



Idaho National Laboratory

RELAP5-3D Assessment for NGNP Application

Model Validation and Benchmark Exercises

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Outline

- **Background and goals**
- **Method of analysis**
- **Model I, Model II:**
 - **Problem description**
 - **Results**
- **Conclusions**
- **Questions and references**

Background and Goals

- **Project goals:**
 - **To assess performance of RELAP5-3D by using models from an IAEA report and comparing results to those obtained using other codes**
- **IAEA-TECDOC-1163**
 - **“Heat Transport and Afterheat Removal for Gas Cooled Reactors Under Accident Conditions”**
 - **Contains numerous model validation and benchmark exercises related to the reactor cavity cooling system (RCCS).**

What is the RCCS?

- **Designed to “remove all of the core afterheat in the unlikely case of failure or unavailability of the main and all other shutdown cooling systems” (1)**
- **Serves as “an ultimate heat sink, ensuring the thermal integrity of the fuel, core, vessel, and critical equipment within the reactor cavity for the entire spectrum of postulated accident sequences” (1)**

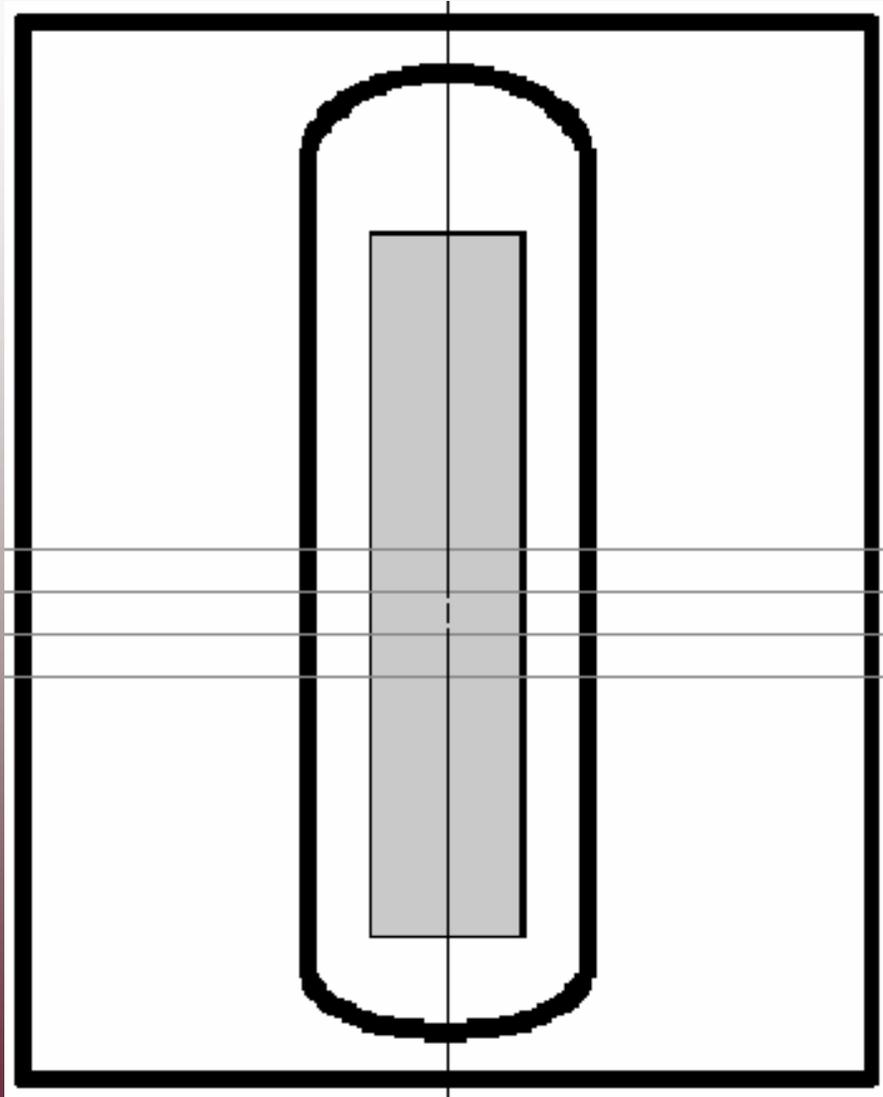
Method of Analysis

- Relap5-3D v2.3.6
- MATLAB script
 - Input model parameters such as dimensions and power or temperature profiles
 - Shape factor determination
 - Simplified
 - More complex
 - Nodalization and simplification of model geometry

Shape Factors

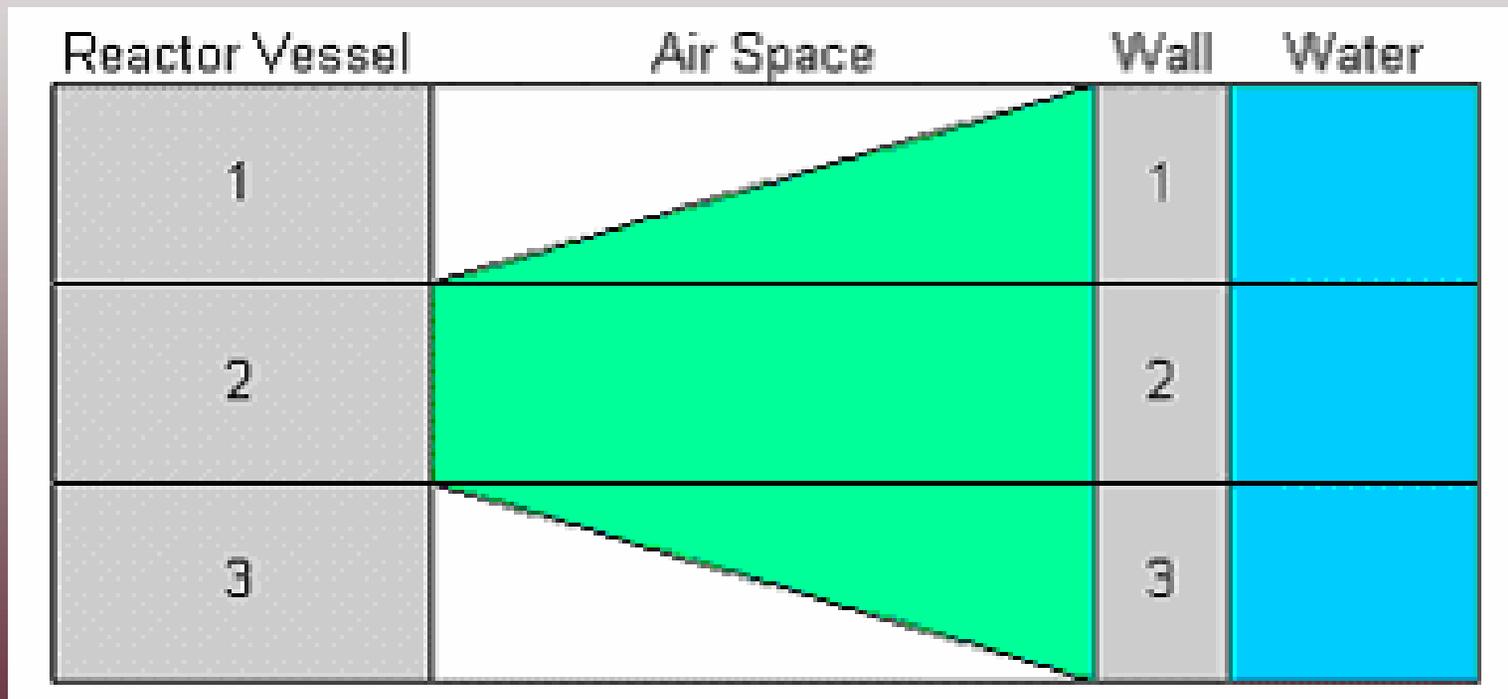
- **“The fraction of thermal energy leaving the surface of object 1 and reaching the surface of object 2, determined entirely from geometrical considerations” (3)**
 - **Also known as configuration factors or view factors**
 - **Howell, professor at Texas University at Austin, has list of correlations for different geometries**

Shape Factors: Generic Geometry



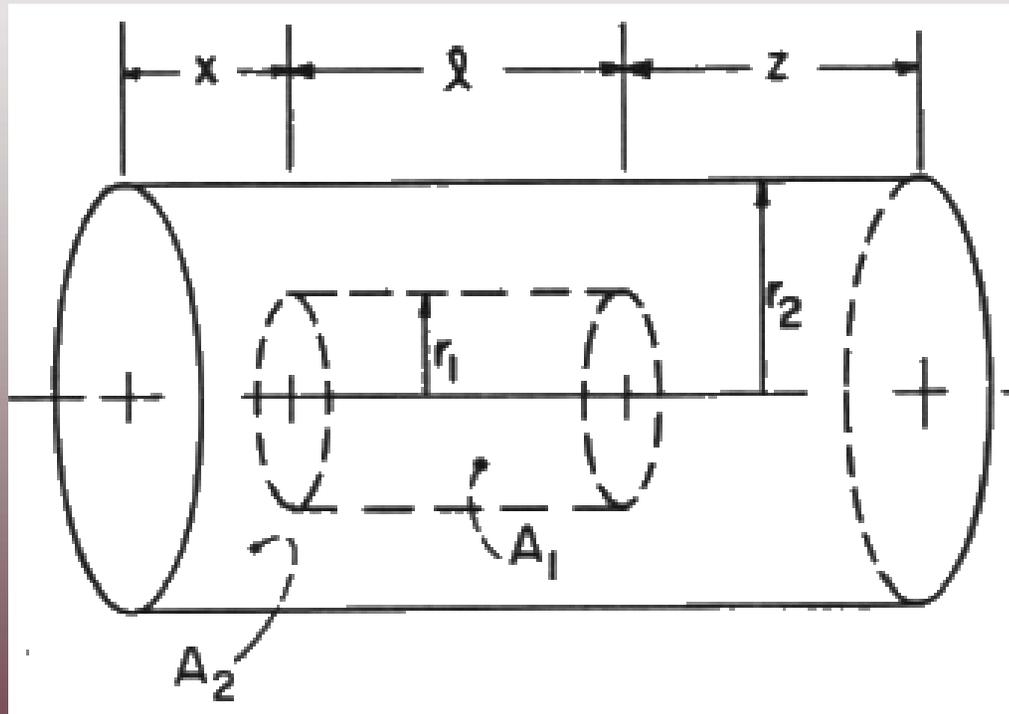
Shape Factors: Generic Geometry

- Option 1: only considering those cells straight-across
- Option 2: incorporating all adjacent cells



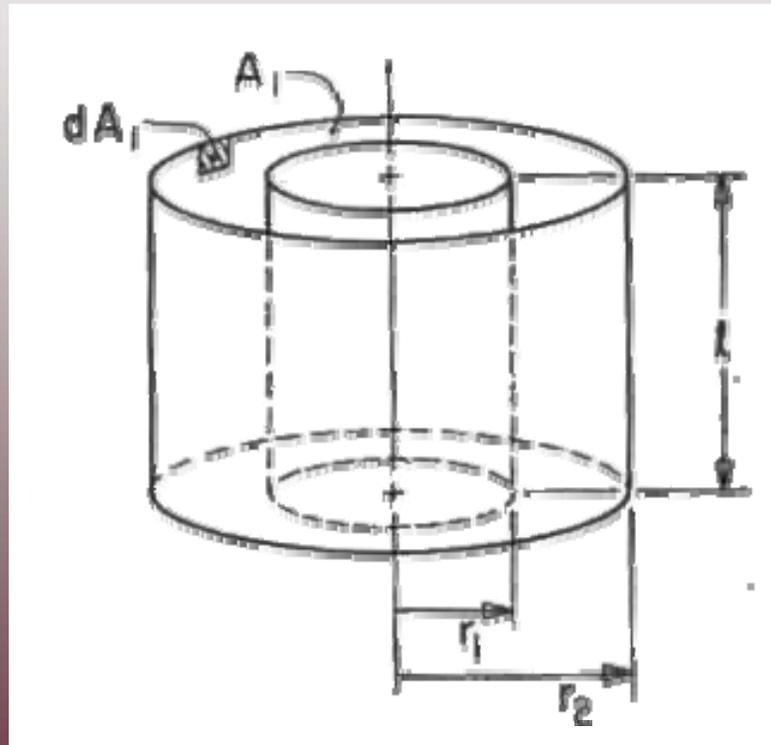
Shape Factor Determination

- **C-95: Inner coaxial cylinder to outer coaxial cylinder; inner cylinder entirely within outer (4)**



