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January 3, 1985

TMI Program Office
Attn: Dr. B. J. Snyder
Program Director
US Nuclear Regulatory Commission
Washington, DC 20555

Dear Dr. Snyder:

Three Mile Island Nuclear Station, Unit 2 (TMI-2)
Operating License No. DPR-73
Docket No. 50-320
Characterization of Fuel Material in the Lower
Region of the Reactor Vessel

Attached for your review and approval is a Safety Evaluation Report (SER) addressing a proposed plan to characterize fuel deposits in the lower region of the Reactor Pressure Vessel. This plan proposes insertion of miniature ion chamber detectors into the lower vessel through the incore monitoring guide piping. The ion chambers will be used to perform vertical profiling of the gamma activity in the lower region of the reactor vessel. Additionally, the attached analysis shows the proposed activity can be performed without jeopardizing the reactor vessel integrity and without undue risk to the health and safety of the public.

An application fee of $150.00, as required pursuant to 10 CFR 170, is also attached.

If you have any questions concerning this information, please call Mr. J. J. Byrne of my staff.

Sincerely,

F. R. Standerfer
Vice President/Director, TMI-2

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FRS/RBS/jep

Attachments: (GPU Nuclear Check No. 0013374)

cc: Deputy Program Director - TMI Program Office, Dr. W. D. Travers

TITLE

Safety Analysis of Measuring Uranium Fuel Material Collected in the Lower Region of the TMI-2 Reactor Vessel via Gamma Profiling of the In-Core Detectors

INTRODUCTION

This Safety Evaluation related to a method proposed for determining whether loose fuel materials have settled at the bottom of the reactor vessel and for estimating the volume and weight of the fuel debris there. Vertical profiling of the gamma activity between the lower core support structure and the bottom of the Reactor Pressure Vessel (RPV) at a number of radial locations is the proposed approach. It is proposed that the measurements be carried out with miniature ion-chamber detectors, where access for profiling is via several center calibration tubes of the in-core detectors already in place.

The selected in-core positions will initially be probed by use of a dummy detector wire of the same size and stiffness as the actual probes. This will verify that there are enough clear passage tubes available for the subsequent measurements.

This safety analysis examines potential impacts that the proposed probing may have on the integrity of the in-core monitoring guide piping and consequently on the RPV pressure boundary. Included are a description of the in-core monitoring system and guide piping, an outline of safety functions of affected systems/components, a discussion of potential damage mechanisms, and an explanation why the proposed measurements (probing) will not affect safety functions.

SYSTEM DESCRIPTION

The in-core instrumentation system was installed in order to provide monitoring of the power distribution within the core and reactor coolant core outlet temperature. Each in-core detector assembly includes an outer inconel sheath (0.292 inch O.D. and 0.250 inch I.D.), seven neutron sensitive detectors, one background detector, one thermocouple, and a hollow inner inconel calibration tube (0.125 inch O.D. and 0.093 inch I.D.). A cross section of an in-core detector assembly is shown in Figure 1. The nine monitoring tubes (0.062 inch O.D.) are arranged in the annular gap formed between the inner and outer inconel tubes. These form, in effect, a thick armored region around the center calibration tube. The inner tube (0.093 inch I.D.) is provided for insertion of a calibration detector. It is proposed that the scanning of the RV below the support plate be carried out via the insertion of probes into the above calibration tube openings. It is important to note the in-core detector assemblies themselves are not part of the primary system pressure boundary.

The instrumentation piping serves as a containment of the in-core detector assemblies. The piping is an extension of the reactor vessel, is filled with primary coolant, and forms part of the primary system pressure boundary. The piping arrangement is shown on Figure 2. The piping is attached to the reactor vessel instrument nozzles and continues downward through a long radius bend (radius of 6'3"), extends horizontally and turns upward through a 12 foot-6 inch radius bend extending up to elevation 347'6" (seal table). Each in-core monitoring guide tube terminates in a closure assembly (high-pressure seal flange) at the seal table. There are a total of 52 in-core detector assemblies. The instrumented core locations are shown in Figure 3.

Each in-core monitoring system pipe run includes; a 3/4" schedule 160 inconel nozzle (penetrating the RPV lower head), a 3/4" x 1/2" schedule 80 reducer,(see Figure 4) and a 1/2" schedule 80, 304L Stainless Steel pipe that runs from the bottom of the RPV to the Seal Table at Elevation 347'. Wall thicknesses are 0.218 inch for the schedule 160 nozzle and 0.147 inch for the schedule 80 pipe. Each of the above pipe runs houses an in-core detector assembly nested inside the pipe . Because the pipes form part of the primary system pressure boundary, damage to the pipes (at an elevation below the primary system reactor coolant level), would result in the leakage of primary coolant from the reactor vessel.

