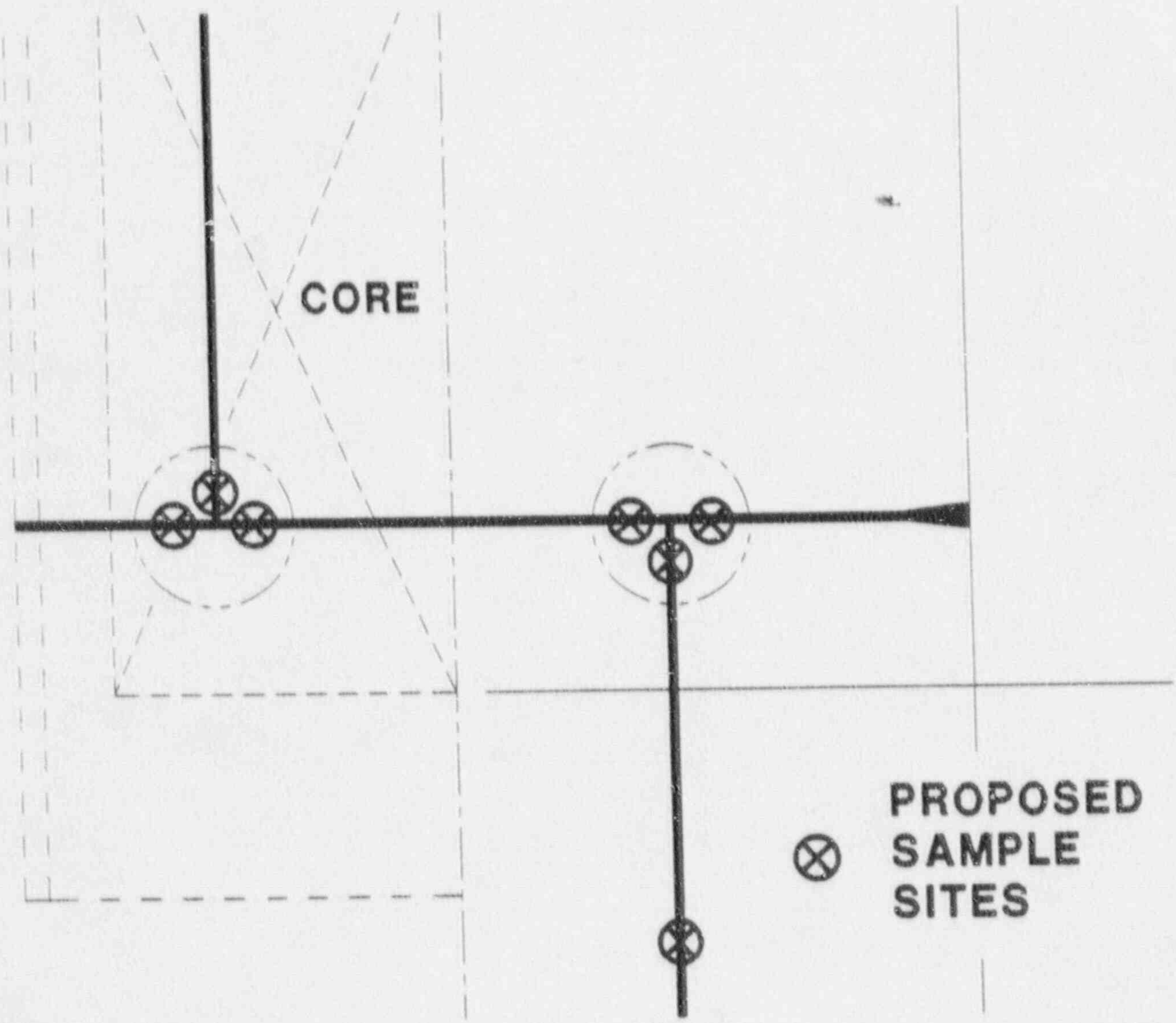
Weld and Plate Locations

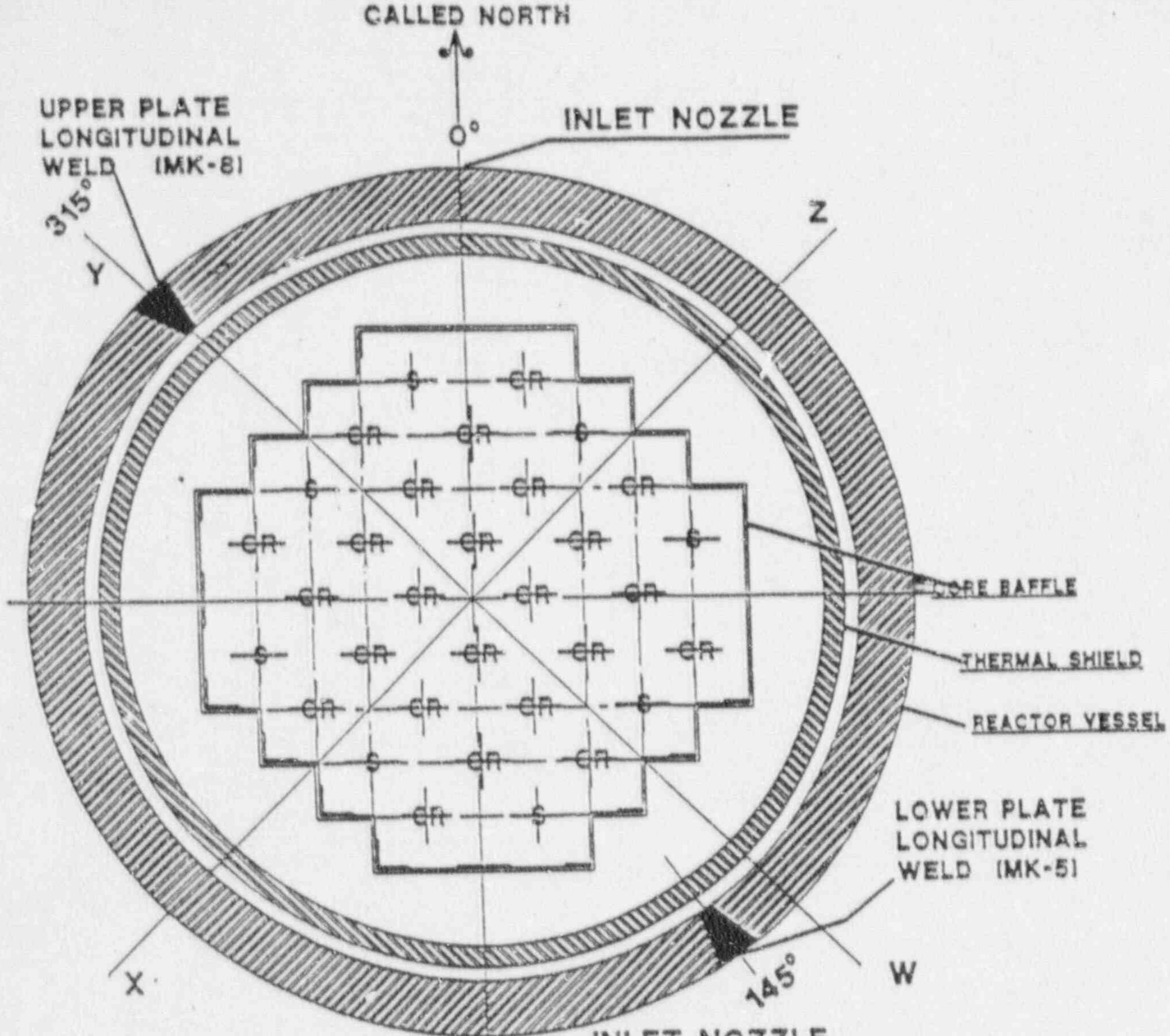


Containment Elevation

WELD SAMPLING PROGRAM
