

Preliminary Analysis and Experiment on Penetration Integrity of the Lower Pressure Vessel under External Vessel Cooling in the KNGR

150

가

ICI thimble

FLUENT
Thermite

가

FLUENT
FLUENT

ejection

Abstract

An experimental program on penetration integrity of the lower pressure vessel has been launched under external vessel cooling in the Korean Next Generation Reactor (KNGR). The objective of this program is to estimate failure or no failure of the penetration including the In-Core Instrumentation (ICI) nozzle and the thimble tube in condition with external vessel cooling to maintain integrity of the reactor pressure vessel during severe accidents. Preliminary analysis has been performed to improve the detailed design of the test section and to define test matrix using the FLUENT computer code. Preliminary experiment has been performed to find the technical problem of test section manufacture and to investigate behavior of the thermite melt. The FLUENT results shows that nozzle ejection will be occurred by weld ablation in condition without external vessel cooling. The FLUENT results and the technical problem in the preliminary test were reflected to the detailed design of the test section.

1.

가

(external vessel

cooling)

가

(IVR: In-Vessel Corium Retention)

[1, 2].

Loviisa

AP 600

[3, 4]

[5].

가

ICI (In-Core Instrumentation)

thimble

ejection

thimble

[6].

ICI

thimble

가

가

가

ICI

thimble

가

FLUENT

thermite

2.

(Korea Next

Generation Reactor: KNGR)[7]

SA508, Grade 3, Class 1

(carbon steel)

ER309L STRIP/FLUX

(stainless steel)

ICI

ICI

690(N06690)

ASME

2142

2143

690

(ENiCrFe-7)

TIG (ERNiCrFe-7)

ICI

가

가

ICI

(stainless

steel)

thimble

가

ICI

thimble

가

Thimble

4,000 MW_{th}

3,4

2,815 MW_{th}

40 %

가

3,4

1

4.74 m

3,4

4.22 m

ICI

61

3,4

thimble

3,4

3,4

thimble

3.

가.

ICI thimble

가

2

ICI

1

가

가 가

가

61

가가

1

thermite

UO

ZrO

가

가

가가

,

thermite

가

가

thermite

(Al₂O₃)

가

FAI[8]

가

SNL

LHF(Lower Head Failure)

[9],

PSI

CORVIS

[10]

3

CORVIS

LHF

가

가

FAI

ICI

thimble

ICI

가

FAI

thimble

ejection

가

가

가

1

, thermite

가 ,

가
Attack In-Vessel)

SONATA-IV(Simulation Of Naturally Arrested Thermal
LAVA(Lower Plenum Arrested Vessel Attack)

[11]

thermite

가 7,900 kg/m³

가

가 3,800 kg/m³

2

61 ICI

가

ICI

ICI

thimble

ICI

4.

가.

FLUENT

[12]

2

가 2,700 K

3 4

30 kg 40 kg

30 kg

40 kg

40 kg

4

가

40 kg

5가

4, 5, 6
ejection 가

thermite 가 LAVA
1
가 thimble

thimble
6 가 7
Thermite
thermite
가

5.

FLUENT
ICI thimble
Thimble 가
2,000. C
가 1.62 W/m.K
10 cm
(MgO)

8 11 가

2,400 K 가 C K

C W/Re
HP Workstation VXi

(0.1 MPa, 0.5 MPa, 1.0 MPa, 1.5 MPa),

(40 kg, 60 kg),

(,),

가

(Safety Depressurization System)

10

10

ICI

가 가

4

6 (LAVA/ICI-No.)

6.

ICI thimble

가

가

FLUENT

thermite

FLUENT

ejection

1. T. G. Theofanous et al., "In-Vessel Coolability and Retention of a Core Melt," DOE/ID-10460, July 1995
2. S. H. Yang et al., "An Experimental Study of Pool-Boiling CHF on Downward Facing Plates," J. of KNS, V. 26 (4), pp. 493-501, 1994
3. T. G. Theofanous et al., "In-Vessel Coolability and Retention of a Core Melt," Nuclear Engineering & Design 169, pp. 1-48, 1997
4. O. Kymalaineen et al., "In-Vessel Retention of Corium at the Loviisa Plant," Nuclear Engineering & Design 169, pp. 109-130, 1997
5. , " In-Vessel Retention ", , 1998
6. J. L. Rempe et al., "Light Water Reactor Lower Head Failure Analysis," NUREG/CR-5642, EGG-2618, October 1993
7. , " (I) - (I) ", , 1994
8. R. J. Hammersley et al., "Experiments to Address Lower Plenum Response Under Severe Accident Conditions," FAI, 1994
9. T. Y. Chu et al., "Experimental Investigation of Creep Behavior of Reactor Vessel Lower Head," OECD/CSNI Workshop on In-Vessel Core Debris Retention and Coolability, Garching, Germany, March 3-6, 1998
10. J. P. Hosemann et al., "Corium Vessel Interaction Studies - Status of the CORVIS Project," NUREG/CP-0133, 1994
11. , " ", KAERI/TR-1334/99, 1999
4
12. FLUENT 5 User's Guide, Fluent Incorporated, July 1998