DISCUSSION

Mechanical Evaluation

The proposed scanning will be performed with miniature ion chamber detectors. The detectors are approximately 0.072 inch in diameter at the tip with a sensitive length of two inches. The integral ceramic-insulated triaxial cable is 0.062 inch in diameter. Each probe will be inserted into the 0.093 inch I.D. calibration tubes (at the seal table) and will be pushed via the 0.062 inch triaxial cable to the bottom of the RPV (the probes will have to negotiate two long radius bends and approximately 120 feet of calibration tube length).

Based on Babcock & Wilcox experience with the insertion/removal of Self Powered Neutron Detectors (SPND) into/out of the center calibration tubes of the in-core detectors, forces on the detector cable range from 1.5 to 3.0 lbs. More limiting cases involved forces as high as 10 lbs. The experience with manual insertion is that when forces in excess of approximately 10 lbs. are exerted the detector wire starts slipping through the operator's hand. Higher forces would likely result in the kinking or damaging of the detector cable.

The Babcock and Wilcox experience also shows that no problems were encountered with the removal of SPND's. Even when higher forces had to be utilized during insertion, the detectors were readily removed by hand with minimal force. Should a probe or dummy wire be stuck in a particular calibration tube, it will be left in the stuck position and no effort will be undertaken to extract the detector/test wire. This will preclude the application of an excessive pull force on the wire and consequently on the guide pipe.

Additional experience has been gained when the in-core detector assemblies were inserted into the core (via the guide piping) following reactor fuel loading (1978). Based on Babcock and Wilcox experience; forces as high as 34 to 38 lbs are required in order to insert an in-core detector assembly into the guide piping installation, and the loading mode of the in-core guide piping is similar to that of inserting probes into the center calibration tubes of the in-core detector assemblies when the latter are fixed in place. Each of the 52 guide piping assemblies have successfully accomodated the insertion of the detector assembly.

The primary concern is whether insertion forces may result in structural failure of the in-core monitoring guide piping and/or the compromising of the primary system pressure integrity.

The probes to be inserted into the center calibration tubes of the in-core detectors are totally surrounded by the in-core detector assembly and will not be in physical contact with the guide piping (3/4" Sch. 160 nozzle and 1/2" Sch. 80 pipe) housing the detector assembly.

It is also unlikely that the in-core detector sheaths below the RPV lower head have degraded, because the RPV was never completely emptied. The presence of water in the RV would have limited the temperature at the lower head to near saturation temperature for 2200 psig (650°F)(See Reference 1). The conclusion is that there is little risk of direct mechanical damage to the guide piping from the proposed probing and that and probing can and should proceed.

If the load bearing capability of the in-core detector assembly is neglected the forces exerted on the detector wire (during both insertion and removal) may be transmitted to the guide piping via the in-core monitors. The forces can be assumed to produce reaction forces which induce an additional stress increment in the guide piping. A calculation was undertaken in order to determine the incremental stresses that may be induced in the in-core monitoring guide piping as a result of the proposed probing. It was calculated that the highest stress perturbation that may be induced by the probes is 31 psi (axial stress in 1/2" Sch. 80 pipe). Calculations were based on "as-built" as well as "as designed" conditions. This stress level is extremely small when compared with the allowable stress for the pipe material (ANSI/ASME B31.1, 15,700 psi) and other stress components such as dead weight and RCS pressure transients as depicted in the following table..

Yield Strength (Stainless Steel)	39×10^3 psi
Allowable Stress, ANSI/ASME B31.1, (Tension)	15,700 psi
Max. Stress Due to Dead Weight of Piping and Contents at Supports, (Bending)	630 psi
Raising Reactor Coolant System (RCS) Pressure by 50 psi, (Tangential-Tensile)	123 psi
Pipe Stress due to Hydrostatic Pressure (17 psig)	42 psi

Probing of In-Core Detector Calibration Tubes

(i) Bending Stress in Pipe (near RPV Nozzle) 6.2 psi
(ii) Aixal Stress in Pipe (Tension) 31. psi

A study was made to find the potential impacts certain variations from as-built conditions would have on the load bearing capacity of the incore piping.

One area studied was the inability of Hanger IMH-9 (Figure 5) to function as designed. Hanger IMH-9 is the only hanger in the basement horizontal pipe run designed to securely clamp the incore piping. All other hangers act as guides, allowing for expansion and contraction.

The mechanics of the guide piping are such that if Hanger IMH-9 were eliminated, reaction forces at this hanger would be eliminated. With reaction forces eliminated, insertion or removal forces applied to the probe wire at the seal table cannot result in a net horizontal force on the guide piping. Horizontal is defined as "the axial direction of the pipe section parallel to the basement floor". Therefore, no bending of the guide piping at the RPV nozzle weld (Figures 2 and 4) will result from probe insertion or removal.

