3. Background

In Section 3.1, we first briefly describe the basic features of the Davis-Besse nuclear plant, and then in some more detail the reactor pressure vessel head in Section 3.2, and the CRDM nozzle geometry, materials and construction in Section 3.3.

3.1 Overview of the Davis-Besse Plant

The Davis-Besse Nuclear Power Plant utilizes a "raised loop[a]" pressurized water reactor (PWR) Nuclear Steam Supply System (NSSS) designed and manufactured by the Babcock & Wilcox (B&W) company. The PWR plant design uses circulating high pressure water – reactor coolant – to remove the energy generated by the fission process in the fuel in the reactor core. In turn, this energy is used to generate steam in the steam generators, which then feed a turbine generator and finally generate electrical power.

The Davis-Besse plant received a construction permit on March 24, 1971, an operating license on April 22, 1977, and began formal commercial operation on July 31, 1978 [1].The plant shut was down at 18 to 24-month intervals – termed refueling outages (RFOs) – in order to remove spent nuclear fuel assemblies and insert fresh fuel assemblies to the reactor core. At the time of the shutdown for the 13th refueling outage (13RFO), Davis-Besse had accumulated 15.78 effective full power years (EFPY)[b] of operation[2]. Table 3-1 summarizes some of the key design and operating parameters of the Davis-Besse PWR nuclear plant and the B&W NSSS.

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[a]The term "raised loop" is a description applied to the Davis-Besse NSSS where the steam generators are elevated above the reactor pressure vessel (RPV) coolant inlet and outlet nozzles as shown in Figure 3-1. This is in contrast to the eight other plants that were built and operated with a B&W designed NSSS (only six of which remain in operation), all of which had a "lowered loop" configuration where the steam generators were lowered with respect to the RPV.

[b]EFPY is measure of the operating time in years of a nuclear reactor calculated as though the reactor had operated at full rated power continuously. Since the reactor undergoes shutdowns for refueling and other reasons and does not always operate at 100% rated power, EFPY is clearly less than the chronological operating time, which in the case of Davis-Besse was approximately 24 years.

3.2 The Davis-Besse Reactor Pressure Vessel Head

Figure 3-2 is an overall view of a typical PWR reactor pressure vessel (RPV), and shows the general arrangement of the RPV itself, the RPV head, and the control rod drive mechanisms (CRDM) and support structure. The RPV head itself is constructed of thick low alloy steel, clad on the inside with stainless steel, which is resistant to the corrosive action of the boric acid in the primary coolant water.

Expanded cross sectional views of the upper head of the Davis-Besse RPV are shown in Figures 3-3 and 3-4, and a plan view showing the CRDM layout is shown in Figure 3-5. These figures also show the general layout of the CRDM support structure, the mirror insulation, and the location of the 18 "mouse-hole" access and inspection openings.

As can be seen from these figures, the CRDM nozzles occupy most of the available space between the RPV head and the CRDM support steel and insulation, particularly in the top central region where CRDM nozzles 1, 2 and 3 are located, where the clearance is only a few inches at most.

Figure 3-6 is a photograph of the underside of the RPV head after its removal with the control rods still in place. Figures 3-7 and 3-8 are photographs through an access hole cut through the RPV head and CRDM service structure at 13RFO following the discovery of the RPV head wastage corrosion at Nozzle 3. The generally congested nature of the layout inside the service structure, and the limited access space around the CRDM nozzles are evident in these photographs.

3.3 The Davis-Besse CRDM Nozzles

The nuclear fission process in the reactor is controlled by means of the control rods, which are raised or lowered by the control rod drive mechanisms (CRDMs). The control rods have a high boron content which absorb neutrons, and so lowering the control rods into the core of the reactor slows down the fission process and reduces the reactor power output.[3] Full insertion of the control rods shuts down the reactor. The CRDMs are mounted on nozzles welded into the RPV head.

A second means for controlling the nuclear fission process is provided by means of boric acid dissolved in the circulating reactor coolant. Again, the boron in the boric acid absorbs neutrons, and so a high boric acid content is used early in the fuel cycle when the fuel is new to assist the control rods in maintaining the desired power output. As the fuel is used up over the 18 or 24 month fuel cycle, the boric acid content is gradually reduced, reaching almost zero by the time the fuel is spent, when an RFO is taken to load new fuel.

Since boric acid is generally corrosive to carbon and low alloy steel, the entire reactor coolant system in contact with the primary coolant water is made from corrosion resistant materials such as stainless steel and Alloy 600.

The Davis-Besse RPV head has 69 CRDM nozzles welded to the head, with 61 of these being used for CRDMs. The nozzles are fabricated from Alloy 600, and are attached to the RPV head by an Alloy 182 J-groove weld[4]. Figure 3-9 shows the design of a typical B&W plant CRDM nozzle. It is noted here that the flanged design was unique to the B&W design, and in fact was a source of constant boric acid leakage in the 1990's at B&W plants. A comparison of the Davis-Besse CRDM material, design, fabrication and operating parameters with other B&W plants is provided in Table 3-2 [5].