1.

	TMI-2	W PWR (Typical)	Korean Standard PWR	KNGR
Inner Dia. of the Lower Reactor Vessel(m)	4.44	4.20	4.22	4.74
Thickness of the Lower Reactor Vessel (m)	0.127	0.14	0.1524	0.165
Total Number of the ICI Nozzles	52	58	45	61
Material and Outer Dia. of the ICI Nozzle(m)	Inconel, 0.0508	Inconel, 0.0274	Inconel 690, 0.0762	Inconel 690, 0.0762
Thickness of the ICI Nozzle(m)	0.01746	0.0064	0.0286	0.0286
Thickness of the Water Filled Annulus (m)	0.00423	0.0023	0.00381	0.00381
Material and Outer Dia. of the Thimble Tube(m)	Inconel, 0.00742	St. Steel, 0.008	St. Steel, 0.01143	St. Steel, 0.01143
Thickness of the Thimble Tube(m)	0.000535	0.0012	0.001245	0.001245

2.

	KNGR	Test Section
Geometry of the Lower Reactor Vessel	Hemi-sphere	Flat Plate or Flat Plate with Curvature
Thickness of the Reactor Vessel(m)	0.165	0.165
Number of the ICI Nozzle	61	1
Outer Diameter of the ICI Nozzle(m)	0.0762	0.0762
Thickness of the ICI Nozzle(m)	0.0286	0.0286
Thickness of Water Filled Annulus (m)	0.00381	0.00381
Outer Diameter of the Thimble Tube(m)	0.01143	0.01143
Thickness of the Thimble Tube (m)	0.001245	0.001245

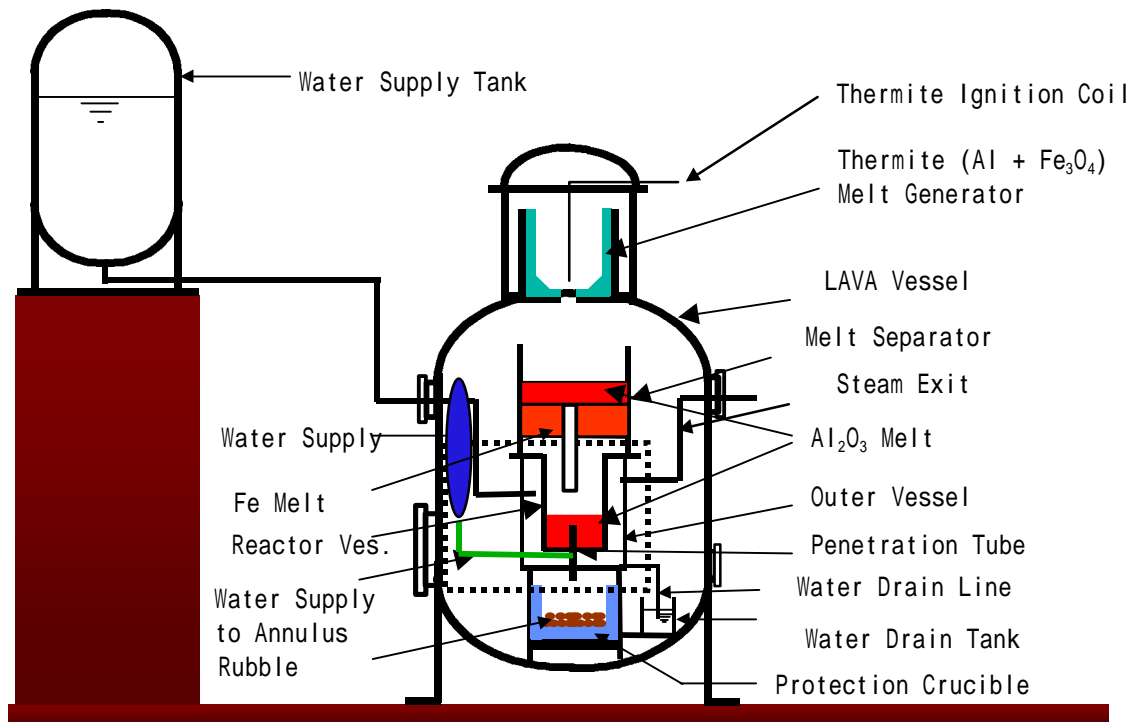
3.