It is also noteworthy that the selection of input data and governing assumptions for the calculation was done in a manner that increases the margin of conservatism of the analysis. For example: the contribution of the in-core detector assembly (inner and outer inconel tubes and inconel sheaths) in resisting loading was totally neglected, and the maximum force that may be exerted on the detector wire with manual insertion was taken as 10 lbs. (in actuality lower forces are employed).

Chemical Environment

The potential corrosive effects of the chemical environments (internal and external) on in-core monitoring system guide piping have also been evaluated. The key item of concern is the possibility of chloride stress corrosion cracking of austenitic stainless steel. Table 1 provides a list of materials used for the incore piping.

Primary Coolant Environment

The reactor coolant water chemistry since the incident is summarized in the following Table:

Period/Date	Average 79/80[f]	6/25/84[g]
pH at 77°	7.9	7.65
Boron, ppm	3420[a]	5019
Sodium, ppm	1120[b]	1500
Chlorides, ppm	3.8	1.2
Hydrogen, std cc/Kg	19	1.0[c]
Oxygen	ND[d]	[e]

(a) Equivalent to 19,540 ppm of boric acid.
(b) Equivalent to 1950 ppm as sodium hydroxide.
(c) 7-18-83
(d) None Detected, May 1980.
(e) Not measured.
(f) Reference 1
(g) Reference 2

NOTE: Since early April 1979, the RCS chemistry has been maintained at a basic pH (average of 7.7 at 77°F). The effect of pH on stress corrosion cracking (SCC) will be discussed in subsequent paragraphs.

External Environment

Following the March 1979 incident the reactor building (RB) basement (floor at elevation 282'6") was flooded with water. This began with a few feet of water on March 28, 1979 and as leakage occurred over the next 2-1/2 years the water level increased to eight (8) feet. The RB basement remained submerged (with 8 feet of water) until the start of water processing via the submerged dimineralizer system (SDS) on September 23, 1981 (Reference 3). Processing of RB sump water was completed on August 31, 1982. Like other RCS components certain portions of the external surfaces of the in-core monitoring guide piping were submerged in the RB sump water. The horizontal portion of each guide pipe is at elevation 282'0" and remained submerged for approximately 3 years. The chemistry of sump water for the reference period has been characterized as:

Boron, ppm	1760[a]
Sodium, ppm	1350[b]
pH at 77°F	8.6
Chlorides, ppm	14
Assumed Air-Saturated	

(a) Equivalent to 10,000 ppm boric acid.
(b) Equivalent to 2350 ppm as sodium hydroxide.

Stress-Corrosion Cracking is caused by the combined effects of tensile stress and corrosion and is probably the most widely encountered form of failure of stainless steels in an aqueous chloride environment at temperatures above 175°F. In general, it has been found that lowering the pH of chloride solutions accelerates the cracking rate. For stress corrosion cracking to occur it is necesssary for tensile stress, chlorides and elevated temperature all to be present. Increasing the chloride content greatly reduces the stress at which cracking has been observed in stainless steels at 180°C (356°F). At higher temperatures, cracking has been observed to occur at lower chloride ion concentrations.

Chlorine has been shown to produce stress corrosion cracking of stressed, sensitized stainless steel at ambient temperatures. In borated water solutions, the stress corrosion cracking of sensitized and non-sensitized type 304 and 316 stainless steel with chlorides has been observed to be strongly pH dependent. Tests conducted at Westinghouse (Reference 4) included the testing of the susceptibility of 304 SS in solutions containing chlorides. The tests were conducted in solutions containing 2500 ppm Boron with temperature profiles simulating a loss of coolant accident (24 hours at 280°F, gradual cooldown to 140°F in approximately 17 days and maintained at 140° for test duration up to 16 months). The chloride ranged from 0.1 ppm to 500 ppm and the pH ranged from 4.5 to 10 (at 77°F) with NaOH.

These tests have shown that SCC only occurs at acidic pH levels (pH 7.0). At basic pH values of 8.0, 9.3 and 10.0 and 100 ppm chlorides, no cracking was noted to occur in type 304 and type 316 specimens for 12 - 16 months. These tests also showed that the time for initiation of cracking of sensitized U-bend specimens of type 304 austenitic stainless steels in neutral solutions of 7.0 pH having 100 ppm chloride was 7-1/2 months. These tests incorporated five different sample configuration (single and double U-bend samples, stressed C-ring samples, plate, and pipe sections). Materials included 304 and 316 stainless steel in four different metallurgical conditions (as-received, annealed and pickled, sensitized and welded conditions).