Cracking of Alloy 600 in primary water has occurred over the years in steam generator tubing, pressurizer heater sleeves, and other RCS components. It is generally accepted that such cracking occurs as a result of the combination of a susceptible material, high residual stresses, and an aggressive environment, and these factors are considered in more detail in subsequent section of this report. In particular, a more detailed discussion of the CRDM nozzle and weld material properties, as well as the nozzle installation and welding process, is provided in Section 8.1.

However, it is noted here that, as shown in Table 3-2, Davis-Besse CRDM nozzles 1 through 5 were all manufactured by B&W from the same heat of Alloy 600, that this heat of alloy 600 experienced considerable cracking at Oconee-3 where it was used for 68 of the 69 CRDM nozzles, and that four of the five Davis-Besse CRDM nozzles manufactured from this heat of Alloy 600 (nozzles 1, 2 3 and 5) all experienced cracking. The significance of the use of this susceptible heat of Alloy 600 and the cracking experienced in CRDM nozzles manufactured from it at Oconee-3 and Davis-Besse is discussed in detail in Sections 4 and 8 of this report.

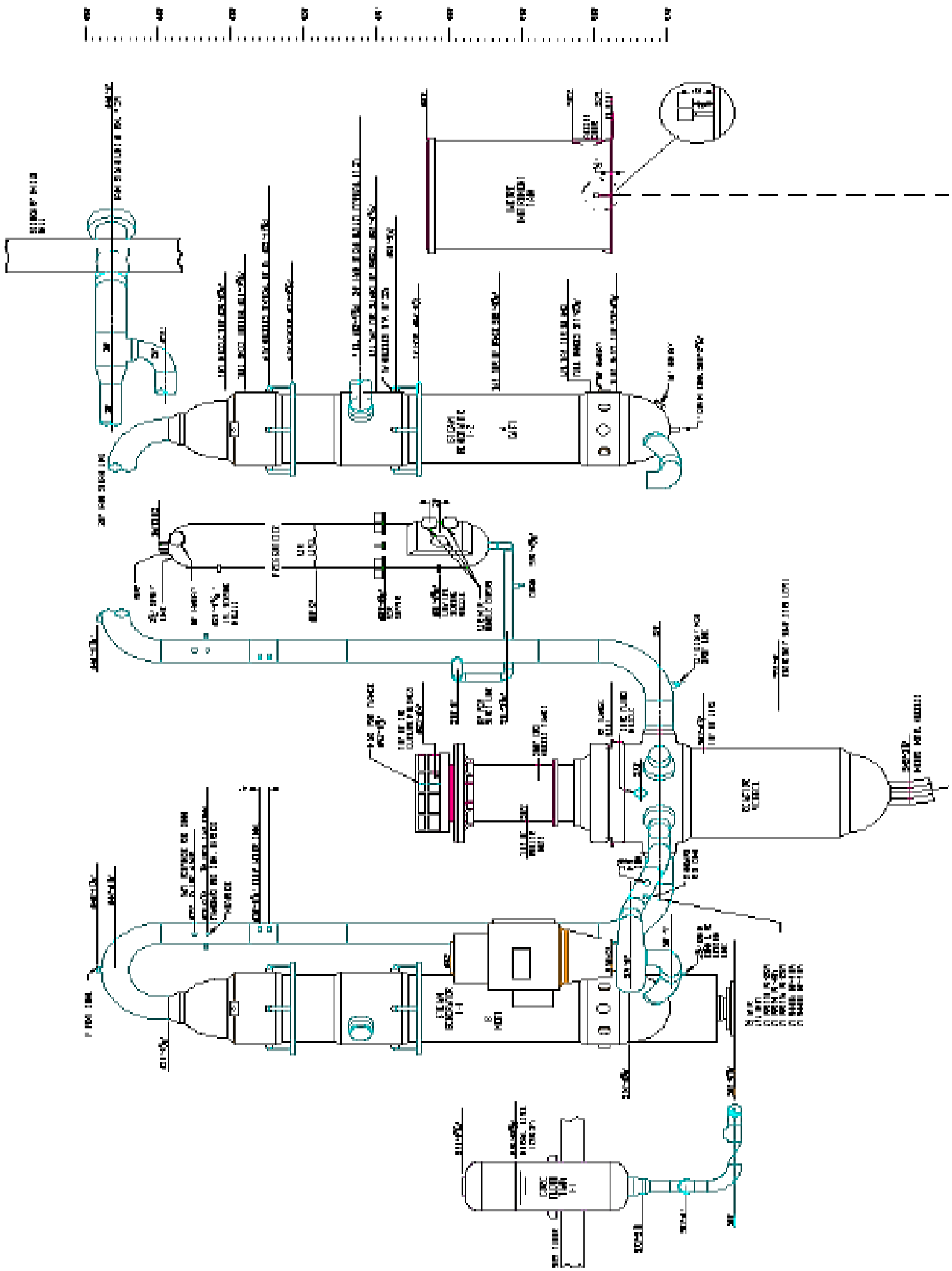

Figure 3.1   Davis-Besse NSSS Showing “Raised Loop” Configuration

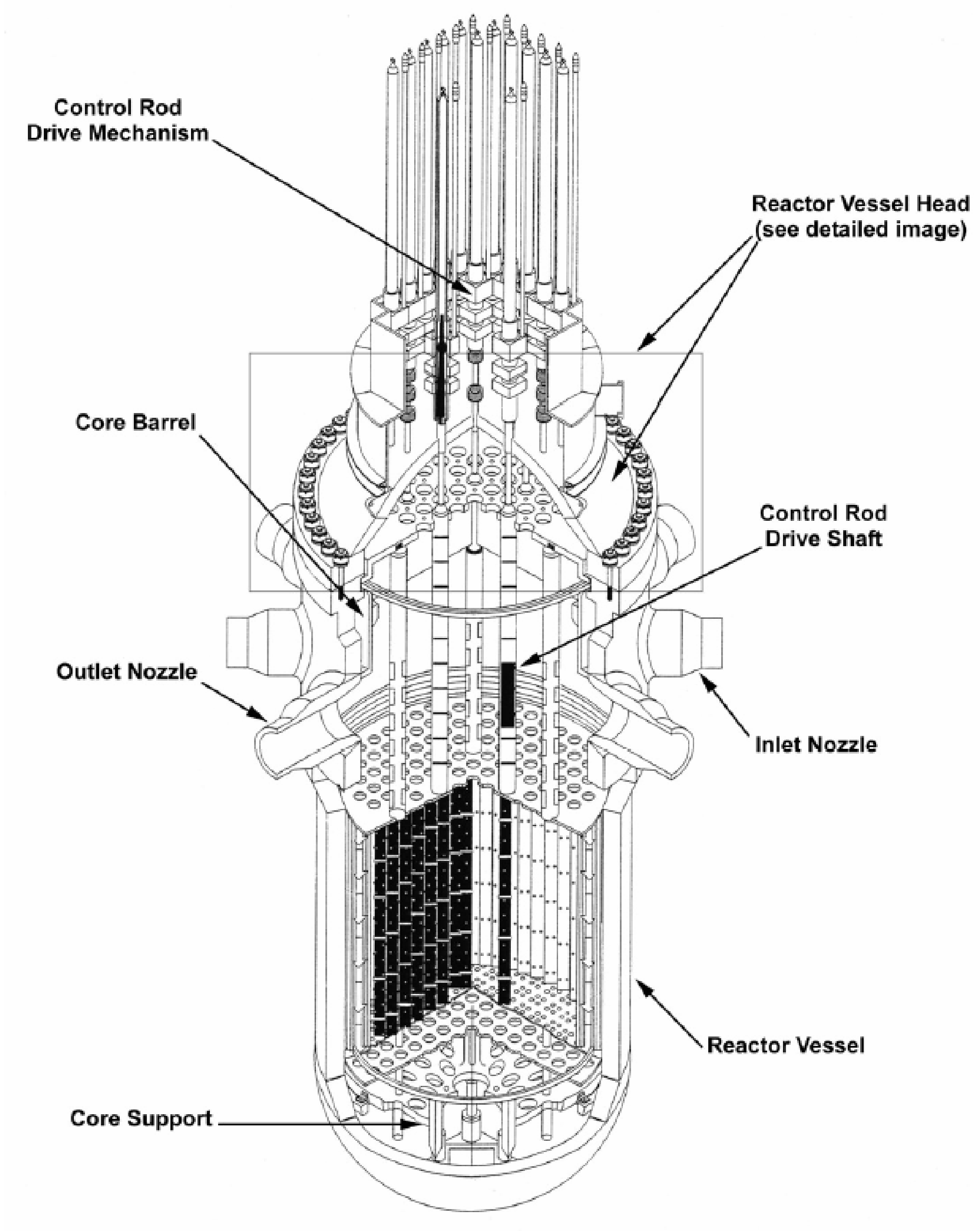

Figure 3.2 Typical Reactor Pressure Vessel Head General Arrangement

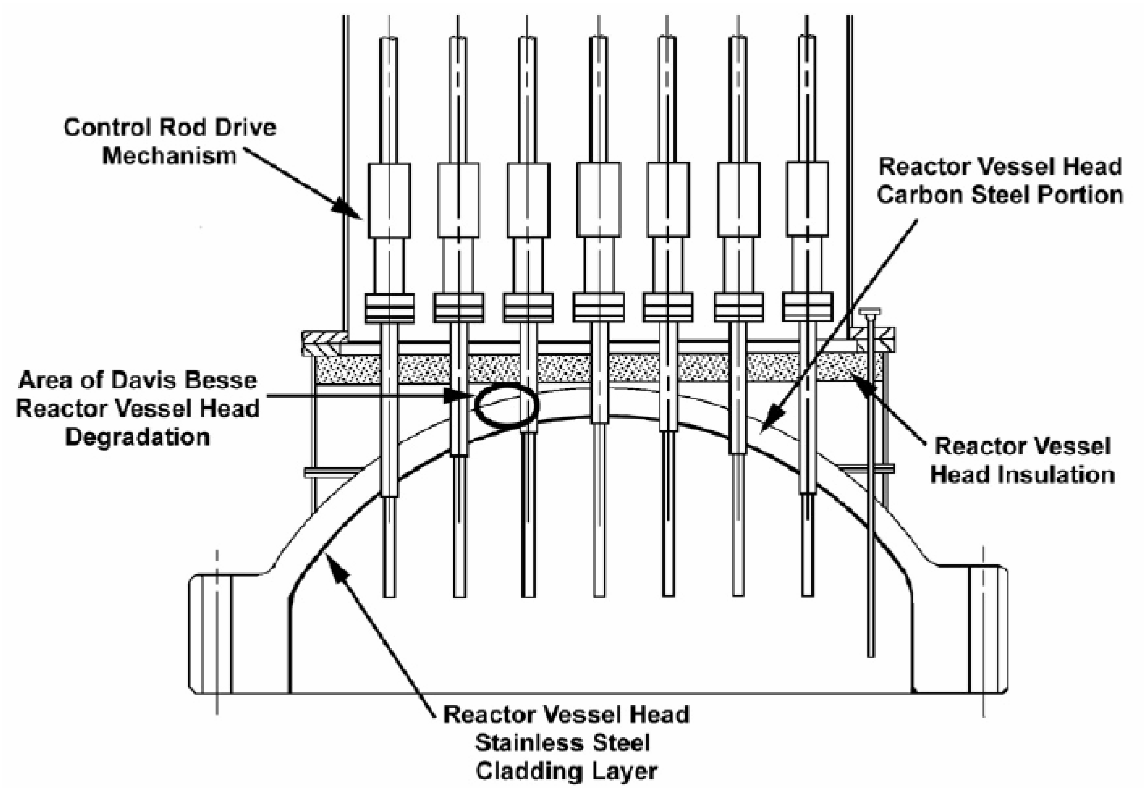

Figure 3.3 Davis-Besse Reactor Pressure Vessel Head Sectional View