	KAERI	FAI	CORVIS	LHF
Place	KAERI, Korea	FAI, U.S.A.	PSI, Switzerland	SNL, U. S. A.
Reactor Type	KNGR	W PWR, GE PWR, BWR	BWR(03/xx), PWR(04/xx)	PWR
Total Test Number	6	10	3(large scale)	2(LHF-4, LHF-5)
Simulant	Al ₂ O ₃ 40 kg, 60 kg	Thermite 20 kg, 40 kg	Thermite 800 kg, Al ₂ O ₃ 400 kg,	Electrical Heater
Condition of Outer Vessel	With External Vessel Cooling	With External Vessel Cooling	Without External Vessel Cooling	Without External Vessel Cooling
Main Focus of Experiment	Tube Ejection by Weld Ablation	Penetration Depth of Debris through Annulus	Failure Mechanism of Penetration	Failure Mechanism of Penetration
Mail Results	-	No Penetration Failure	Failure of BWR Drain Line	Penetration Weld Failure

4.

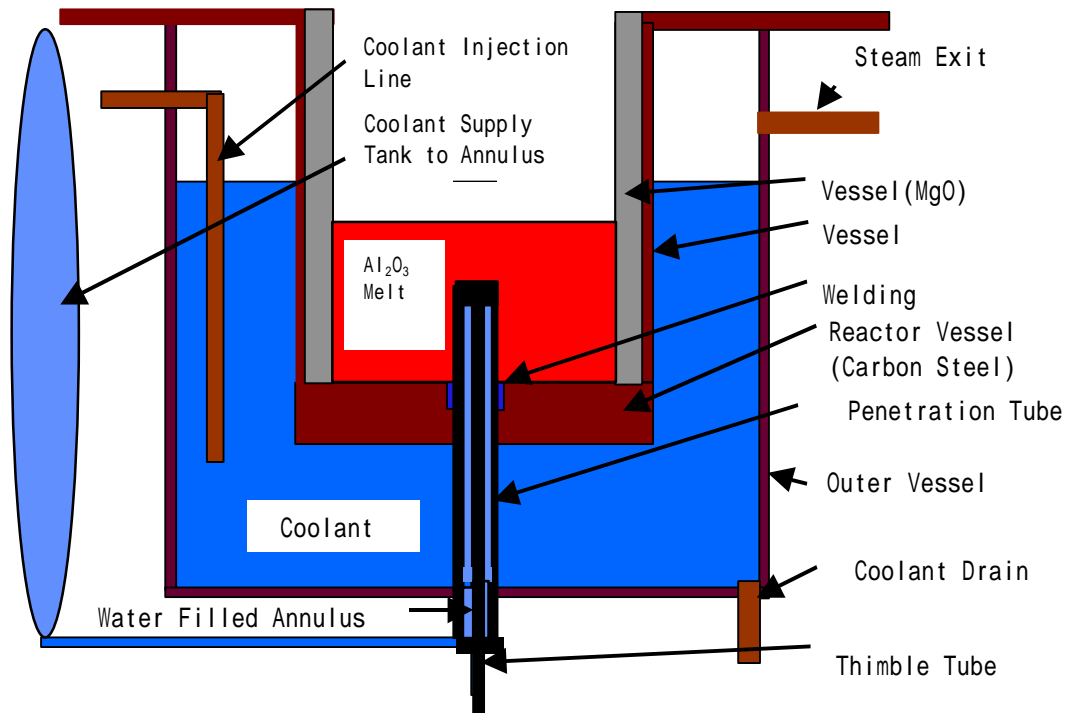
Test No.	Pressure (MPa)	Geometry	Simulant Mass (kg)	Remarks
LAVA(*)/ICI-DRY	0.1	Flat Plate	40	No External Vessel Cooling
LAVA/ICI-1	1.0	Flat Plate	40	Base Case
LAVA/ICI-2	1.5	Flat Plate	40	Influence of In-Core Water
LAVA/ICI-3	1.5	Flat Plate	40	Influence of High Pressure
LAVA/ICI-4	1.0	Flat Plate	60	Influence of Mass
LAVA/ICI-5	1.0	Flat Plate with Curvature	40	Influence of Vessel Geometry

(*) LAVA = Lower-plenum Arrested Vessel Attack



1.