The susceptibility of type 304 stainless steel to SCC in solutions containing chlorides was also tested at Oak Ridge National Laboratory (Reference 5). The tests were conducted with borated water solutions containing 3000 ppm boron and temperatures simulating a loss of coolant accident (1 day at 285°F, 7 days at 212°F, and 2 months at 180°F). Stress corrosion cracking was noted to occur with as low as 5 ppm chloride at pH of approximately 4.5. No cracking was observed at a pH of 9.3 and 100 ppm chloride.

Based on the above test data and a Babcock and Wilcox RCS component evaluation (Reference 1) the chemistry that has existed in the RCS since conditions stabilized should have had no adverse effects on the stainless steel components comprising the in-core monitoring guide piping. The basic pH (7.6) environment is beneficial in controlling general corrosion and has been shown to minimize the possibility of SCC of austenitic stainless steel (304L SS). During the past 5 years the RCS chloride level has been 1-3 ppm, and never exceeded 6 ppm. Currently the chloride level is about 1.2 ppm. The pH has ranged from 7.6 to 8.4, with an average of about 7.8. It is therefore concluded that the chemistry conditions that have existed in the RCS since March 28, 1979 should not have had an adverse effect on interior portion of the in-core monitoring guide piping. It is also important to note that the RPV penetration nozzles are made of Inconel-600, an alloy (72% Ni, 17% Cr), which is immune to chloride SCC and has excellent resistance to alkalies.

Although portions of the reference piping system were submerged for approximately three (3) years in the RB sump water and this solutions is known to have contained 14 ppm of chlorides, other conditions necessary for promoting SCC did not exist. First of all stress levels were low, the highest stress level being due to deadweight and is estimated at 640 psi (1.6% of yield stress). Temperatures were also low (sump water temperature is estimated at less than 100°F), and the pH of the sump water (which is the key factor in controlling SCC) was approximately 8.6 which is well above the danger zone. It is thus concluded that the stainless steel and inconel components comprising the exterior of the in-core monitoring guide piping were not subjected to SCC.

System Pressure Retaining Characteristics

From the March 1979 incident until the removal of the RPV head in July 1984, the RCS was subjected to various internal pressures. THe RCS pressure was maintained at 300 $\pm$ 60 psig from May 1979 to April 1980 and was subsequently lowered to a pressure of 90 $\pm$ 10 psig.

The RCS was also subjected to pressurization loading in association with the decontamination of the RCS by use of the submerged demineralizer system (SDS). The last pressurization was on April 14, 1984, and the primary system remained at a pressure of 50 psig until June 15, 1984 when depressurization occurred. Based on calculations, this pressure resulted in a tensile stress of approximately 125 psi in the guide piping (1/2" SCH. 80). It is known that the incore piping system successfully withstood the subject stress and no leaks resulted from system pressurization.

The SDS operation as discussed above can be used as further evidence that the in-core monitoring guide piping system is structurally intact and is capable of withstanding a stress perturbation of at least 125 psi. The maximum stress for probing of in-core detectors was calculated as 31 psi, and since this is one fourth the stress in association with the routine pressurization of the RCS during SDS processing (which the system withstood successfully), it is concluded that the probing of the in-core detectors poses no risk to the guide piping and their pressure retention integrity.

Leaks are not anticipated to result from the reference probing. However, should a small leak occur, procedures are in place to respond to such leaks.

CONCLUSIONS

The proposed scanning of in-core detector calibration tubes has practically no impact on the physical integrity of the in-core monitoring guide piping and poses essentially no risk to the primary system pressure boundary. This is based on the following findings and observations:

(a) The proposed miniature ion-chamber detectors and connected triaxial cables are extremely small in size (diameter of cable is 0.062 inch), are of limited strength, and are of high flexibility (high slenderness ratio). The axial loading that the probes can transmit to in-core monitoring guide piping is thus minimal.

(b) The in-core monitoring guide piping is a system designed, constructed and tested as part of the primary system pressure boundary (ASME code, Section III). As such, the system was designed and successfully tested at a pressure of 2500 psia and a temperature of 650°F.

(c) In order to inhibit corrosion the in-core monitoring system guide piping was constructed of stainless (304L) and Inconel-600 (RPV penetrations are Inconel-SB167). The system is thus not susceptible to general corrosion.

(d) The Babcock and Wilcox experience with the insertion and removal of SPND's into the center calibration tubes of the in-core detectors, shows that the forces exerted on the detector wires normally range from 1.5 to 3.0 lbs.

(e) The maximum incremental stress induced in the in-core monitoring guide piping as a result of the proposed probing was calculated to be 31 psi. This constitutes only 0.2% of the allowable stress for the pipe material (ANSI/ASME B31.1 - allowable stress is 15,700 psi) and is also exteremly small when compared with other stress components such as; dead-weight, hydrostatic head, and RCS pressure transients.