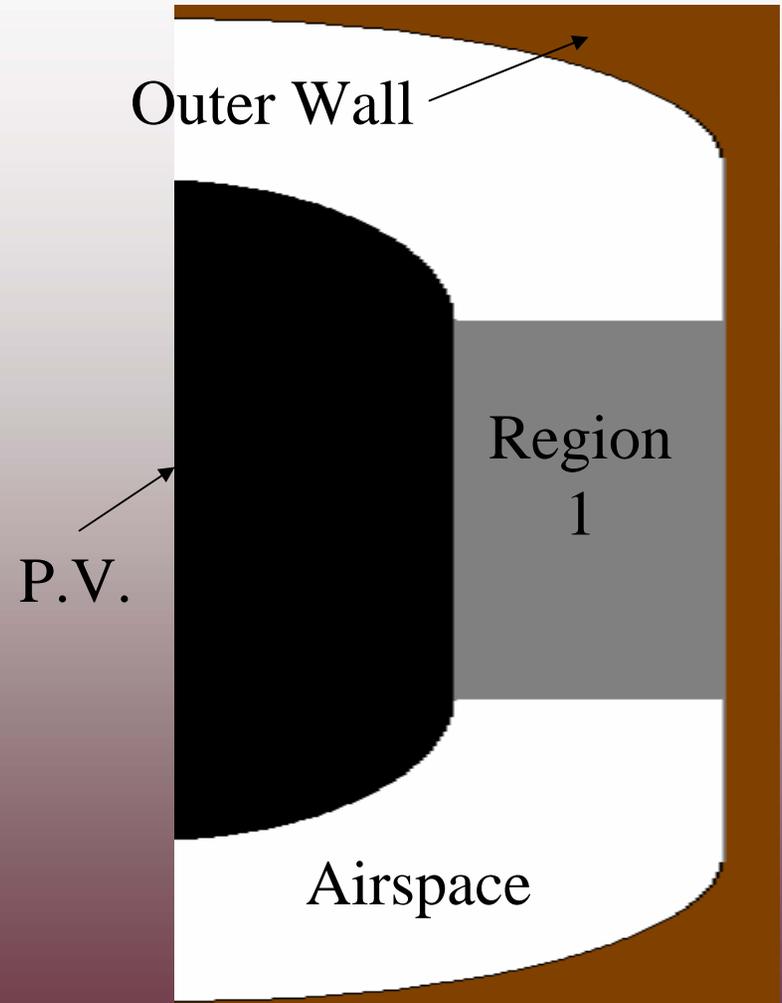
Shape Factor Determination

- B-55: Element at end of outer cylinder to inside of outer coaxial cylinder (4)



Shape Factor Determination: B-55

- **Region 1, shown here, is the region of application of B-55**
 - **Where both inner and outer walls are of constant radii**



Shape Factor Requirements

- Shape factors for a given cell must satisfy the following relations:
 - Reciprocity

$$A_1 F_{1-2} = A_2 F_{2-1}$$

- Summation

$$\sum_j^{no._cells} F_{i-j} = 1.0$$

Treatment of Remainder

- In the shape factor determination described,

$$\sum_j^{no._cells} F_{i-j}$$

will likely not sum to 1.0 because the airspace is not modeled as being capped nor are the cylinders of infinite length

- To force this summation to equal 1.0 and to maintain agreement in reciprocity, the remaining shape factor is placed in:

$$F_{i-i}$$

Model Nodalization

- RELAP's radiation model has a limit of 99 cells per enclosure
 - Implies a maximum of 49 “inner” seeing 49 “outer”
 - Sets upper bound for nodalization of geometry
 - Only using one large enclosure for the distributed shape factors
 - Numerous enclosures for the straight-across only shape factors
 - One for each set of inner and outer cells

Treatment of Ellipses

$$r_{cyl} = r_{max} * \left(1 - \frac{\left(r_{max} - \frac{h}{2} \right)^2}{b} \right)^{1/2}$$

where: r_{cyl} = radius of discretized cylinder
 r_{max} = maximum radius of ellipse
 h = discretized height set by user input
 b = small radius of ellipse, total height

- The half-height is used to determine the radius of the discretized cylinder to guarantee that a cylinder of zero radius is not input into RELAP

Model I: VGM Reactor

- “a modular type-high temperature helium cooled reactor” (1)