SAMPLE LOCATIONS AND NUMBERS

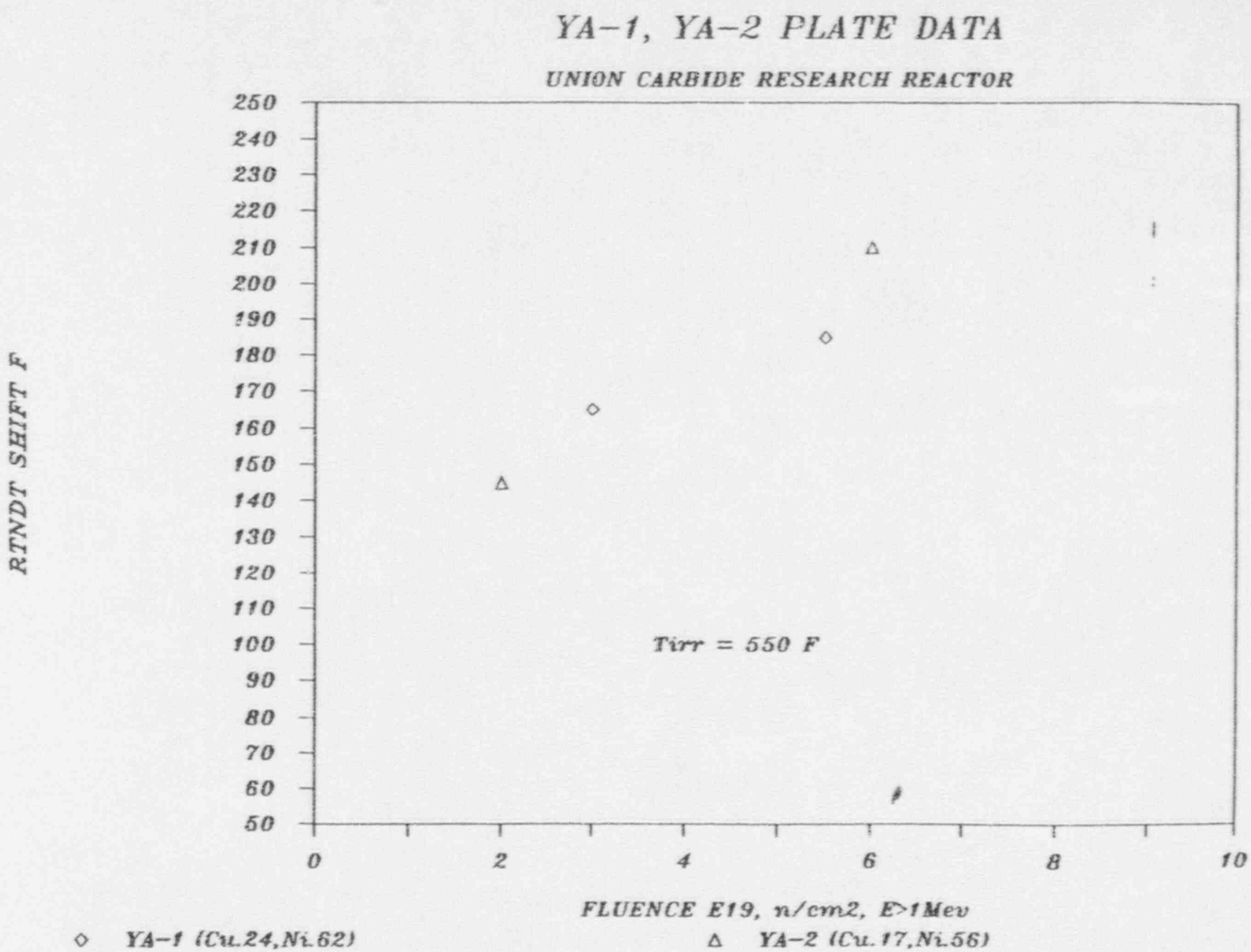
- LOCATIONS ARE SELECTED TO MINIMIZE CUTTING OF THE THERMAL SHIELD
- SAMPLE LOCATIONS ARE APPROXIMATELY 180 DEGREES APART
- FOUR CIRCUMFERENTIAL WELD SAMPLES AND THREE LONGITUDINAL WELD SAMPLES ARE PROPOSED