(f) The probes to be inserted into the center calibration tubes of the in-core detectors, are totally surrounded by the in-core detector assembly which serves as an armor around the probe (see Figure 1), and are not in physical contact with the guide piping. There is thus no risk of direct mechanical damage to the guide piping from the proposed probes.

(g) It is estimated that the accident temperature of the in-core monitoring guide piping (under the RPV lower head) never exceeded 560°F and system materials did not suffer metallurgical degradation.

(h) The chemistry conditions that have existed in the RCS since March 28, 1979 (Average pH of 7.8 at 77°F) should have had no adverse effects on the in-core monitoring guide piping materials. Specifically the internal chemical environment should have precluded the possibility of chloride stress corrosion cracking of inside surfaces.

(i) Stress corrosion cracking of the piping system due to its immersion in the RB sump water should have been precluded by the following factors: pH of sump water was maintained at 8.6, temperatures are estimated at 100°F, and tensile stress levels are low (1.6% of yield stress).

(j) The decontamination of the RCS by use of the SDS (feed and bleed operation) included raising the RCS pressure by 50 psig (June 1984). This pressurization is estimated to have raised the stress levels in the 1/2" SCH.80 guide piping by 125 psi. The fact that the system successfully withstood SDS operating pressure gives evidence with respect to the structural integrity of the piping system and demonstrates that the degree of corrision degradation (if any) is limited. It may thus be concluded the pressure retention integrity of the incore piping system is intact.

(k) The RCS pressure history shows that from May 1979 until April 1980 system pressure was maintained at 300+60 psig. In May 1980 system pressure was lowered to 90+10 psig. Stress levels in the in core monitoring guide piping (1/2" SCH. 80) due to the above pressures are estimated at 750 psi and 225 psi respectively. The above gives further evidence with respect to the structural integrity of the incore piping system.

Based on the above information, it is concluded that the proposed insertion of the miniature ion chamber detector into the lower region of the RPV can be accomplished without undue risk to the health and safety of the public.

LIST OF REFERENCES

1. Babcock & Wilcox. TMI-2 Reactor Coolant System Component Evaluation. Task 27. S. K. Brown, et. al. May 1980. BAW-1629.

2. Technical Planning Department. July 1984. Data Report on Reactor Coolant System Sample Results. TPO/TMI-122, Rev. 0. Middletown, PA. GPU Nuclear Corporation.

3. GPUNC, Data Report. Reactor Building Basement History and Present Conditions. TMI-2 Technical Planning Department. November 1982. TPO/TMI-027.

4. Westinghouse Nuclear Systems Report No. WCAP-7798L. by E. D. Whyte and L. F. Picone. "Behavior of Austenitic Stainless Steel in Post Hypothetical Loss of Coolant Environments. November 1971.

5. Oak Ridge National Laboratory, Report ORNL-TM-2412. Design Considerations of Reactor Containment Spray Systems, Part X. by J. C. Gries and G. E. Creek. May 1971.

TABLE 1

In-Core Monitoring System Piping Materials Characterization

#	Description	Size/Schedule	Material
1	RPV Pentration Nozzle	3/4" SCH.160	Inconel SB 167 (Inconel-600)
2	Conc. Reducer Butt Weld	3/4" to 1/2" SCH.80	Ni-Cr-Fe
3	Pipe (From Bottom of Vessel to Seal Table).	1/2" SCH.80	304L SS
4	Conc. Reducer Butt Weld	3/4" X 1/2" SCH. 160	F 304L SS
5	Conc. Reducer Butt Weld	3/4" x 1/2" SCH. 80	F 304L SS
6	Pipe (Near Seal Table)	3/4" SCH. 160	304L SS
7	Weld for Instrument Nozzle to Head		SB-195 ER-Ni-Cr-Fe-3 (INCO 182T)