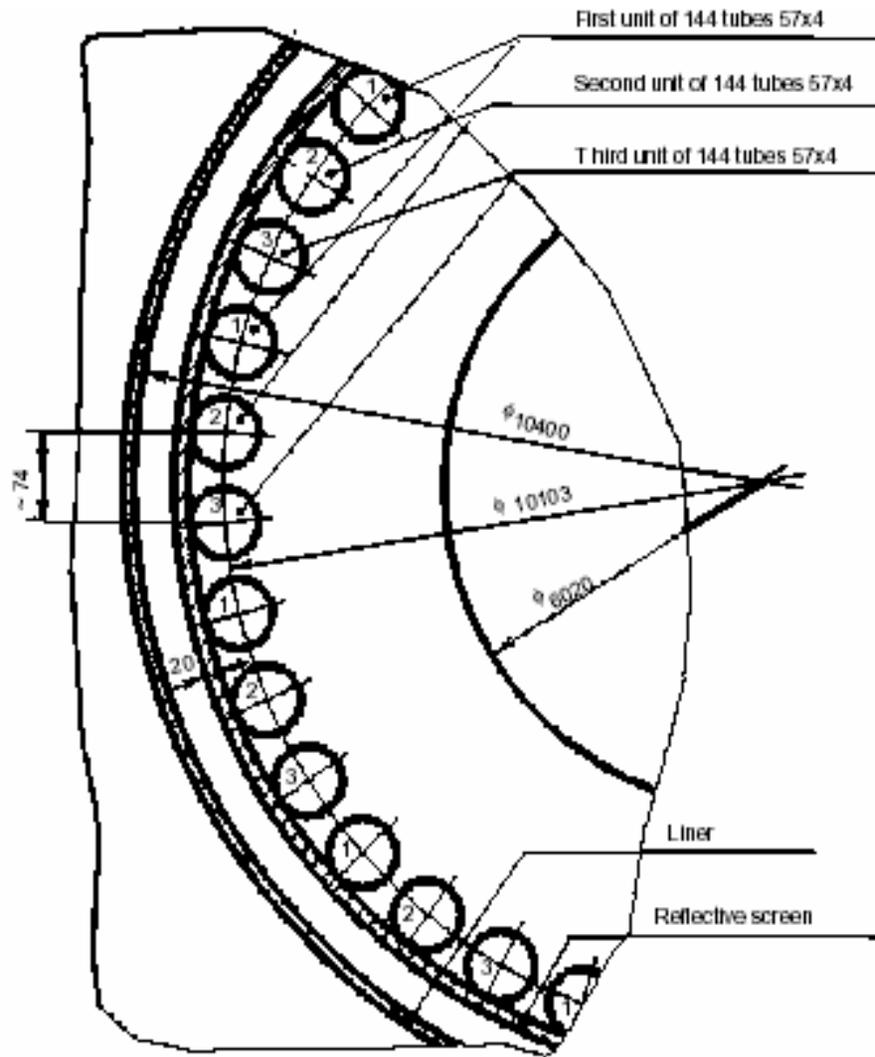


Fig. 3-2 Reactor cavity cooling system

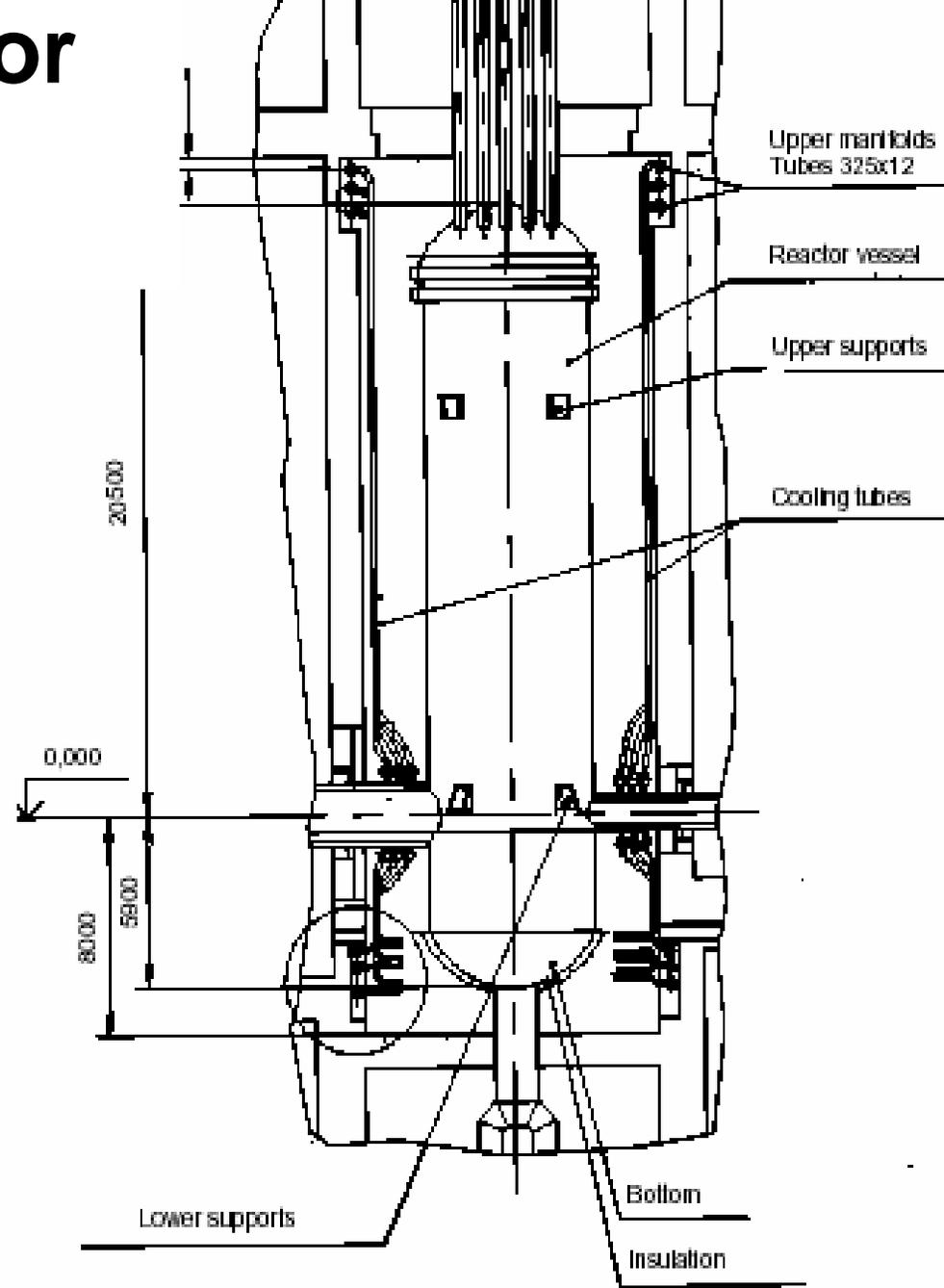


Fig. 3-1 Arrangement of the reactor cavity cooling system

Modeling Cooling Tubes

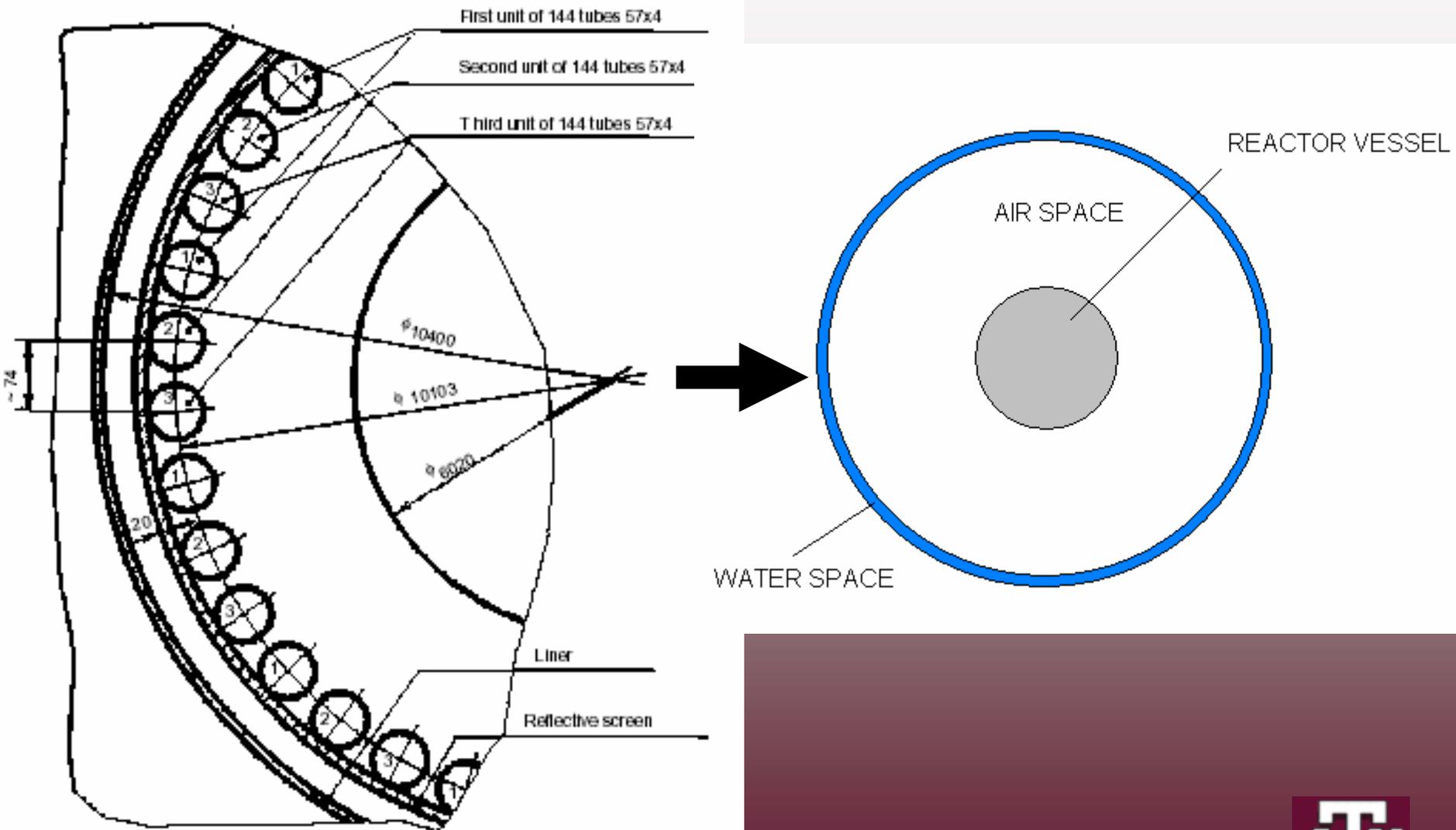
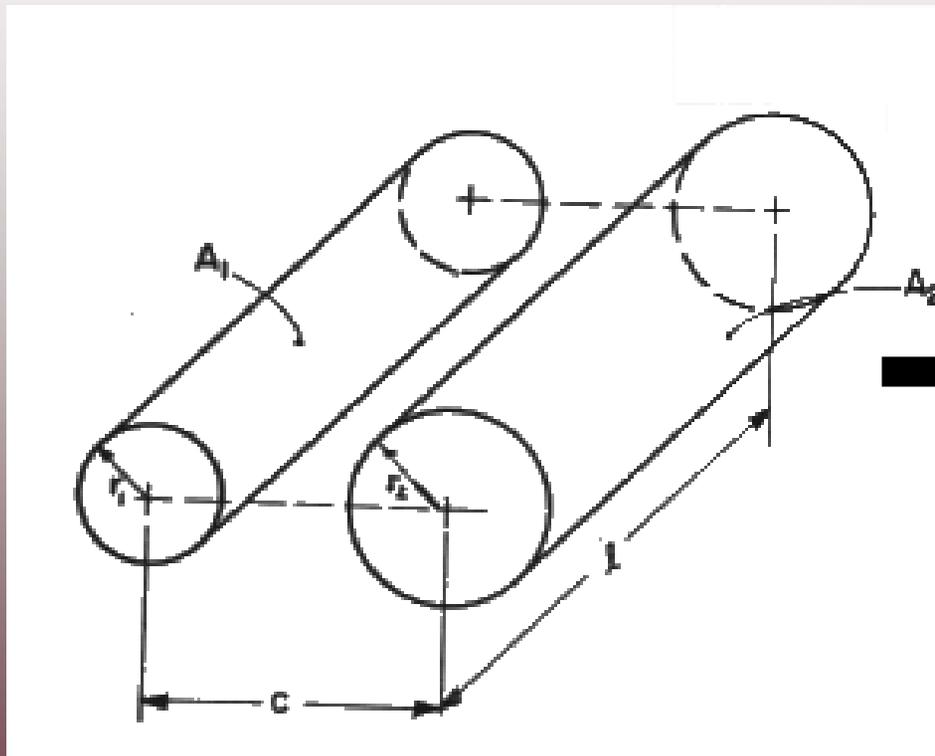


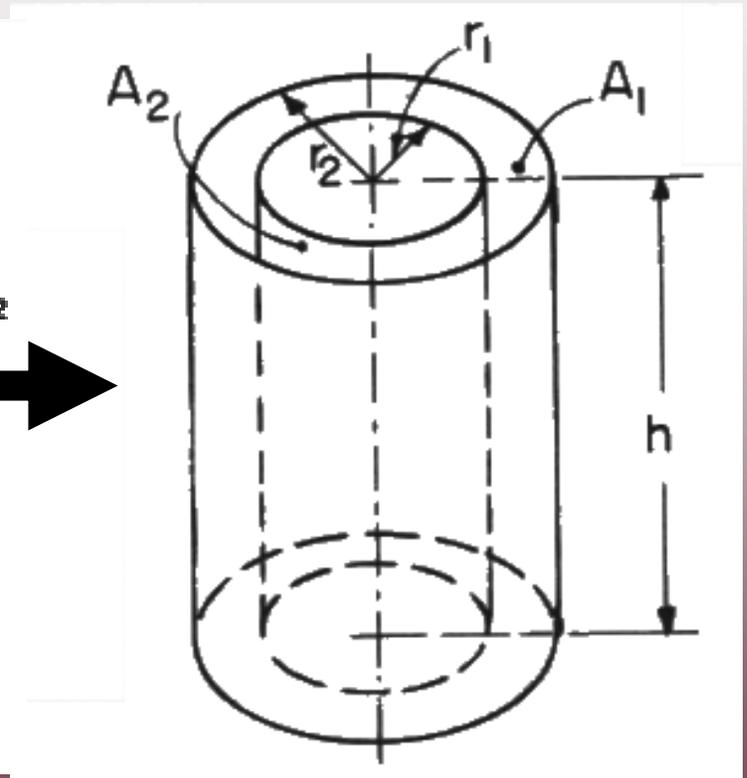
Fig. 3-2 Reactor cavity cooling system

Maintenance of Shape Factor

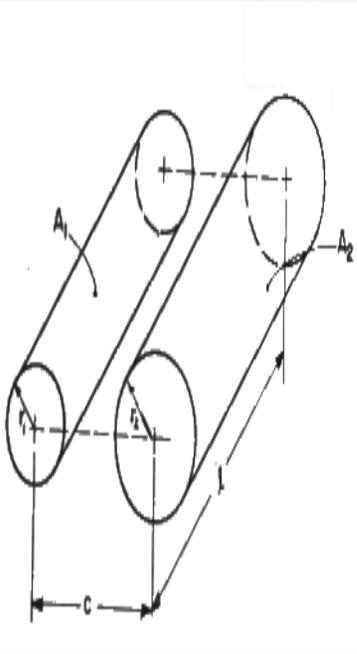
Geometry 1



Geometry 2



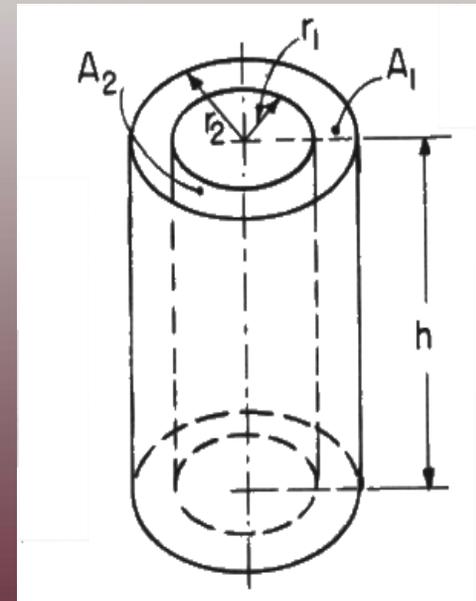
Maintenance of Shape Factor



- C-101, another Howell correlation, yields a shape factor from a single channel to the center cylinder for Geometry 1
- 432 channels, so the shape factor from the center to all channels is computed from:

$$A_1 F_{1-2..i} = \sum_{j=2}^i A_j F_{j-1}$$

- Maintaining this shape factor from all cooling channels to center, can calculate radius of equivalent cylinder for Geometry 2 using C-92