CORE
PROPOSED
SAMPLE
SITES



NOTE: Axes WY and XZ are regions of low fluence

Longitudinal Weld Locations


YA-1, YA-2 PLATE DATA
UNION CARBIDE RESEARCH REACTOR
RTNDT SHIFT F
250
240
230
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
Tirr = 550 F
0
2
4
6
8
10
FLUENCE E19, n/cm2, E>1Mev
◇ YA-1 (Cu.24,Ni.62)
△ YA-2 (Cu.17,Ni.56)

: PLATE 1 = YA 2

PLATE 2 = YA 1

TABLE II
MATERIALS AND HEAT TREATMENT

Material	Chemical Composition[a] (wt %)										Heat Treatment[b]
	Cu	P	C	Mn	S	Si	Ni	Cr	Mo	Al	
Series 1											
YA 2 Plate 1	.17	.009	.23	1.29	.015	.21	.56	.10	.57	.027	1
YA 1 Plate 2	.24	.008	.25	1.40	.011	.23	.62	.11	.59	.02	1
Weld 1	.36	.015	.14	1.38	.012	.22	.78	.07	.55	.02	2
Weld 2	.20	.016	.13	1.11	.013	.17	.04	.05	.53	.004	2
Series 2											
Plate 3	.09	.009	.20	1.29	.017	.22	.58	[c]	.57	.027	1
Plate 4	.09	.011	.21	1.38	.018	.28	.66	[c]	.52	.02	1
Weld 3	.07	.010	.15	1.15	.010	.25	.12	.04	.59	.004	2
Weld 4	.05	.004	.15	1.25	.010	.19	.09	.06	.62	<.001	2

a—Co <.013; Nb, W ≦.01; Zr ≦.002; B ≦.0008; N ≦.012; V ≦.01; As ≦.013; Sn ≦.008; Ti ≦.01.

b—Heat treatment

(1) Austenitized 1600 F (871 C) 4 hr, WQ, tempered 1200 F - 1250 F (649-677 C); stress relief annealed 1150 F (621 C) 40 hr, furnace cooled to 600 F (316 C).

(2) Interstage stress relief annealed 1100-1150 F (593-621 C) ¼ hr minimum; postweld stress relief annealed 1150 F (621 C) 40 hr, furnace cooled to 600 F (316 C).

c—not determined.