FIGURE-1

IN-CORE DETECTOR AND GUIDE PIPE CROSS SECTION

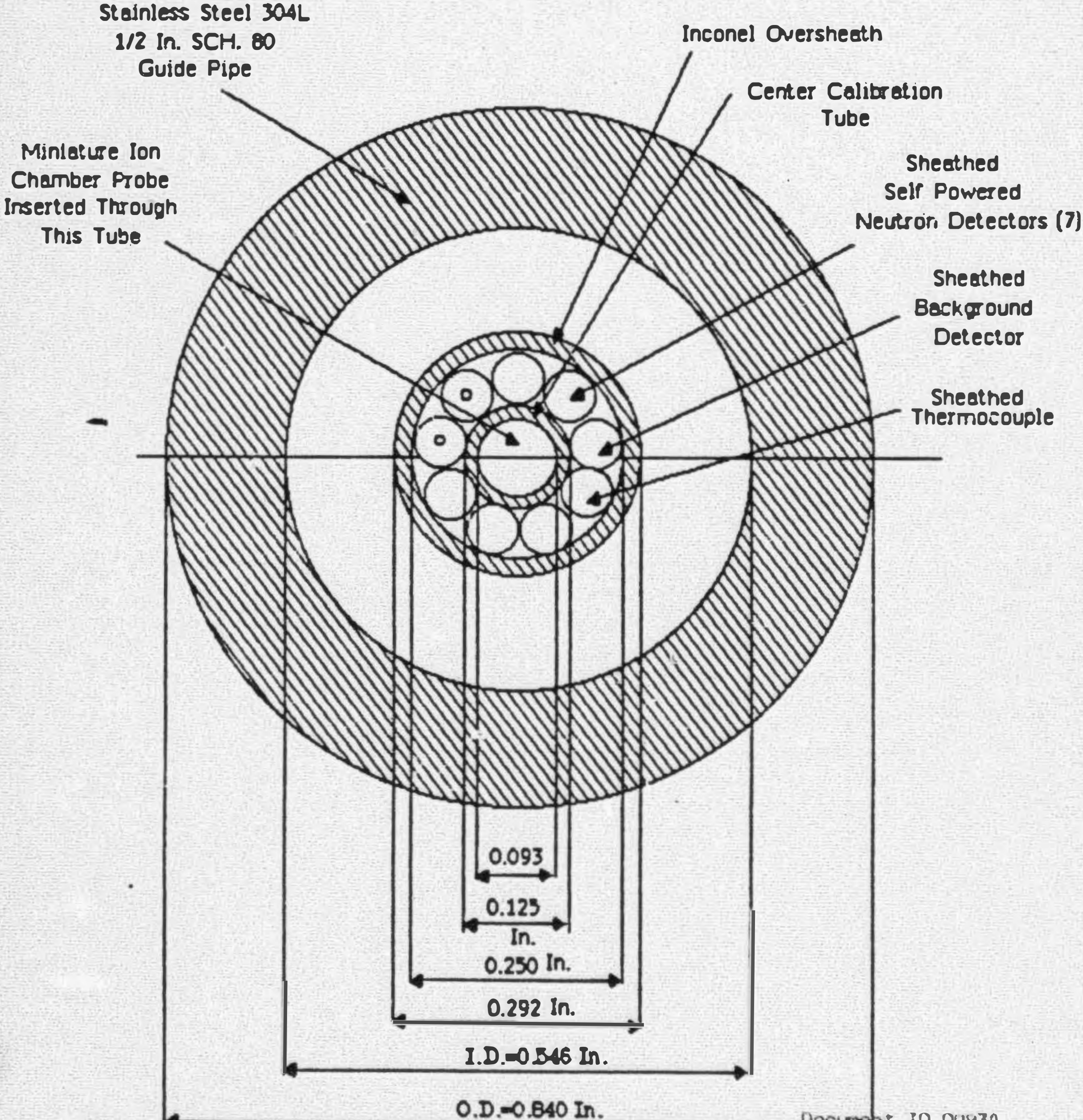

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FIGURE-2