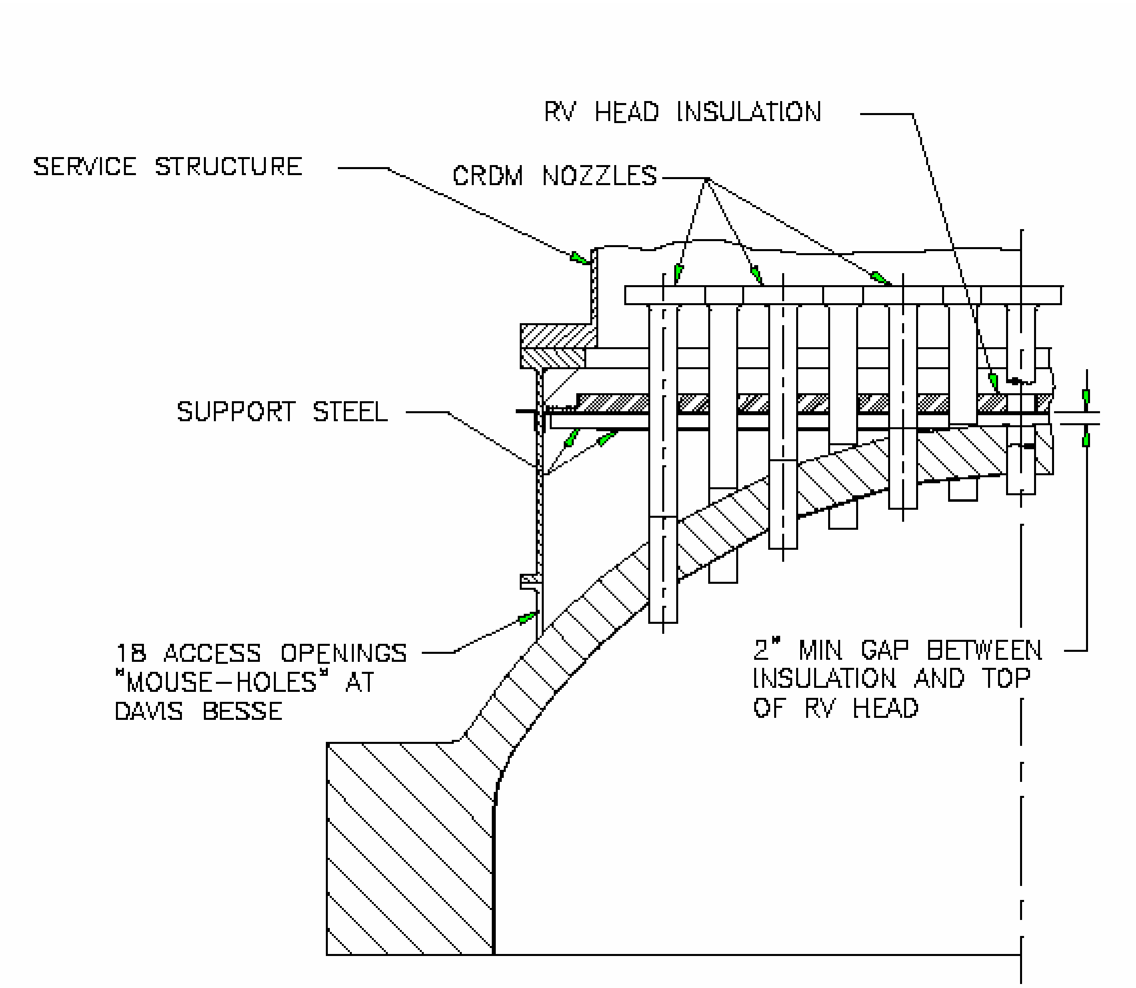

Figure 3.4 Davis-Besse Reactor Pressure Vessel Head Sectional View

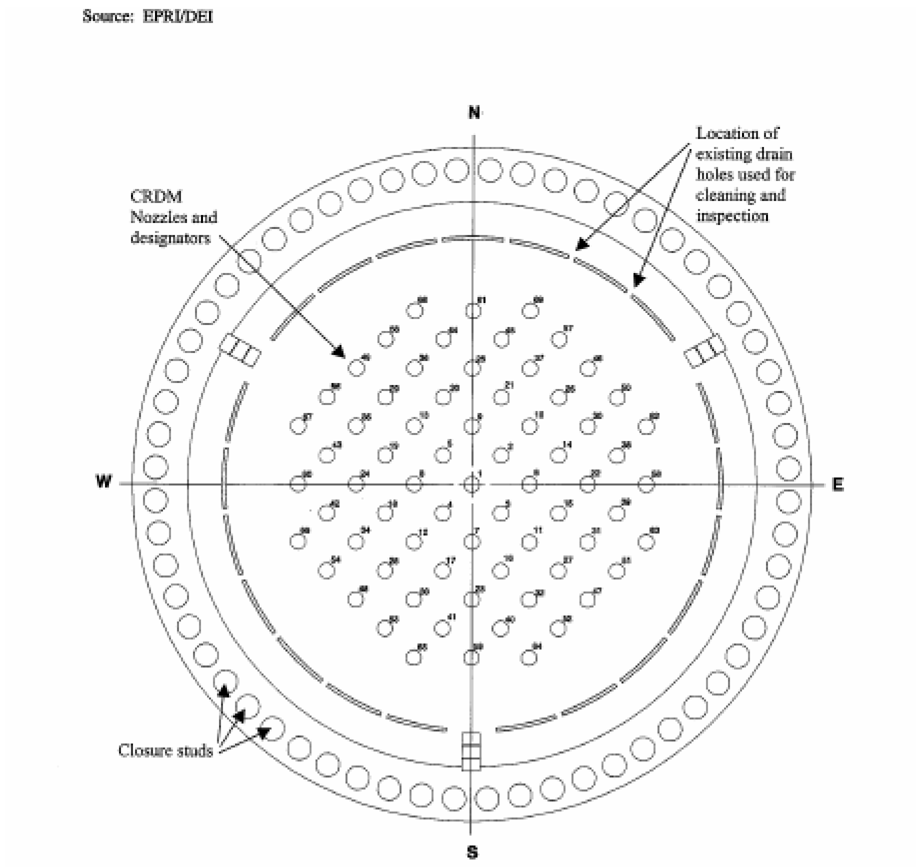

Figure 3.5 Davis-Besse Reactor Pressure Vessel Head Plan View

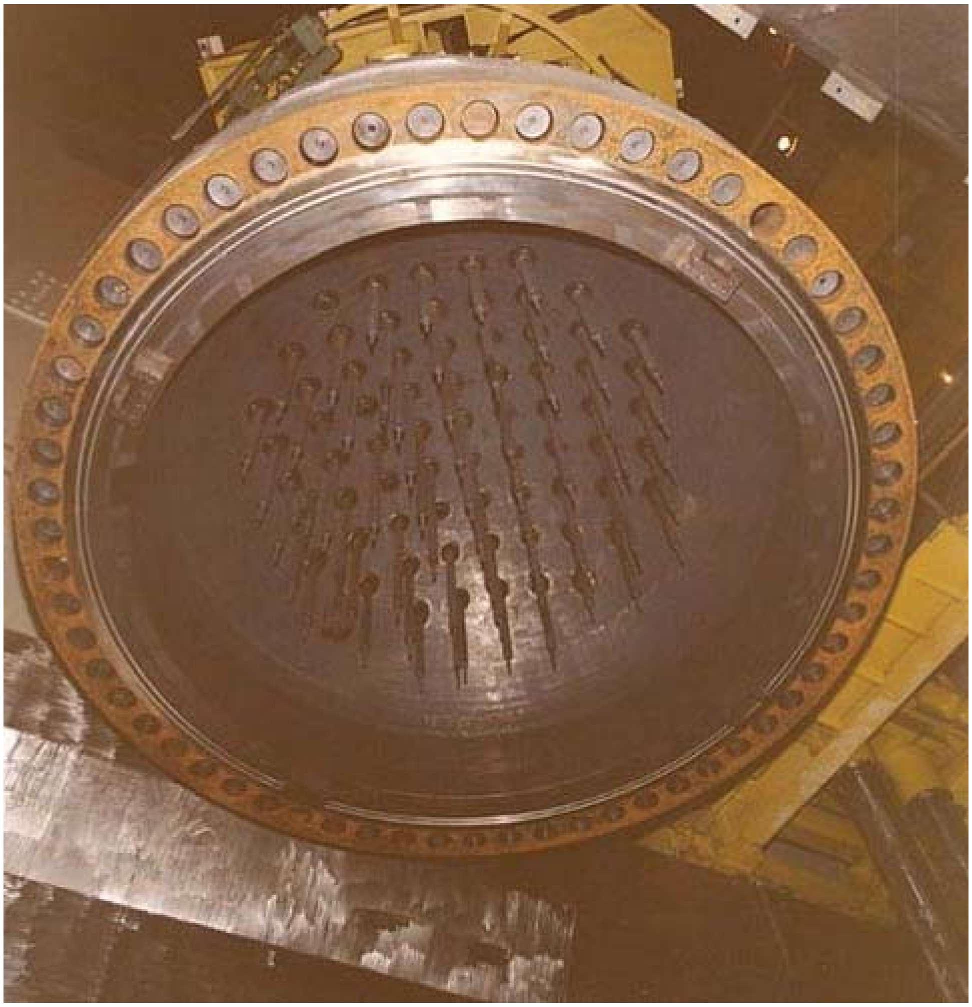

Figure 3.6 View of the Underside of the Davis-Besse RPV Head with Control Rods in Place

Figure 3.7 View through the Access Opening Cut in the RPV Head Service Structure above the Support Steel and Insulation Showing the Close Proximity of the CRDM Flanges