Modeling Pressure Vessel

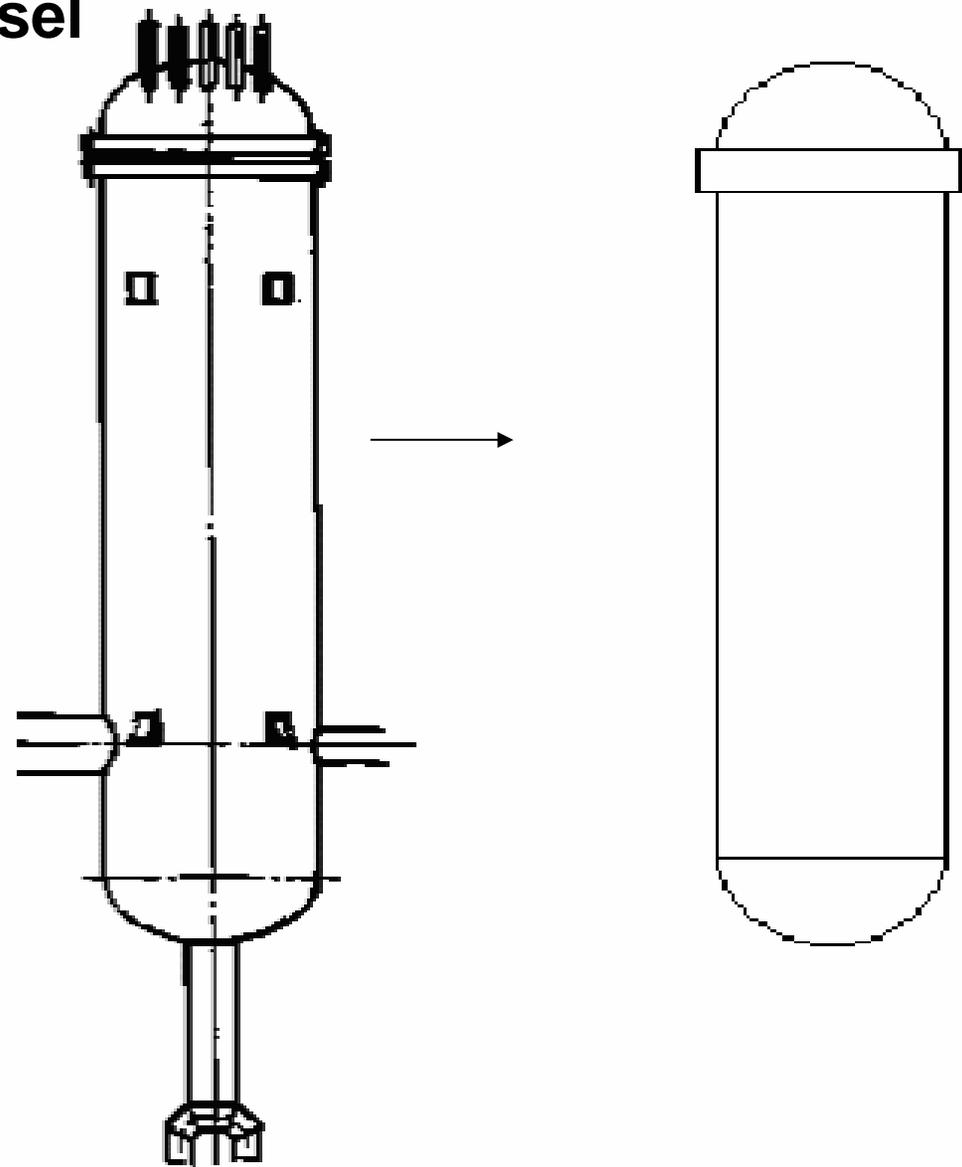
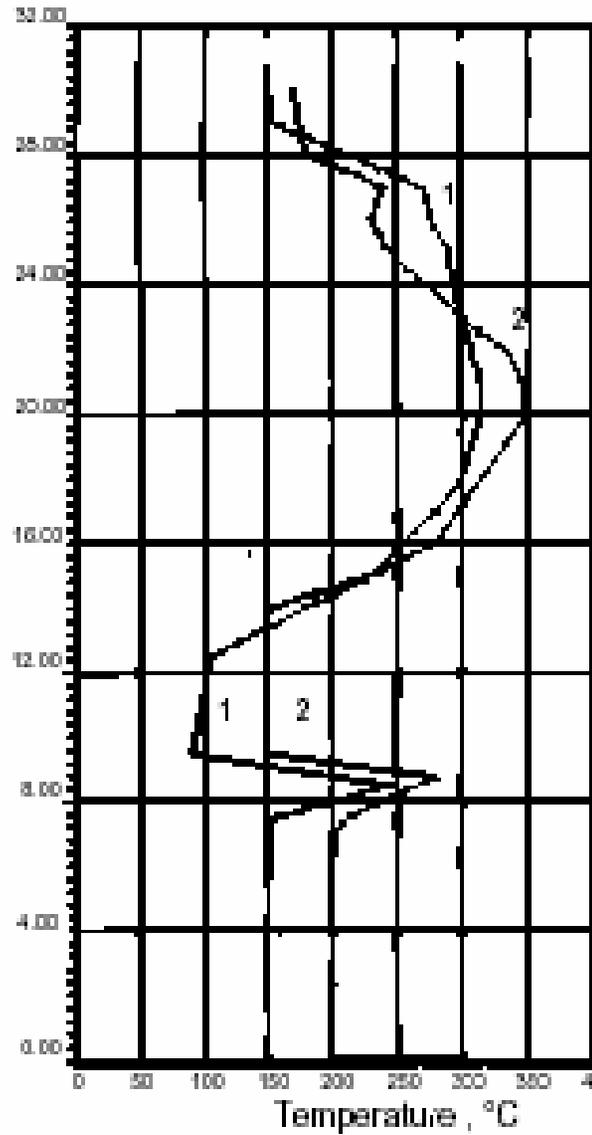
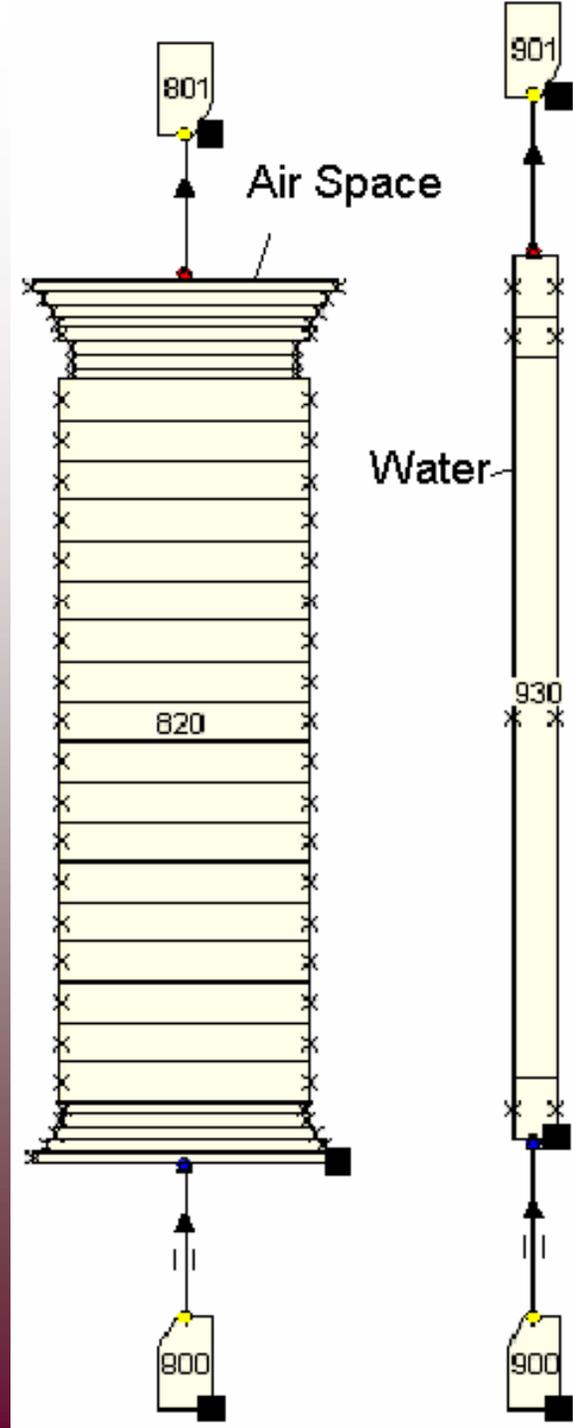


Fig. 3-4 Temperature distribution on the height of the reactor vessel
1 –pressurized conditions
2 –depressurized conditions

Model I: RELAP5 Input Deck

- Modeled as two heat structures separated by a single airspace and surrounded by water
 - Water has a defined flow-rate
 - Air flows by natural convection
- Tried splitting the large airspace (~1-m across) into two parts to better model convection, but found that a single airspace worked better



Model I: Results

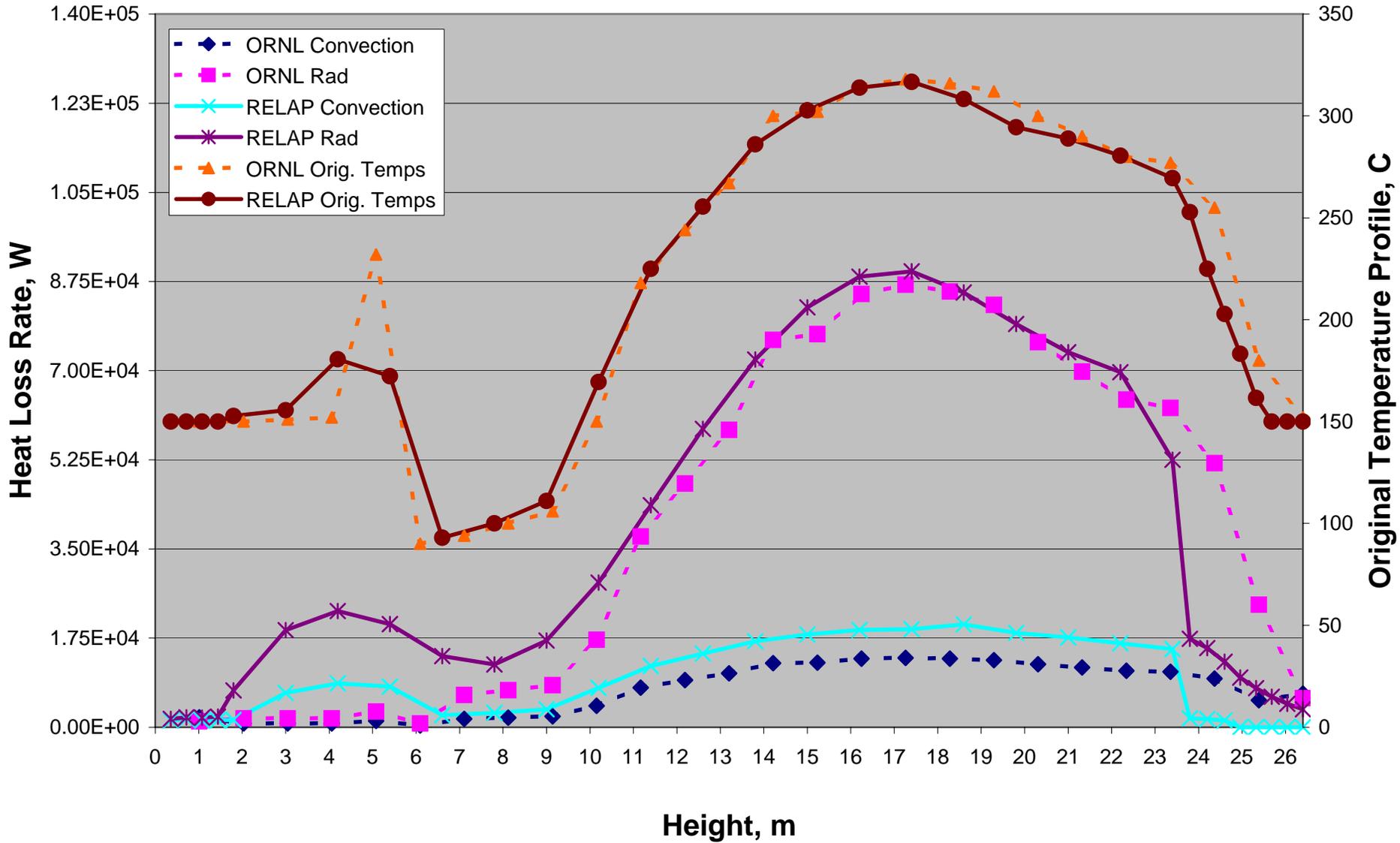
- **Pressurized case:**

	Total Q, MW	Q-Radiative, MW	Q-Convective, MW
China (Thermix)	1.22	1.01	0.21
ORNL (MORECA)	1.23	1.04	0.19
Russia (SM1)	1.28	1.03	0.25
Relap5-3D	1.26	1.02	0.24