TYPICAL IN-CORE DETECTOR ASSEMBLY INSTALLATION CHANNEL

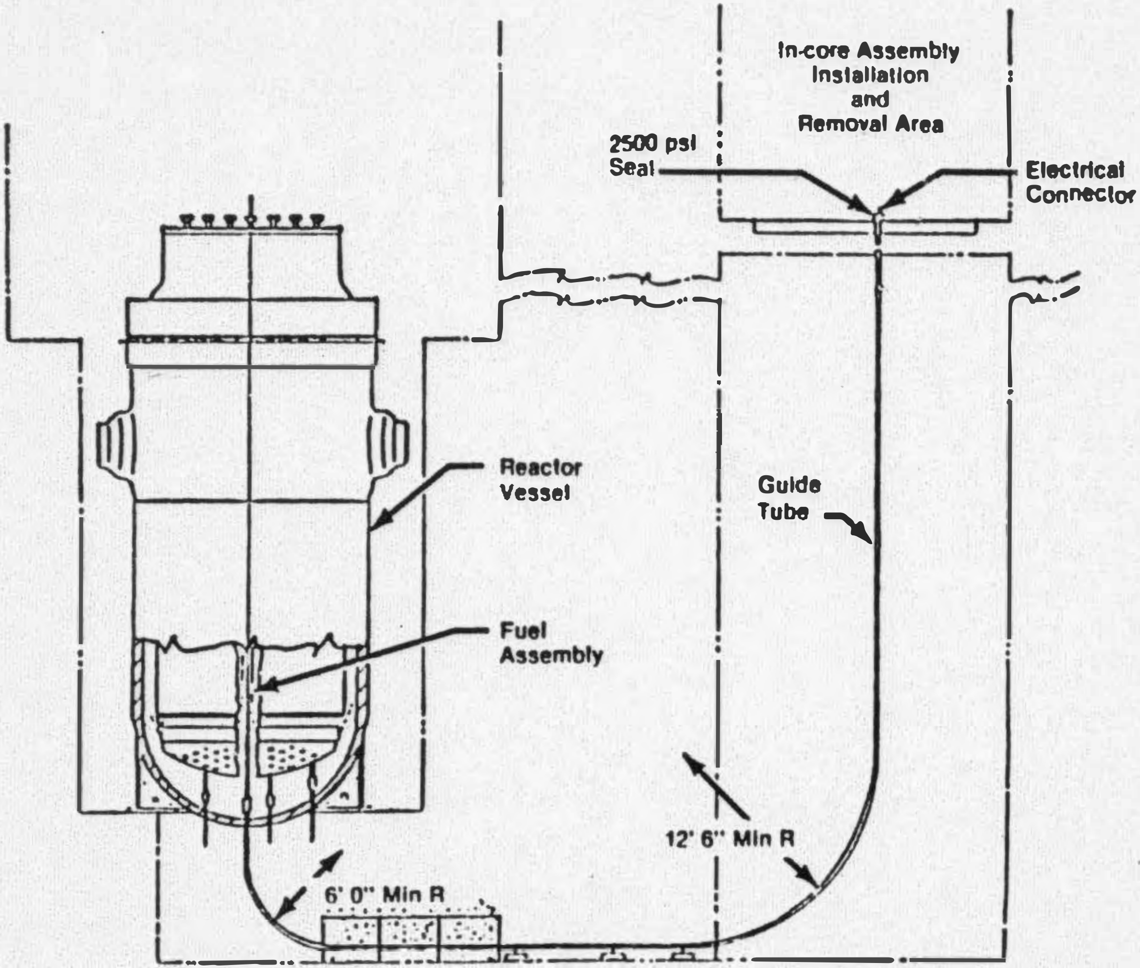
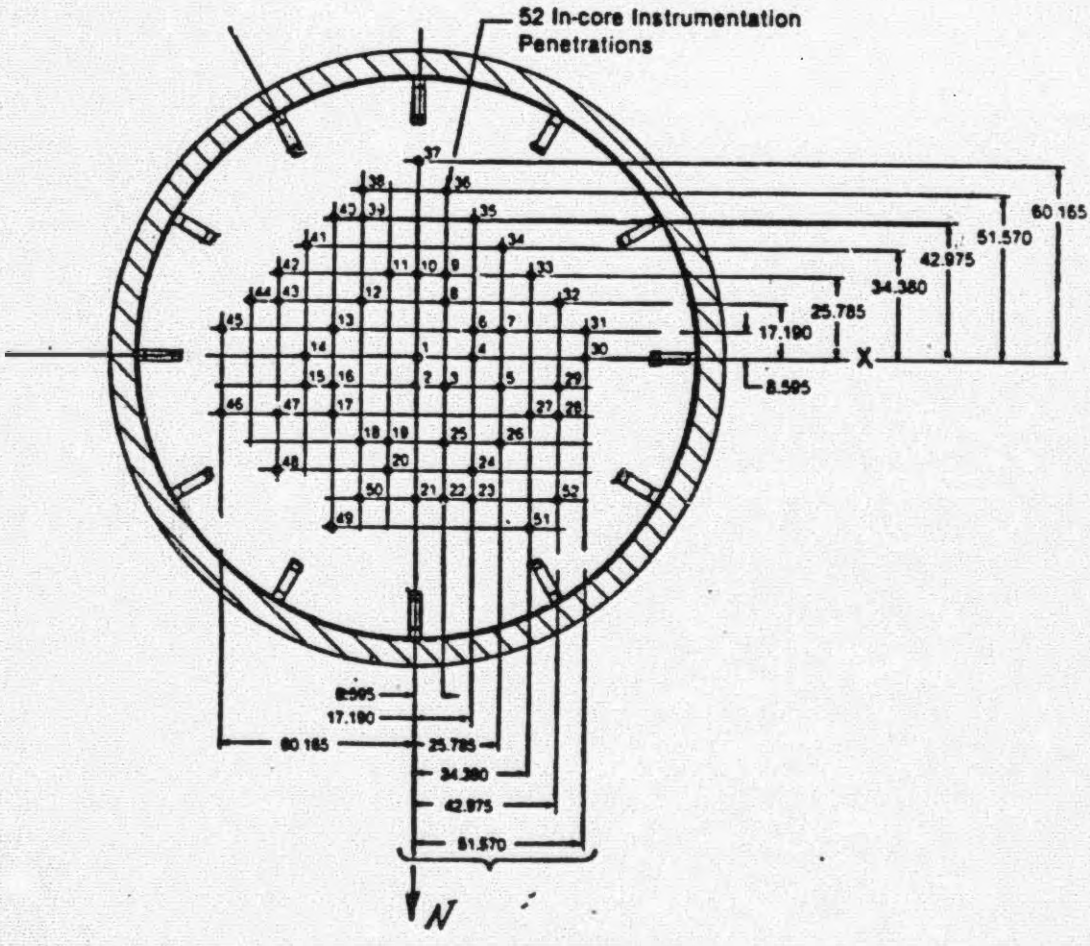