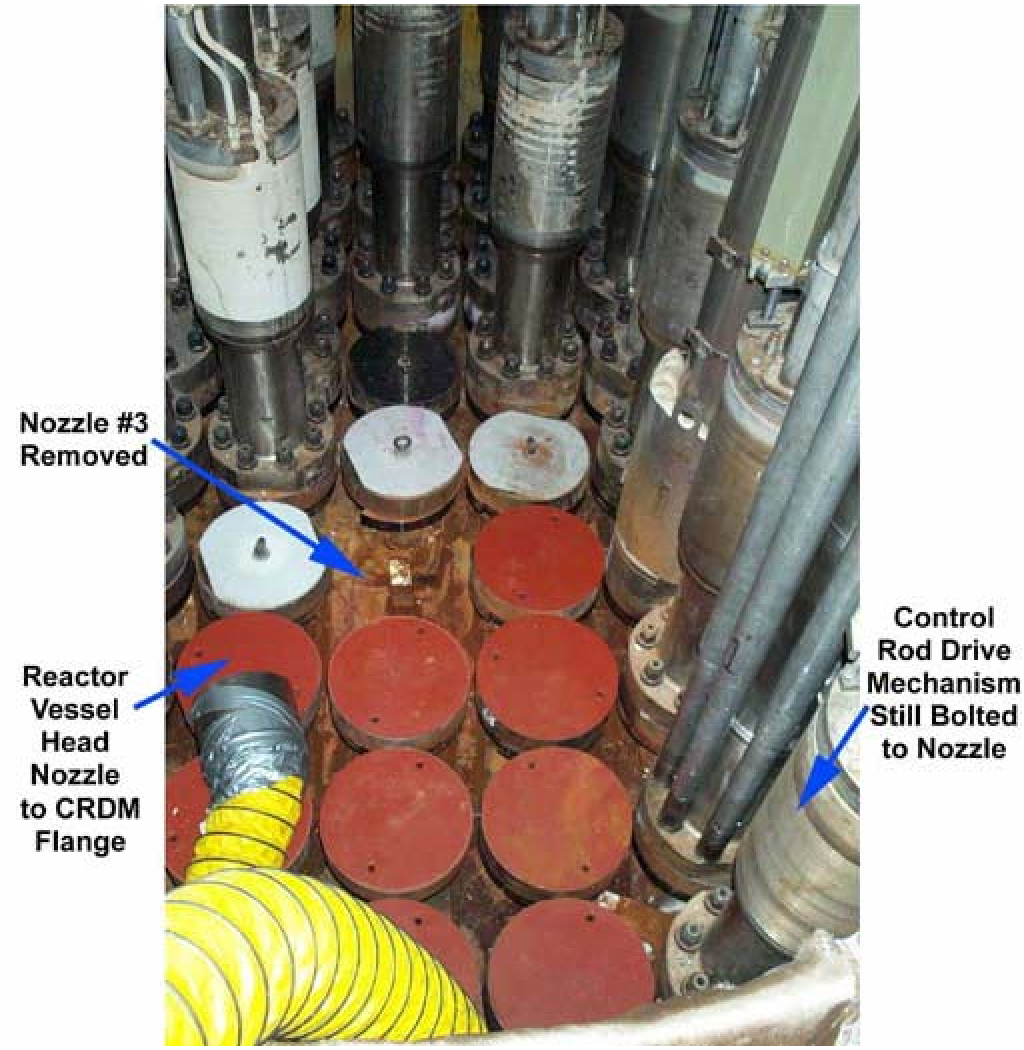

Figure 3.8 View through the Access Opening Cut in the RPV Head Service Structure above the Support Steel and Insulation Showing the Close Proximity of the CRDM Flanges