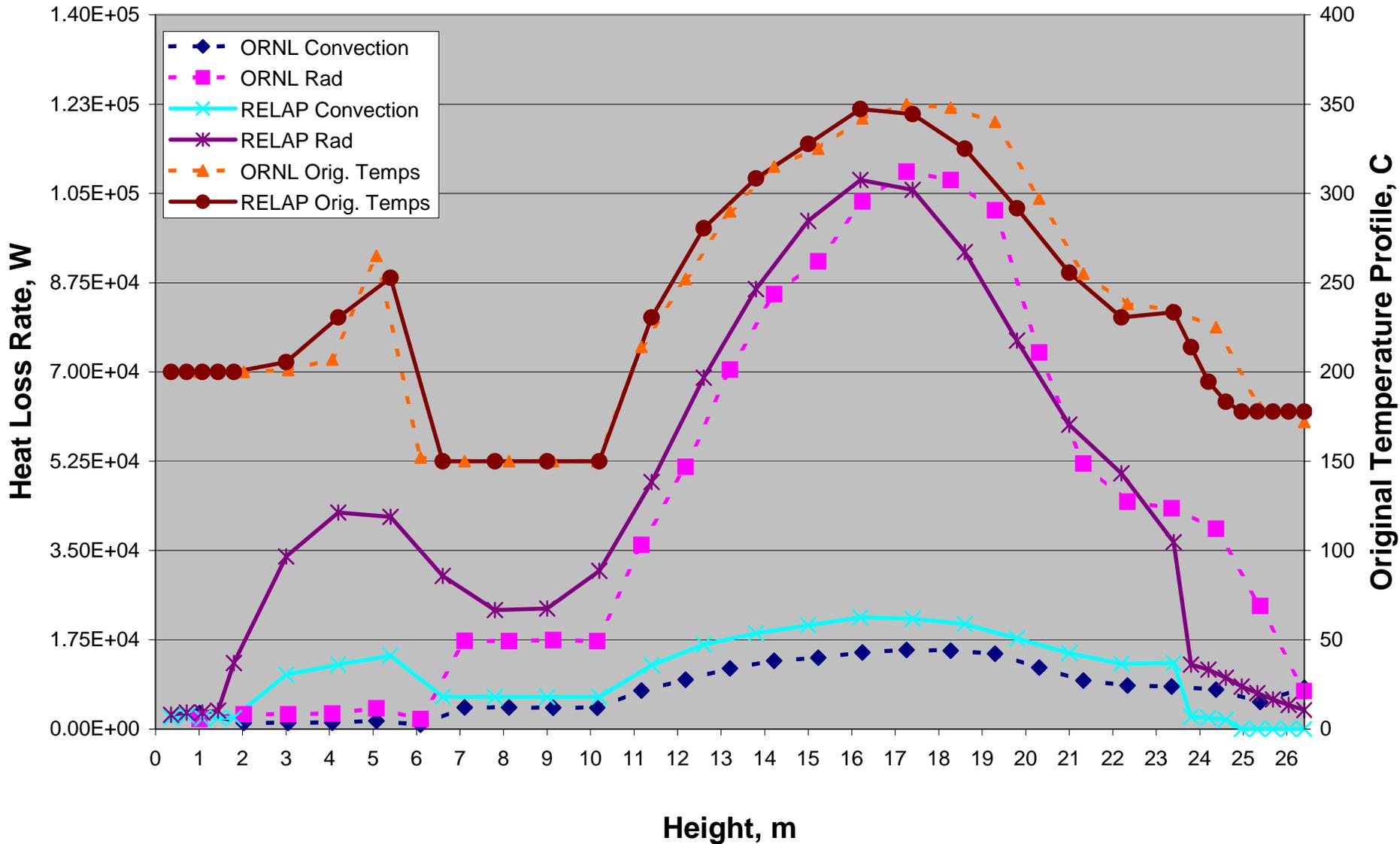
- **Depressurized case:**

	Total Q, MW	Q-Radiative, MW	Q-Convective, MW
China (Thermix)	1.30	1.08	0.22
ORNL (MORECA)	1.33	1.13	0.20
Russia (SM1)	1.36	1.10	0.26
Relap5-3D	1.42	1.15	0.27

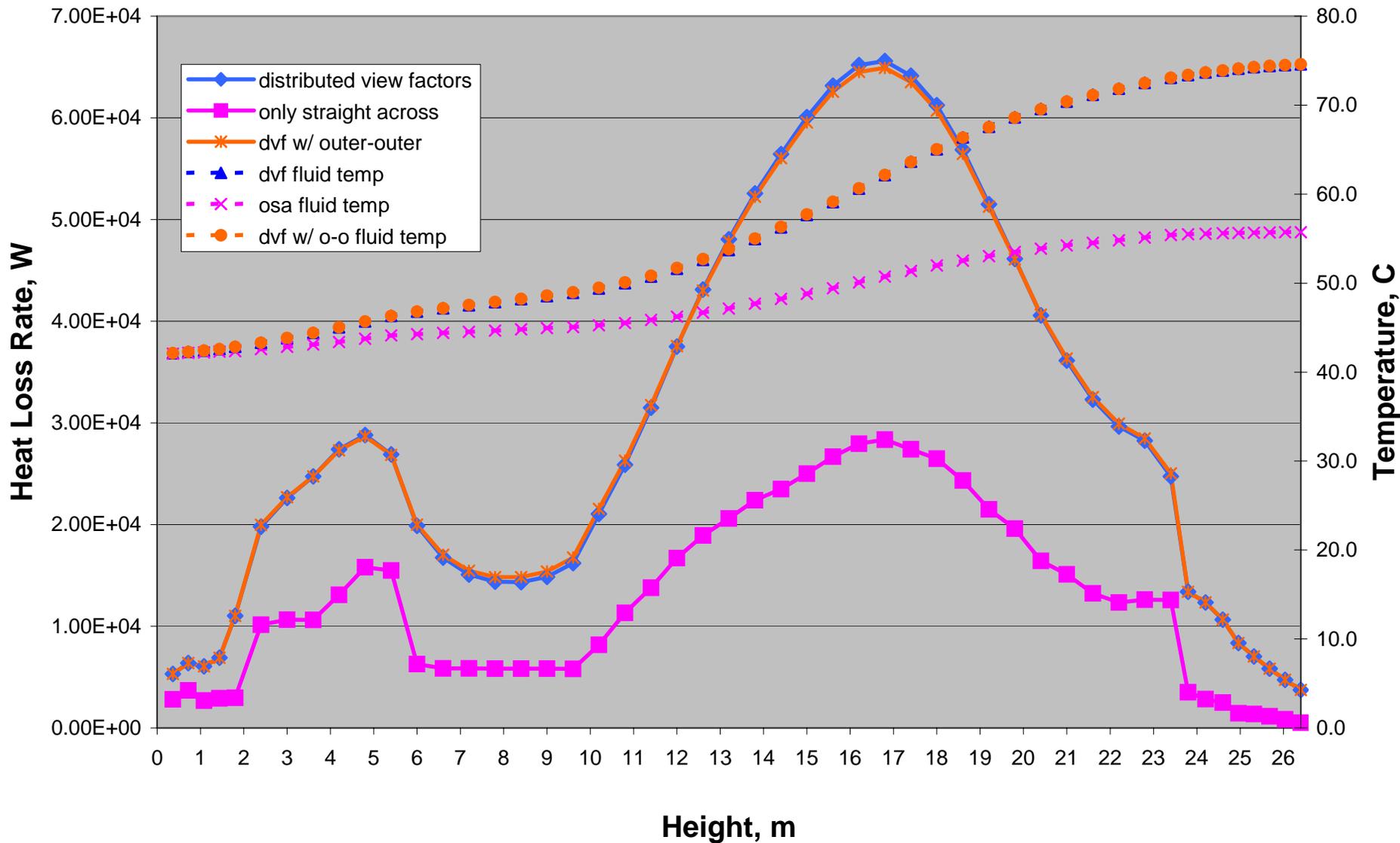
Pressurized Comparison: Single Airspace



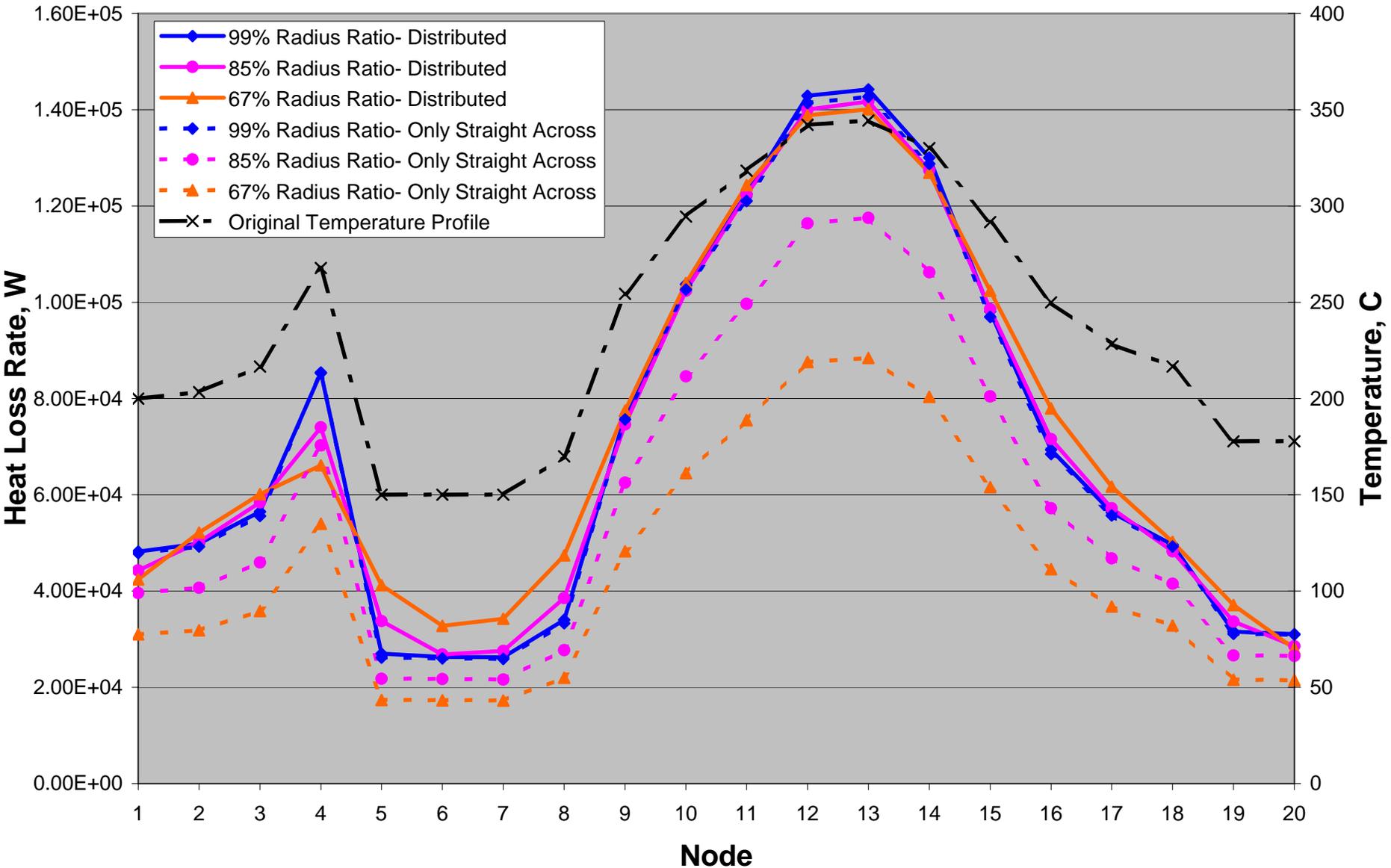
Depressurized Comparison: Single Airspace