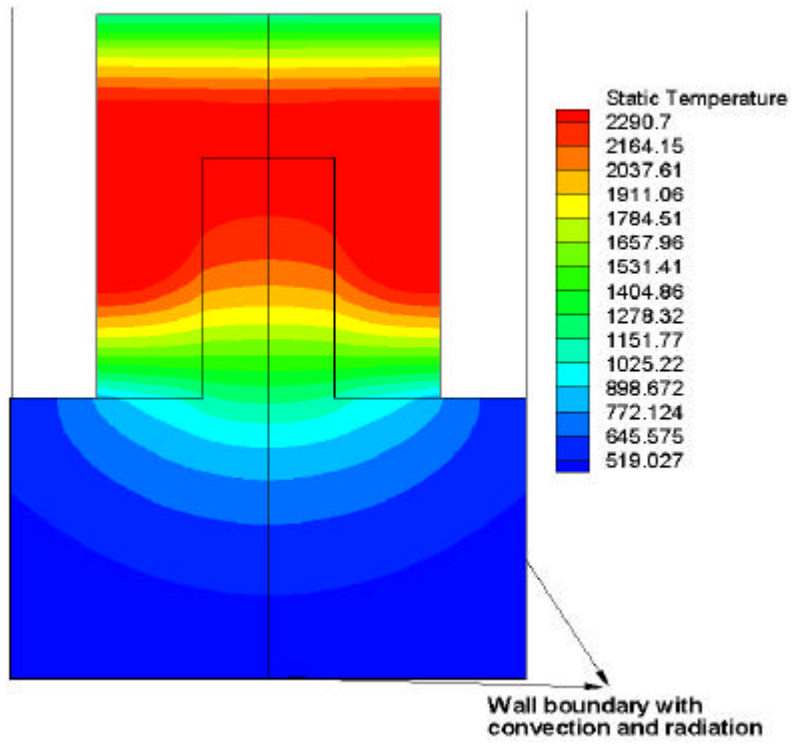
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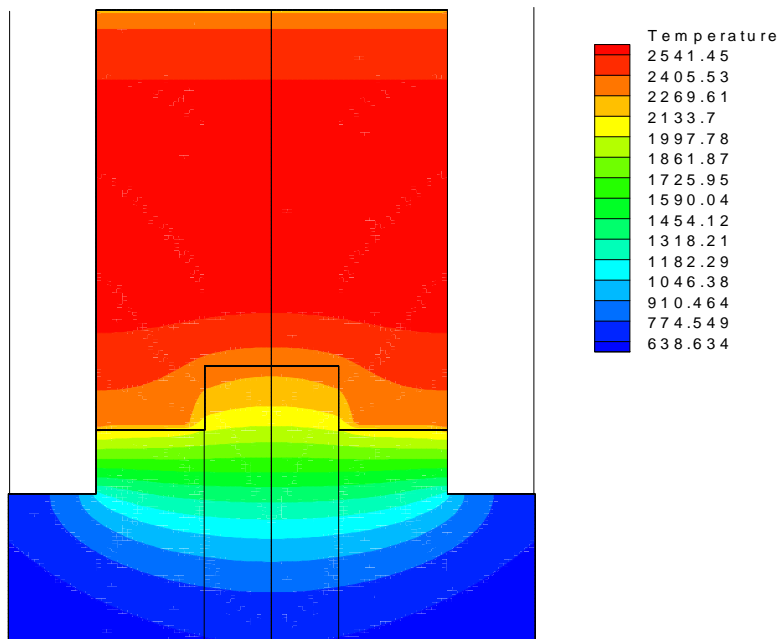
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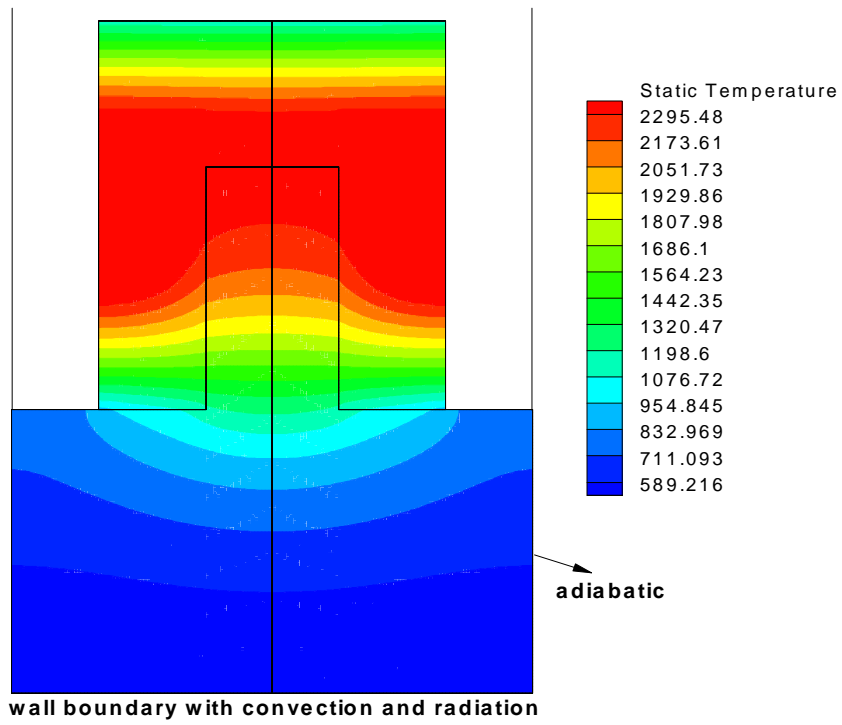
Temperature contours at 2,200 sec