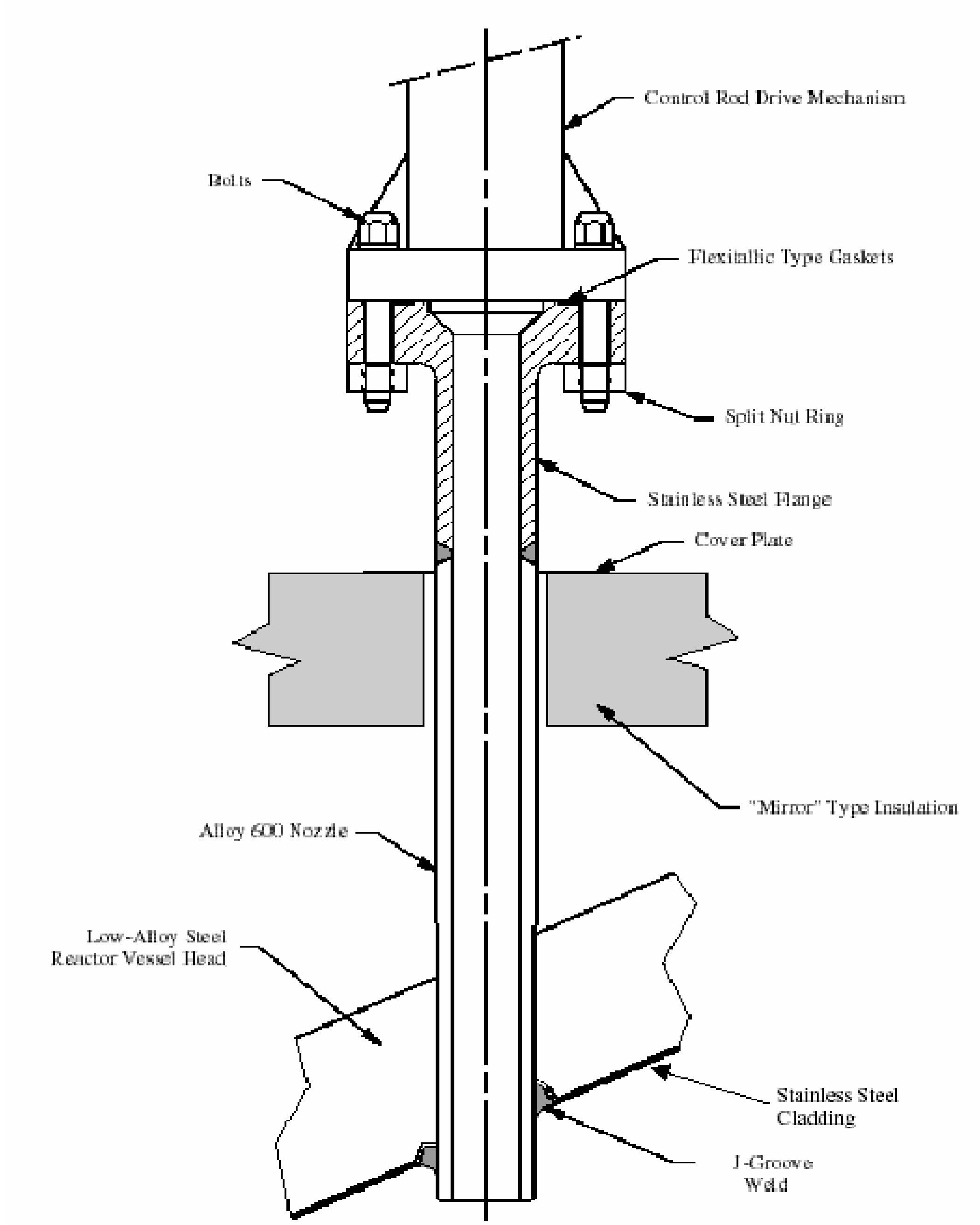

Figure 3.9 Davis-Besse CRDM Nozzle General Arrangement

Table 3.1 Principal Design Parameters of the Davis-Besse Plant

Location	21 miles ESE of Toledo, Ohio
NRC Docket Number	050-00346
Construction Permit Issued	March 24, 1971
Operating License Issued	April 22, 1977
Commercial Operation	July 31, 1978
Operating License Expires	April 2, 2017
Licensed Thermal Output	2772 MWt
Design Electrical Output	882 MWe
NSSS Manufacturer	Babcock & Wilcox
Number of Fuel Assemblies	177
NSSS Loop Configuration	Raised Loop
RPV Design Pressure	2500 psig
RPV Design Temperature	650 Deg. F.
RPV Outlet (Head) Temperature	605 Deg. F [Check]
RPV Inlet Temperature	555 Deg. F [Check]

Table 3.2 Davis-Besse CRDM Nozzle Geometry, Materials and Operating Parameters

Parameter	Oconee 1	Oconee 2	Oconee 3	ANO-1	Davis-Besse	TMI-1	Crystal River 3
NSSS	B&W	B&W	B&W	B&W	B&W	B&W	B&W
Material Supplier	BWTP	BWTP	BWTP	BWTP	BWTP	BWTP	BWTP
RPV Head Fabricator	B&W	B&W	B&W	B&W	B&W	B&W	B&W
Design Nozzle Fit (mils)	0.5 – 1.5	0.5 – 1.5	0.5 – 1.5	0.5 – 1.5	0.5 – 1.5	0.5 – 1.5	0.5 – 1.5
EFPYs Through Feb 2001	20.4	20.3	20.1	8.0	14.7	16.8	14.9
Head Temperature, Deg. F	602	602	602	602	605	601	601
EFPYs Normalized to 600 Deg. F	22.1	22.0	22.7	19.5	17.9	17.5	15.6