Depressurized: Single Airspace, Comparison of View Factor Scenarios



Depressurized: Single Airspace, Radius Ratio (Inner/Outer) Comparison



Model I: Sensitivity to Emissivity

- **Depressurized case:**

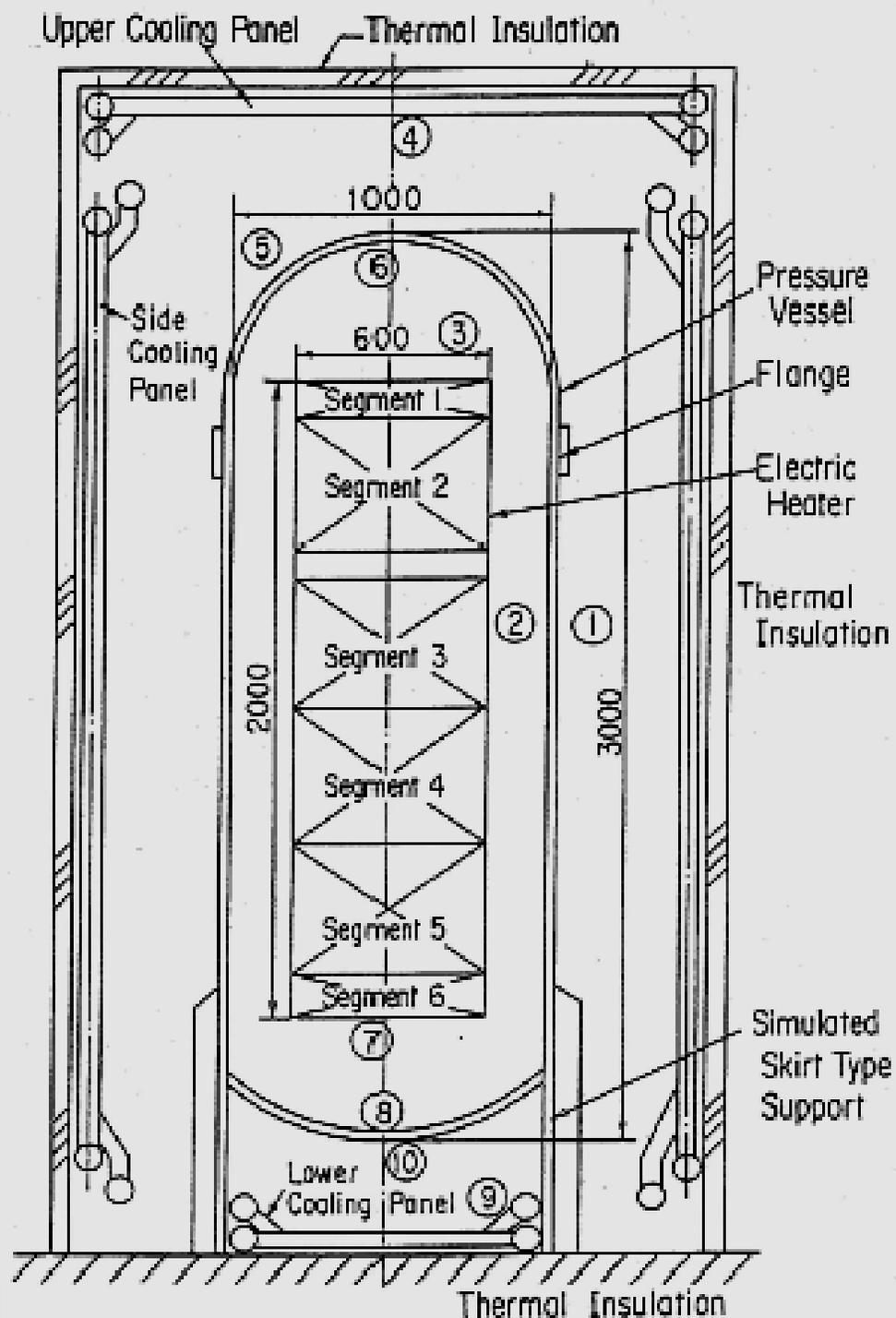
	Total Q, MW	Sensitivity to Emissivity, Total Power %		
		0.80	0.70	0.60
China (Thermix)	1.30	100	83	68
ORNL (MORECA)	1.33	100	83	68
Russia (SM1)	1.36	100	83	68
Relap5-3D	1.42	100	74	55

Model I: Conclusions

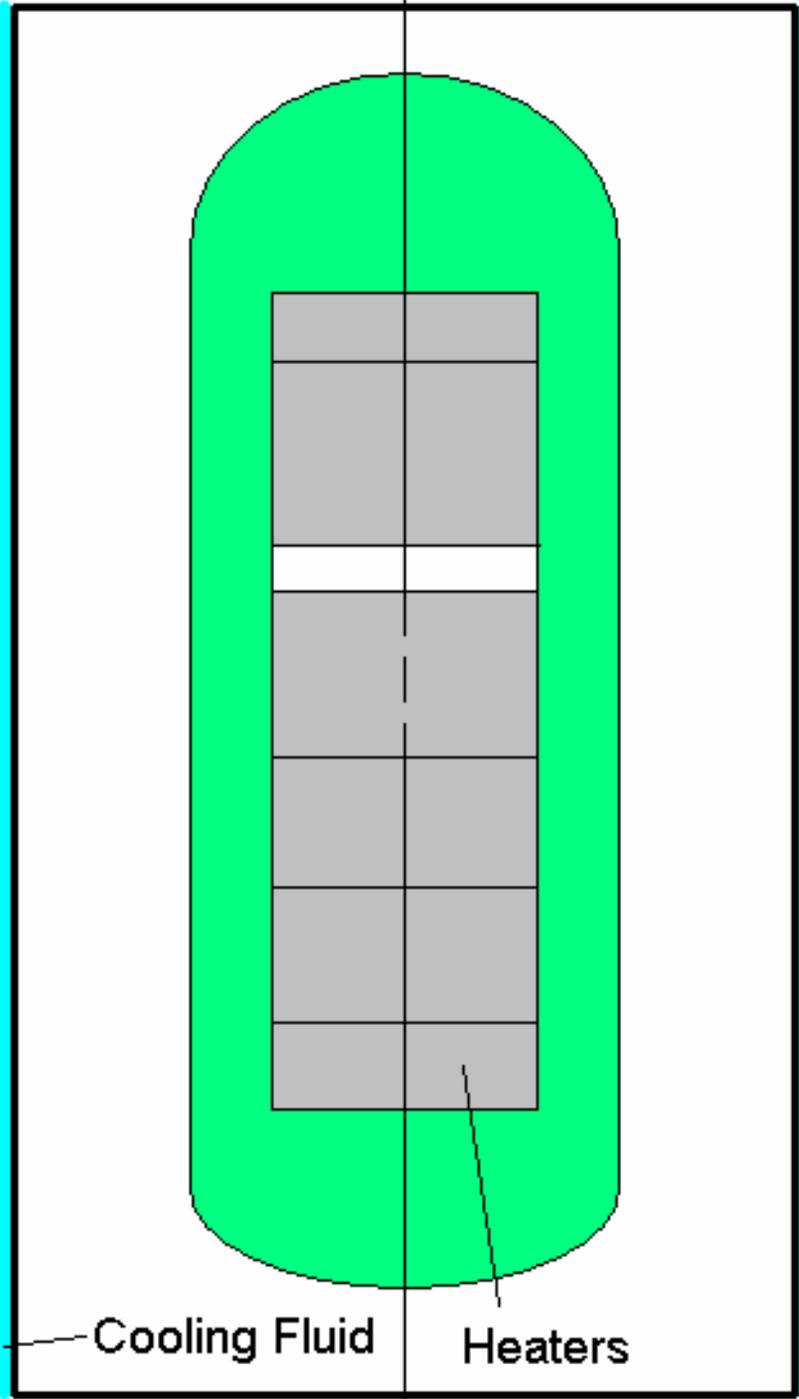
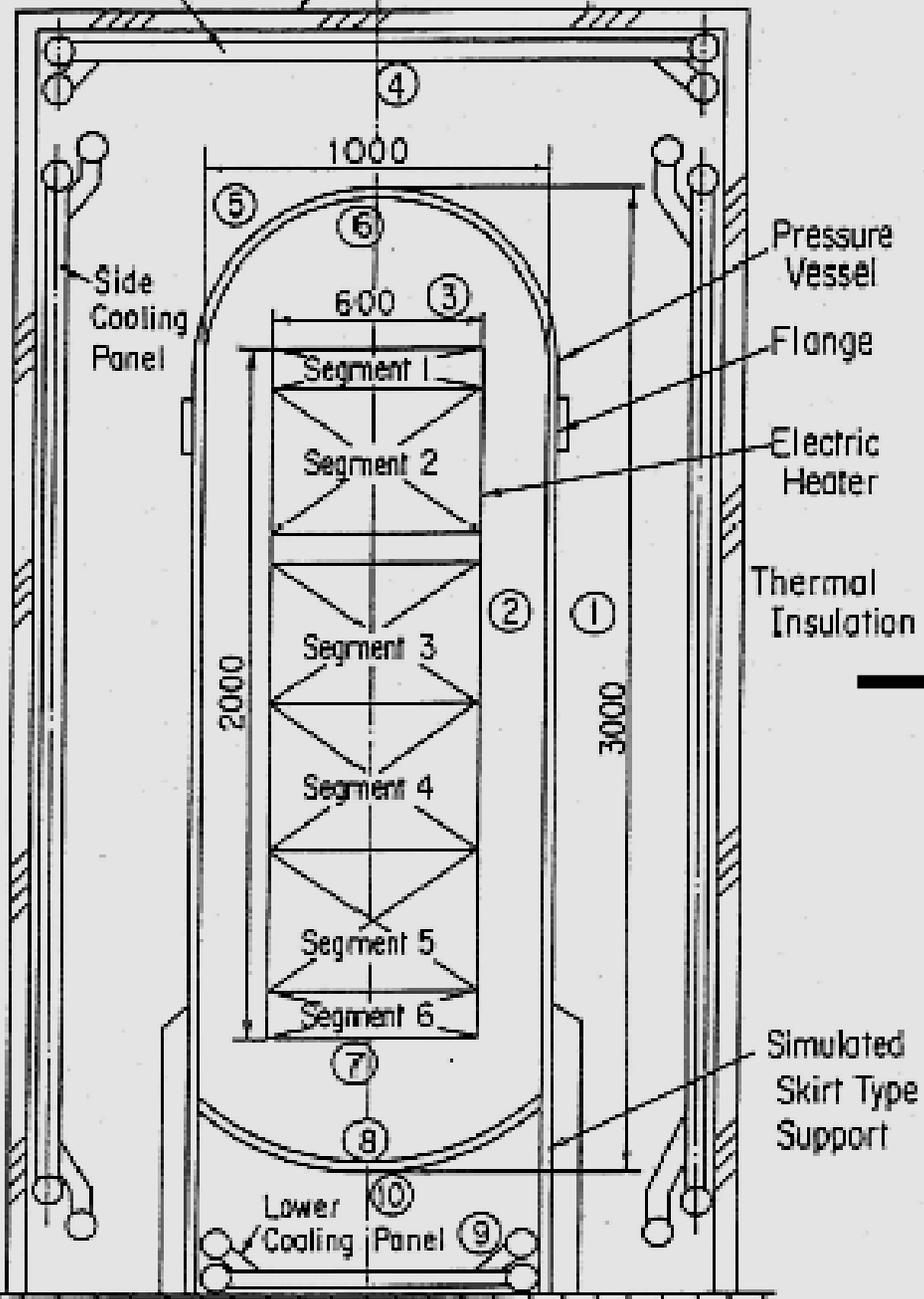
- **RELAP5-3D v2.3.6 calculated radiative and convective heat transfer agrees closely with other benchmark codes**
- **MATLAB script, once assembled, sped up the process of creating an input deck greatly**
 - **Initially, spent much time with attaining reciprocity between areas and view factors**