3. FLUENT (30 kg).



4. FLUENT (40 kg).



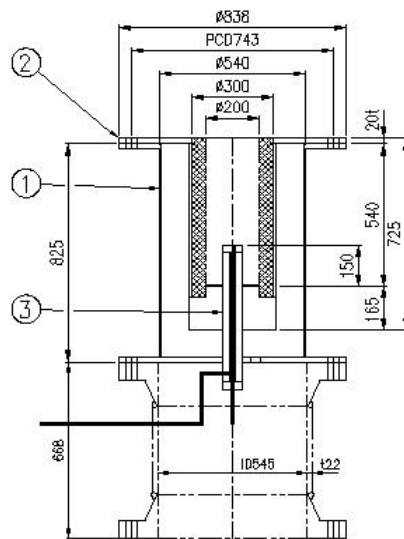
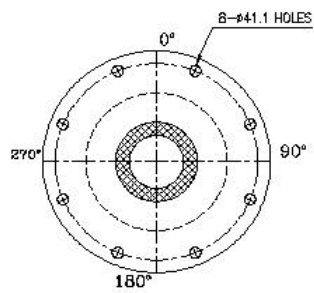
5. FLUENT ().



6. 가



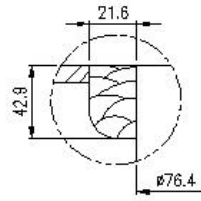
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