TABLE III
TENSILE PROPERTIES OF PLATES AND WELD DEPOSITS

Material	Cu (wt %)	Yield Strength[a] (0.2% Offset) (ksi)	Yield Strength[a] (0.2% Offset) (MN/m²)	Tensile Strength (ksi)	Tensile Strength (MN/m²)	R.A. (%)	Elong. in 1-in. (%)
Normal Copper, Series 1							
Plate 1	.17	61.3[b]	428	85.8	599	69.0	14.5
		60.0[c]	419	85.8	599	70.0	13.0
		54.8[d]	383	82.5	576	65.0	11.0
Plate 2	.24	67.3[b]	470	90.3	631	66.6	13.5
		67.5[c]	472	90.8	634	70.0	12.0
		60.0[d]	419	87.8	613	62.5	10.5
Weld 1	.36	66.6[b]	465	89.3	624	68.0	13.5
		72.0[c]	503	92.5	646	70.0	12.0
		64.5[d]	451	85.3	596	60.0	9.5
Weld 2	.20	74.8[b]	523	87.8	613	73.8	15.5
		72.0[c]	503	86.3	603	72.5	12.5
		63.0[d]	440	83.5	583	70.0	11.0
Low Copper, Series 2							
Plate 3	.09	63.9[b]	446	85.4	597	66.5	14.0
		66.1[c]	462	85.8	599	63.5	13.5
		58.8[d]	411	82.2	574	60.8	11.0
Plate 4	.09	64.8[b]	453	86.5	604	68.6	13.5
		65.9[c]	460	87.4	611	69.3	14.5
		61.6[d]	430	86.9	607	65.0	11.5
Weld 3	.07	71.1[b]	497	86.4	604	71.4	12.5
		73.8[c]	516	86.3	603	71.7	13.0
		65.5[d]	458	84.0	587	67.2	12.3
Weld 4	.05	72.4[b]	506	86.0	601	71.1	11.5
		73.5[c]	513	85.9	600	72.6	13.5
		65.5[d]	458	82.7	578	67.7	12.5

a—Transverse orientation, duplicate tests
(75 F) 0.226-in. dia. specimens
(550 F) 0.226 or 0.252-in. dia. specimens

b— 75 F, .005 inch/min crosshead rate

c— 75 F, .05 inch/min crosshead rate

d—550 F, .05 inch/min crosshead rate

TABLE IV

NOTCH DUCTILITY PROPERTIES OF PLATES, WELD DEPOSITS, AND WELD HEAT AFFECTED ZONES (HAZ) AS-FABRICATED AND AFTER 550 F (288 C) IRRADIATION

A. AS-FABRICATED

	NDT		Cv Energy @ NDT	Cv Transition Temperature				Cv Upper Shelf Energy
				30 ft-lb index		50 ft-lb index		
Material	(deg F)	(deg C)	(ft-lb)	(deg F)	(deg C)	(deg F)	(deg C)	(ft-lb)
Plate 1	0	−18	34	−5	(−21)	25	(−4)	115
HAZ 1	–	–	–	−75	(−59)	−40	(−40)	144
Plate 2	−20	−29	20	10	(−12)	60	(16)	~110
Weld 1	−30	−34	29	−30	(−34)	5	(−15)	107
Weld 2	−50	−46	15	−35	(−37)	−15	(−26)	129
Plate 3	−10	−23	17	20	(−7)	60	(16)	104
HAZ 3	–	–	–	−35	(−37)	−5	(−21)	133
Plate 4	−20	−29	17	0	(−18)	40	(4)	119
HAZ 4	–	–	–	−45	(−43)	−15	(−26)	~130
Weld 3	−70	−57	9	−30	(−34)	−5	(−21)	≧157
Weld 4	−80	−62	10	−35	(−37)	−15	(−26)	144

B. IRRADIATED CONDITION

	Fluence ($\times 10^{19}$ n/cm² >1MeV)		Cv Transition Temperature						Cv Upper Shelf Energy	
			30 ft-lb index			50 ft-lb index				
Material	ϕ^{ee*}	ϕ^{fs}	(deg F)	(deg C)	ΔF	(deg F)	(deg C)	ΔF	(ft-lb)	Δ(ft-lb)
Plate 1	1.8	2.1	140	(60)	145	210	(99)	185	93	22
	5.9	6.7	205	(93)	210	220	(104)	195	94	21
HAZ 1	2.5[a]	2.9[a]	25	(−4)	100	100	(38)	140	114	30
	5.9	6.7	60	(16)	135	135	(57)	175	~114	~30
Plate 2	3.2	3.7	175	(79)	165	225	(107)	165	84	~26
	5.3	6.1	~195	(91)	~185	~245	(118)	~185	86	~24
Weld 1	3.0	3.4	285	(141)	315	345	(174)	340	56	51
	5.3	6.1	320	(160)	350	370	(188)	375	56	51
Weld 2	3.0	3.4	60	(16)	95	120	(49)	135	~98	~31
	5.3	6.1	90	(32)	125	160	(71)	175	~98	~31
Plate 3	3.8	4.4	55	(13)	35	90	(32)	30	107	(+) 3
	5.0	5.7	75	(24)	55	125	(52)	65	111	(+) 7
HAZ 3	3.8	4.4	30	(−1)	65	70	(21)	75	122	11
	5.0	5.7	75	(24)	110	140	(60)	145	~122	~11
Plate 4	3.5	4.0	45	(7)	45	115	(46)	75	130	(+) 11
	4.7	5.4	85	(29)	85	150	(66)	110	130	(+) 11
HAZ 4	3.5	4.0	10	(−12)	55	35	(2)	50	158	(+) 25
Weld 3	4.2	4.9	5	(−15)	35	30	(−1)	35	155	~0
	4.3	5.0	20	(−7)	50	40	(4)	45	155	~0
Weld 4	4.2	4.9	−20	(−29)	≦ 20	5	(−15)	20	147	~0
	4.3	5.0	−20	(−29)	≦ 20	5	(−15)	20	154	(+) 10