Model II: HTTR RCCS

- High Temperature Test Reactor
 - Experimental setup



Upper Cooling Panel Thermal Insulation



Model II: Experiments

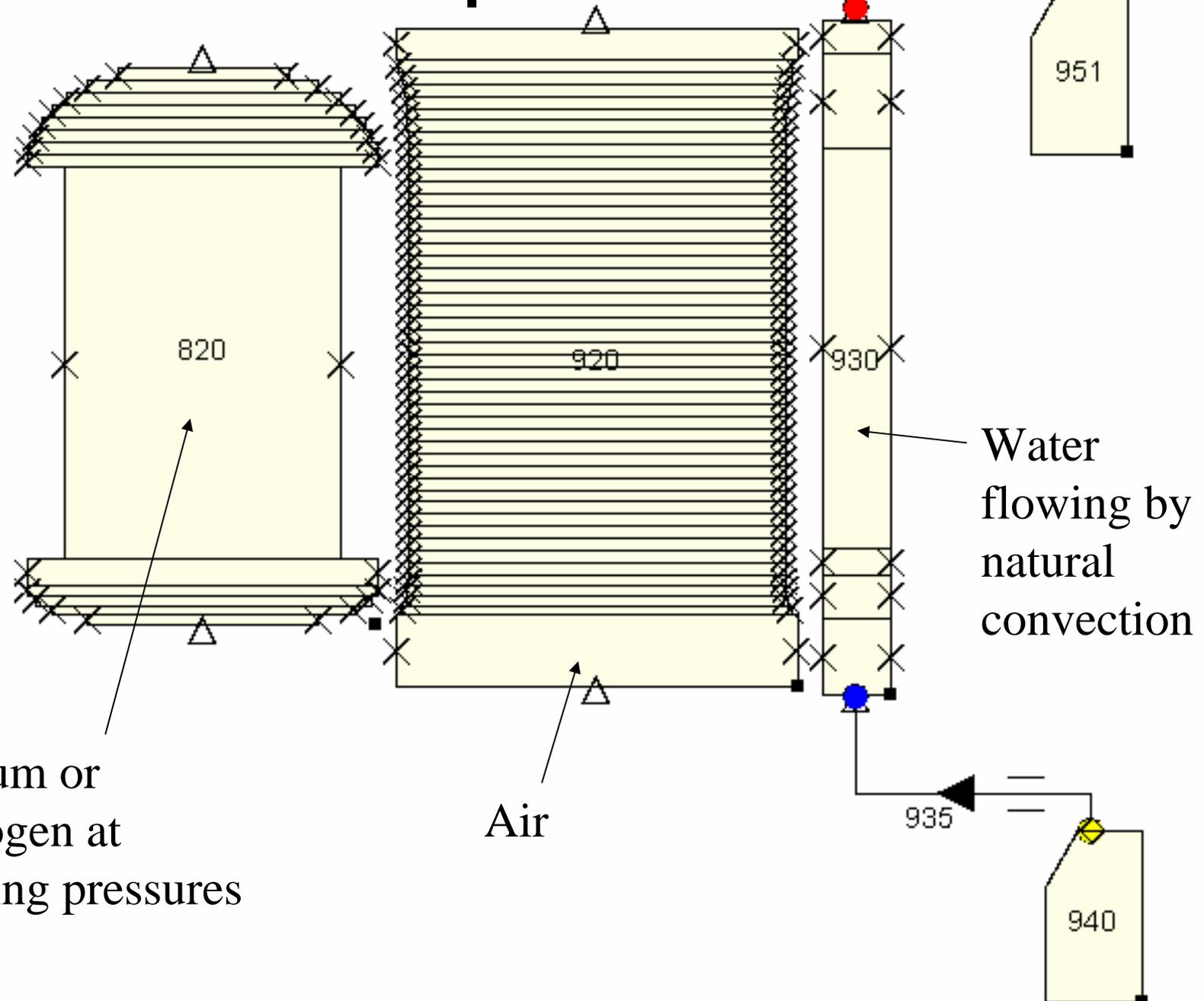
- **Seven different experiments varying:**
 - **Pressure and type of gas used inside the pressure vessel**
 - **Helium or nitrogen**
 - **Heat input from the heating segments**
 - **Cooling fluid**
 - **Air or water**

Model II: Experiment Input

Table 4-0 Detailed condition of the experiments described above are shown as follows:

Benchmark Problem	(I)	(II)	(III)	(IV)	(V)	(VI)-a	(VI)-b
Item of gas		He	N ₂	He	He	He	He
Pressure(MPa)	1.3x10 ⁻⁶	0.73	1.1	0.47	0.64	0.96	0.98
Heat input							
Total input(kW)	13.14	28.79	93.93	77.54	29.71	2.58	7.99
heater segment							
No.1 (kW)	1.01	1.16	5.90	5.63	1.80	0	0
No.2	2.31	3.11	16.05	19.60	5.23	0	0
No.3	2.64	3.52	19.88	21.59	5.68	0	0
No.4	2.46	5.10	22.24	22.70	11.26	0	0
No.5	3.76	10.42	22.13	0	0	0	0
No.6	0.96	5.49	7.72	8.00	5.74	2.58	7.99
Cooling panel	Water	Water	Water	Water	Air	Air	Air
Stand pipes	No	No	No	With	With	With	With

Model II: RELAP5 Input Deck

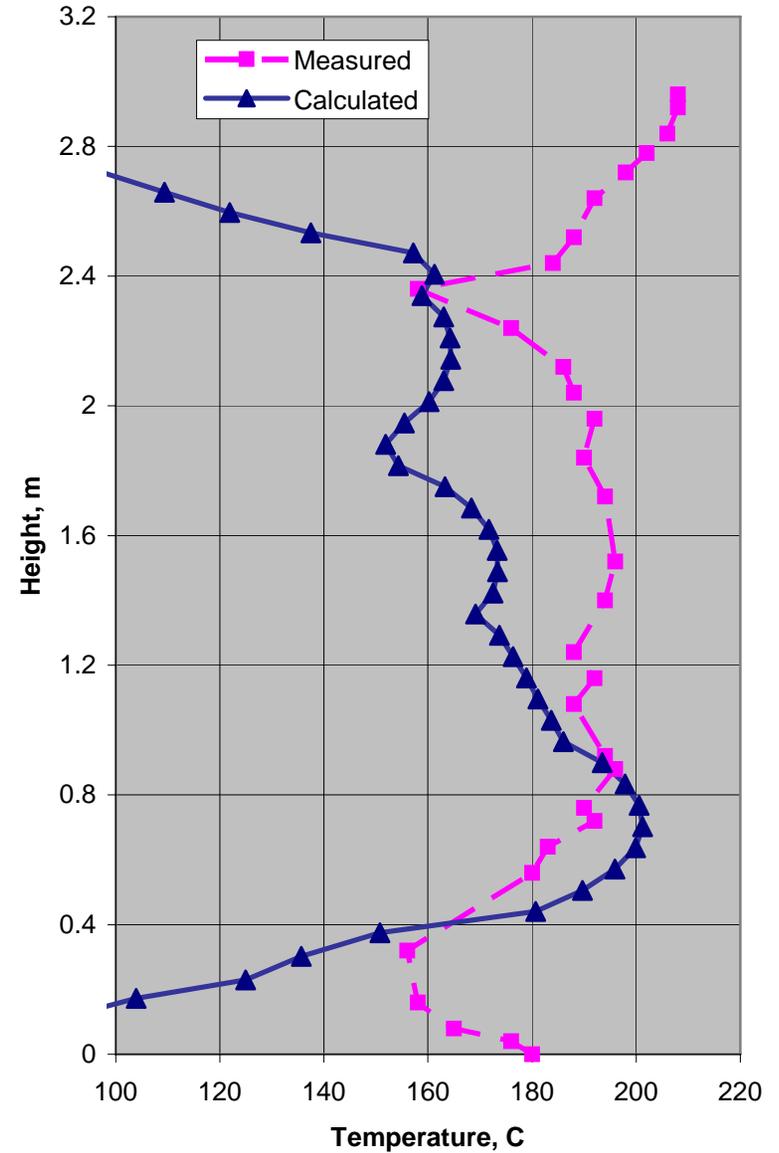
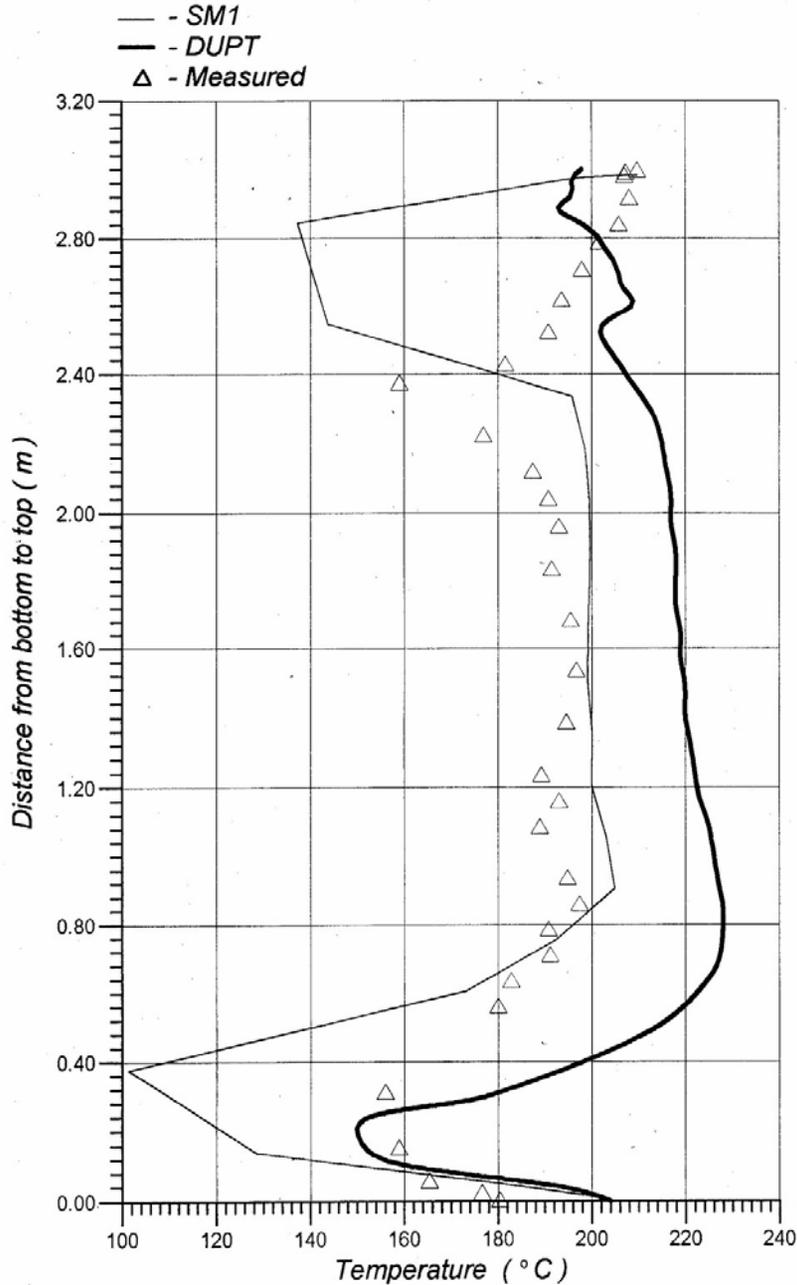