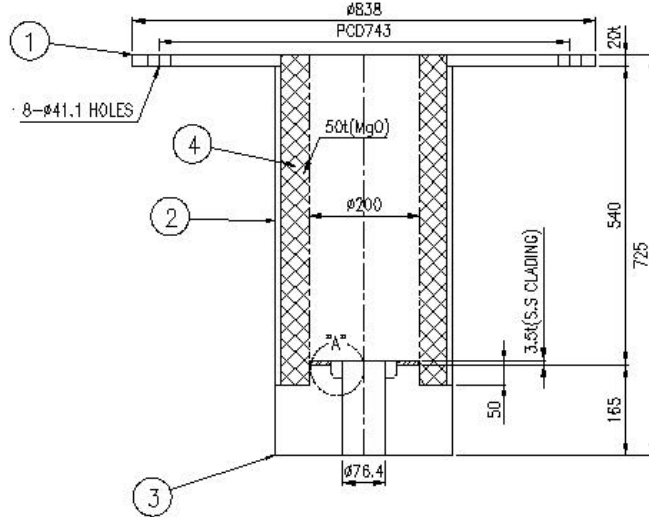
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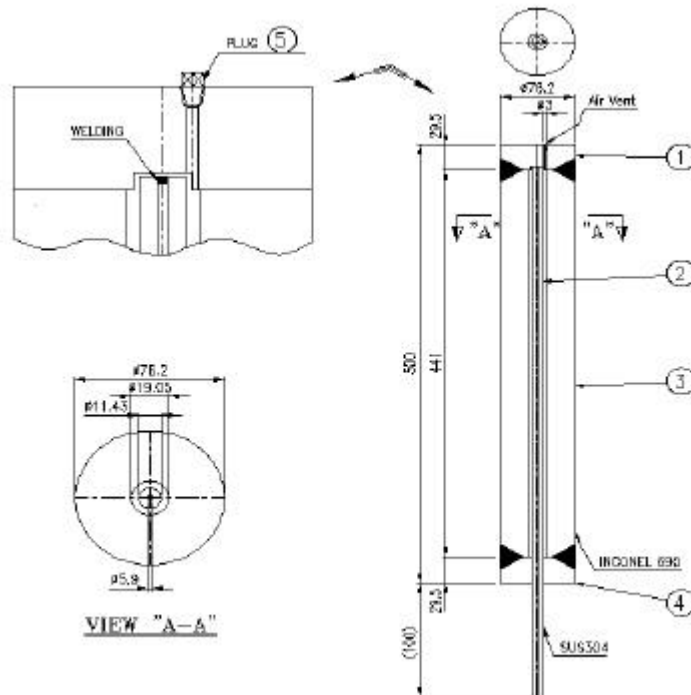
(Layout)



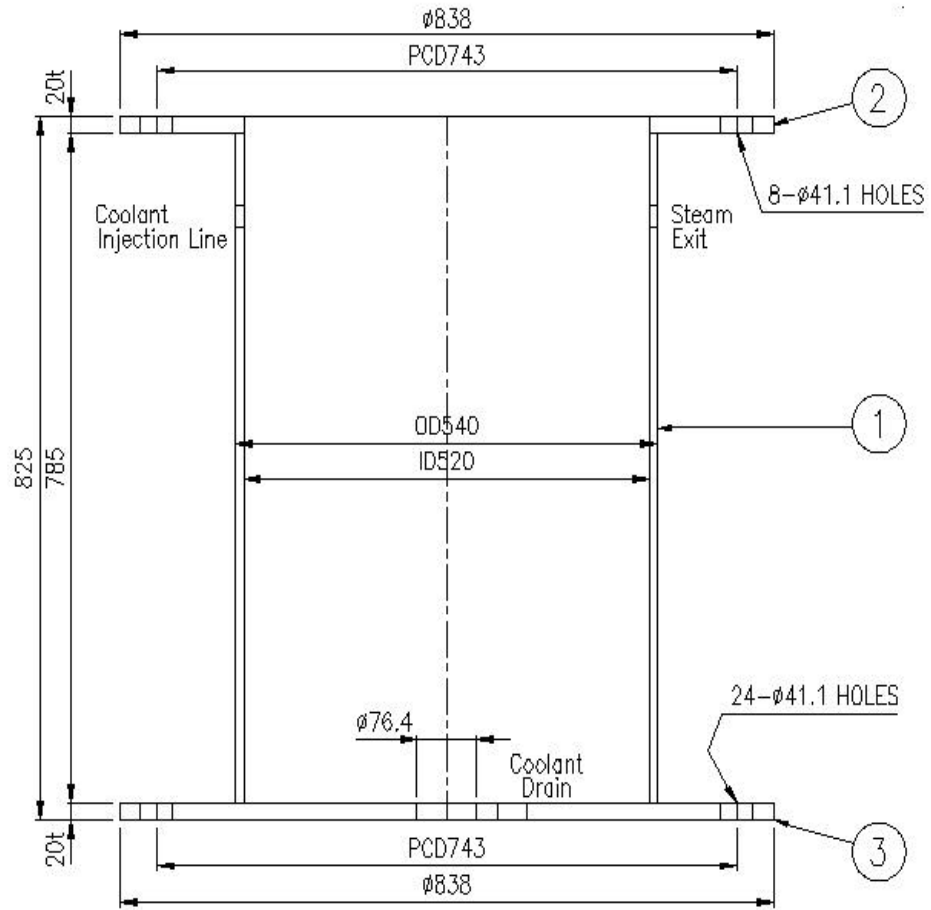
DETAIL OF "A"



9. 가 ()



10. 가 (Thimble)



11. 가 ()