*—ϕ^{ee} >0.1 MeV = 2.0 ϕ^{ee} >1 MeV

[a]—Average fluence, actual values varied between two groups of specimens

References

(1) Perrin, J.S., et. al., "Maine Yankee Nuclear Plant Reactor Pressure Vessel Surveillance Program: Capsule 263", BCL-585-21, Battelle Columbus Laboratories, December 12, 1980.

(2) Combustion Engineering, Inc. Letter, M-NZM-70-003, J.J. Koziol to J.F. Gibbons, "Maine Yankee Surveillance Program", January 27, 1970.

(3) Hawthorne, J.R., et al., "Evaluation of Commercial Production A533-B Plates and Weld Deposits Tailored for Improved Radiation Embrittlement Resistance", Properties of Reactor Structural Alloys After Neutron or Particle Irradiation, ASTM STP 570, American Society for Testing and Materials, 1975, pp. 83-102.

(4) Hawthorne, J.R., "Notch Ductility Degradation of Low Alloy Steel With Low-To-Intermediate Neutron Fluence Exposures", NUREG/CR-1053; NRL Report 8357, Naval Research Laboratory, Washington, D.C., January 14, 1980.

(5) Wullaert, R.A., et. al., "Evaluation of the Maine Yankee Reactor Beltline Materials", Irradiation Effects on the Microstructure and Properties of Metals, ASTM STP 611, American Society for Testing and Materials, 1976, pp. 400-417.

(6) Biemiller, E.C. and Byrne, S.T., "Evaluation of the Effect of Chemical Composition on the Irradiation Sensitivity of Reactor Vessel Weld Metal", Irradiation Effects on the Microstructure and Properties of Metals, ASTM STP 611, American Society for Testing and Materials, 1976, pp. 418-433.

(7) Memo, MEG 369/80, E. Biemiller to P. Anderson, "RT_{NDT} Shift Values for Maine Yankee's Reactor Vessel at the 1/4 T and 3/4 T Positions", June 6, 1980.

(8) Smidt, F.A. and Watson, H.E., "Effect of Residual Elements on Radiation Strengthening in Iron Alloys, Pressure Vessel Steels, and Welds", Metallurgical Transactions, Volume 3, August 1972, pp. 2065-2073.

(9) Smidt, F.A., Jr., and Sprague, J.A., "Property Changes Resulting From Impurity Defect Interaction In Iron and Pressure Vessel Steel Alloys", Effects of Radiation on Substructure and Mechanical Properties of Metals and Alloys, American Society for Testing and Materials, ASTM STP 529, 1973, pp. 73-91.

(10) Biemiller, E.C., "RT_{NDT} Shift With Irradiation For System 80 Reactor Vessel Materials", CENPD-191, Combustion Engineering, Inc., 1976, pp. 19-21.

8101650122