Helium or Nitrogen at varying pressures

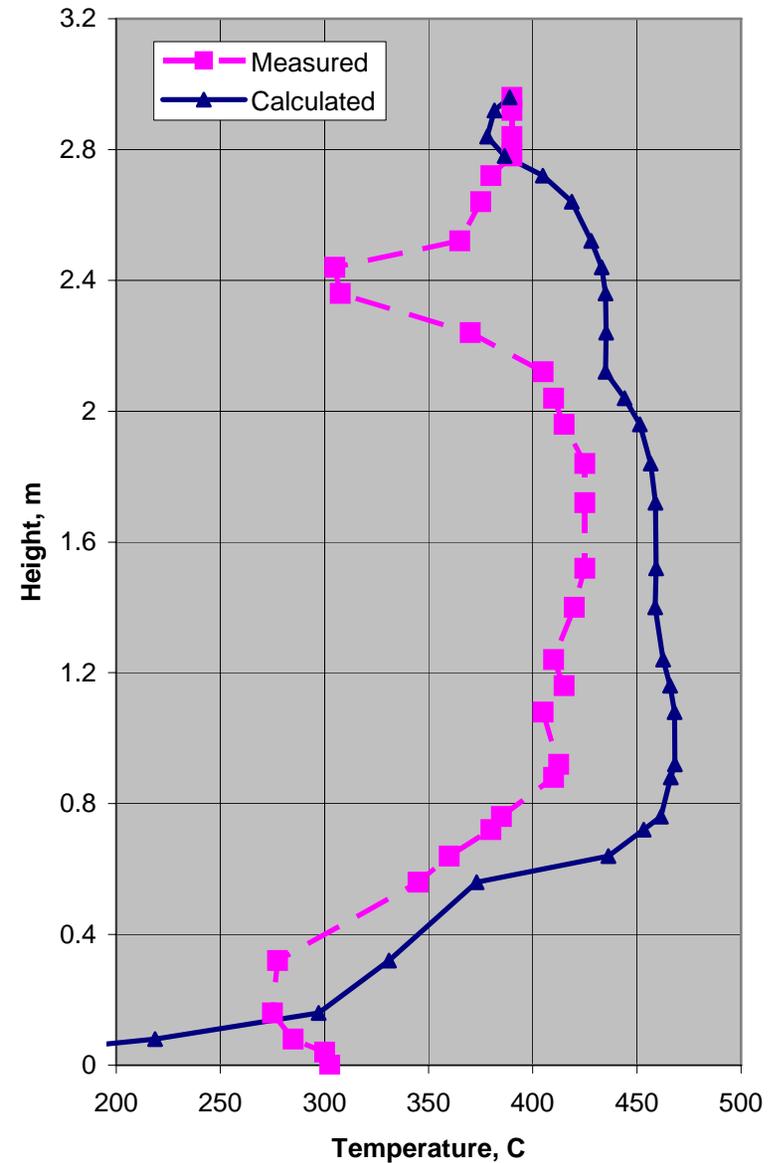
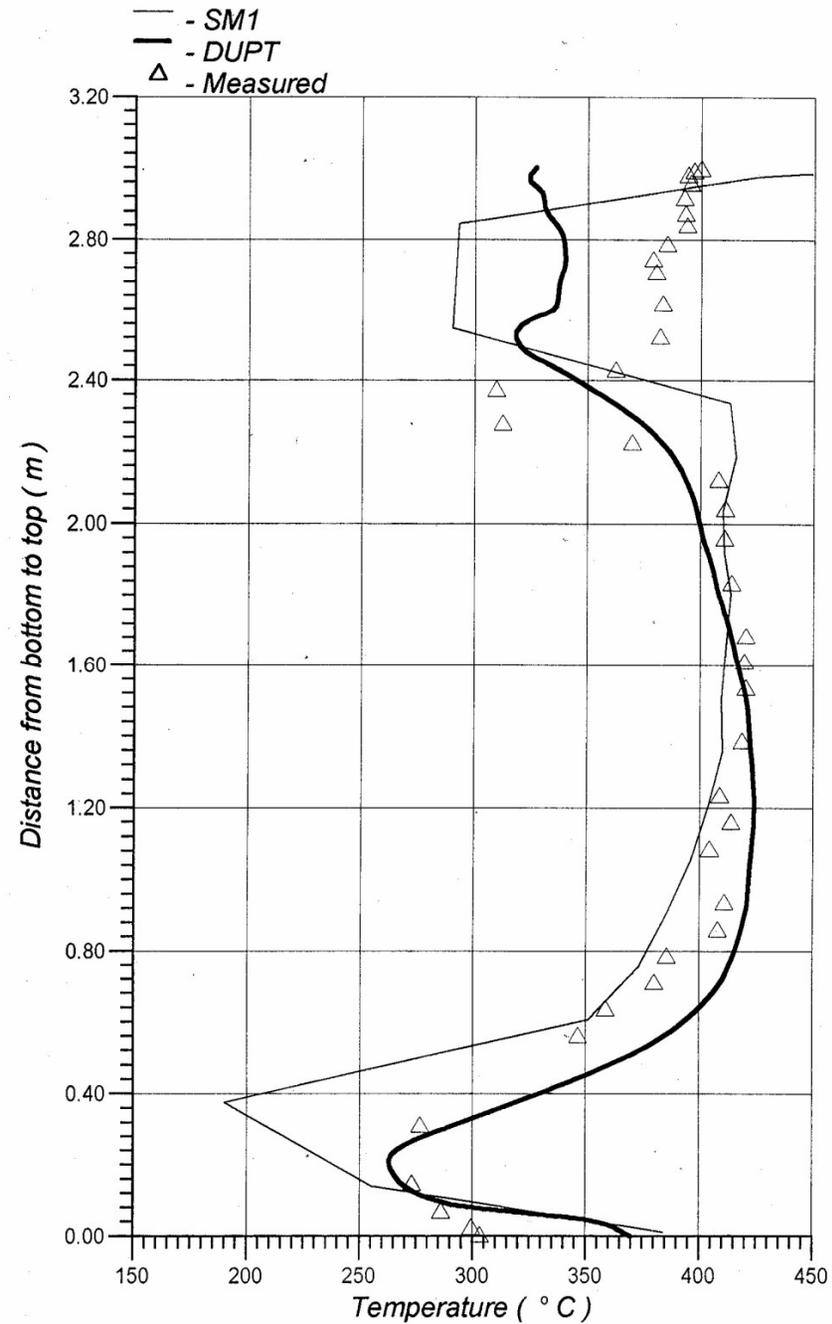
Air

Water flowing by natural convection

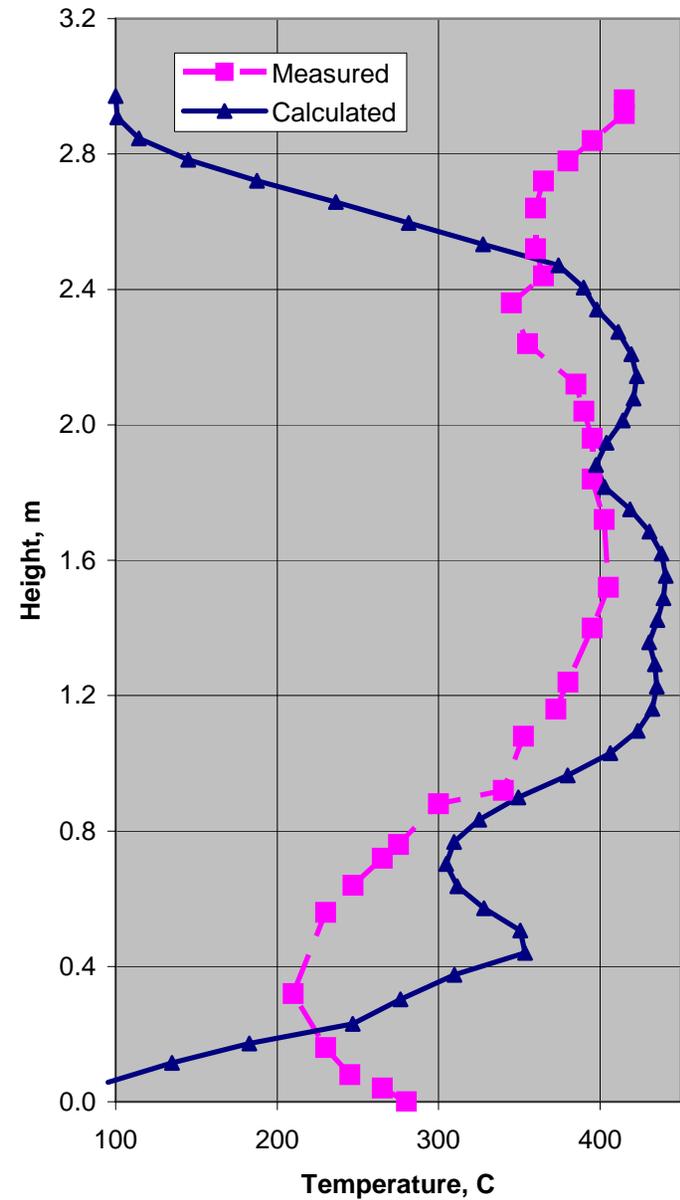
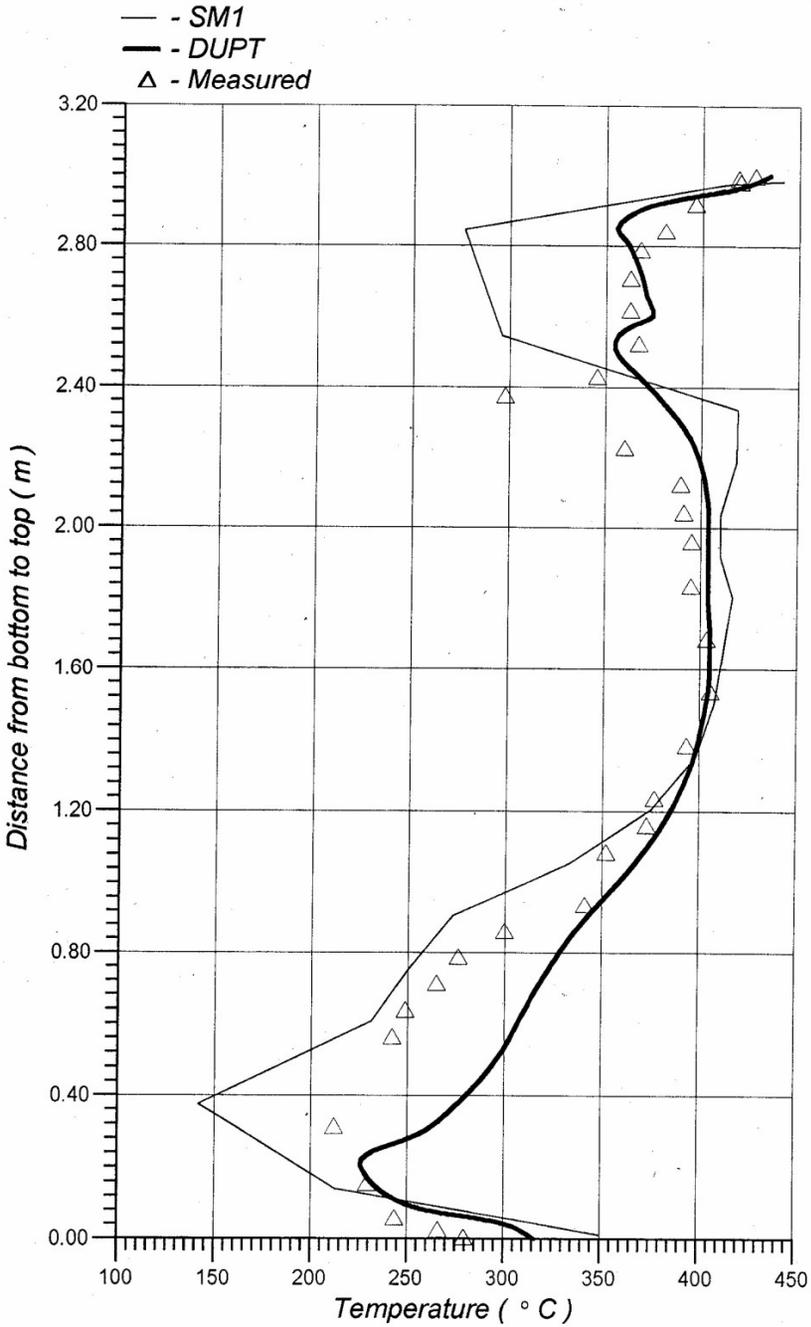
Experiment 2: Vessel Outside Temperature



Experiment 3: Vessel Outside Temperature



Experiment 4: Vessel Outside Temperature



Model II: Conclusions

- **RELAP5-3D v2.3.6 qualitatively captures the temperature profile**
- **Nodalization of the upper and lower ellipses needs to be refined**
- **MATLAB script, once assembled, sped up the process of creating an input deck greatly**

Questions and List of References

1. IAEA. Heat Transport and Afterheat Removal for Gas Cooled Reactors Under Accident Conditions. IAEA-TECDOC-1163 (2000).
2. INL. RELAP5-3D Code Manual. Revision 2.2. INEEL-EXT-98-00834 (2003).
3. “Engineering Fundamentals.” August 6, 2005.
<<http://www.efunda.com>>
4. Howell, John R. “A Catalog of Radiation Heat Transfer Configuration Factors.” University of Texas at Austin. June 29, 2005.
<<http://www.me.utexas.edu/~howell/tablecon.html>>