FIGURE-3

REACTOR PRESSURE VESSEL
IN-CORE INSTRUMENTATION PENETRATIONS
(52 Penetrations)



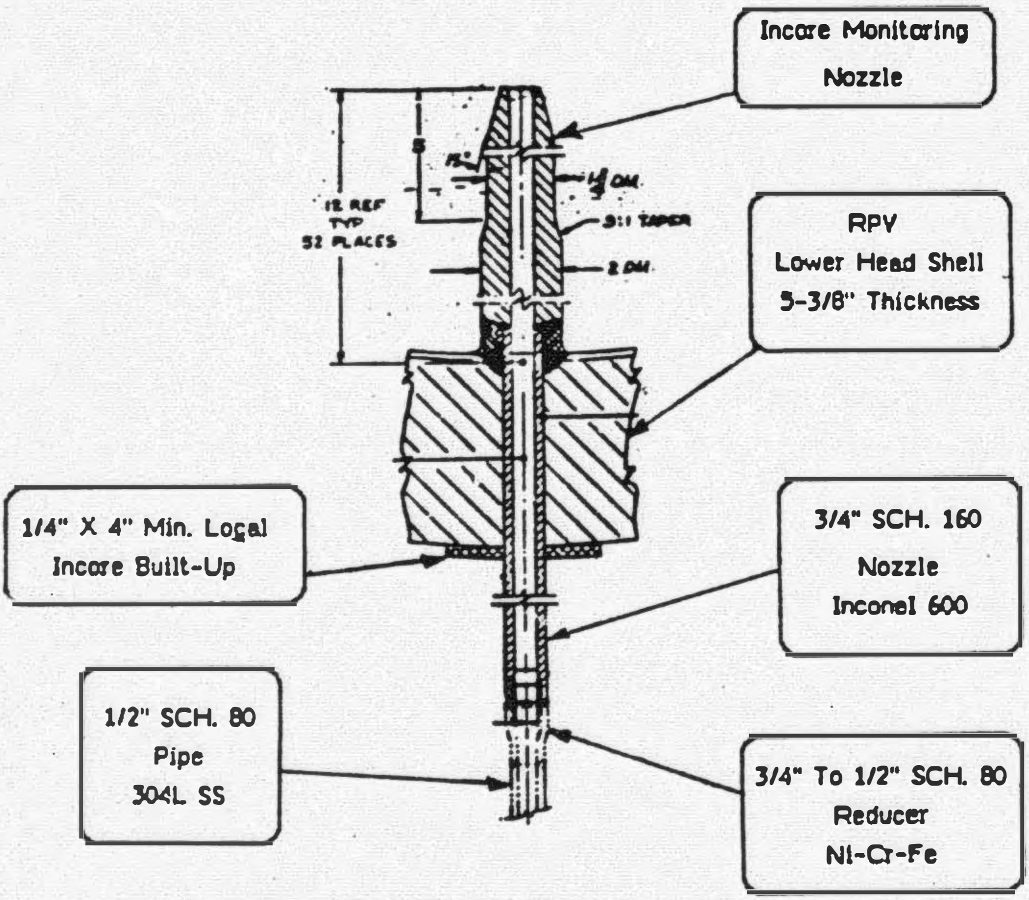
B&W Drawing #136196E, Rev. 7

View Looking Down

FIGURE-4

In-Core Guide Piping-RPV Penetration

Lower Head Penetration Details*



Thickness RPV Lower Head	5-3/8"
Head Penetration Nozzle (Inconel-600)	3/4" SCH. 160
Conc. Reducer (Ni-Cr-Fe)	3/4" x 1/2"
Guide Tube (304L SS)	1/2" SCH. 80

* Reference Dwg. B&W 136196-E, Rev. 7.

FIGURE 5

IN-CORE MONITORING GUIDE PIPING
LOCATION OF PIPE HANGERS PLAN VIEW