EFPYs to reach Oconee 3 EFPY	-0.3	-0.2	0.0	2.1	3.1	4.1	5.9
Access Ports in Lower RPV Head Shroud	Yes	Yes	Yes	No	No	Yes	Yes
Boric Acid on RPV Head	Small Amount	Small Amount	Large Amount Prior to 2000	Some	Large Amount	Some	Some
Number of CRDM Nozzles	69	69	69	69	69	69	69
- With Leaks	1	4	14	1	3	5	1
- With Leaks & Circ Cracks	0	1	4	0	1	0	1
- With Alloy 600 Heat M3935	0	0	68	1	5	0	0
Number of T/C Nozzles	8	0	0	0	0	8	0
- With Leaks	5 Confirmed	N/A	N/A	N/A	N/A	8	N/A
Counterbore at Bottom of CRDM Nozzles	Yes	Yes	Yes	Yes	No	Yes	Yes
As-Built Fit Range for Leaking Nozzles (mils)	Clearance	Clearance to 1.4 Interference	Clearance to 1.0 Interference	0.4 – 0.7	0.1 – 2.0		
Wastage at CRDM Nozzle Leaks	No	No	No	No	Yes	No	No

3.4 References

1. US Nuclear Regulatory Commission, "2005-2006 Information Digest", NUREG-1350, Volume 17, July 2005, Appendix A, Page 98; NRC Web Site "Operating Nuclear Power Reactors"

2. First Energy, Davis-Besse Nuclear Power Station, "Root Cause Analysis Report", Revision 1, CR 2002-0891, August 27, 2002, Section 2.1, Page 2.

3. Samuel Glasstone & Alexander Sesonske, Nuclear Reactor Engineering, Van Nostrand Reinhold Co., New York, (1967), pp. 279-284.

4. *Ibid*.

5. *Ibid*, Table 6, Page 75; source data from MRP-48, EPRI MRP Response to NRC Bulletin 2001-01.