2.12.6 Reduced External Pressure

This analysis demonstrates that under the normal condition of transport reduced pressure condition, the package will satisfy the applicable performance requirements specified in the regulations:

- there will be no loss or dispersal of contents;
- there will be no structural changes that reduce the effectiveness of components required for shielding, heat transfer, or containment;
- any loss of shielding integrity would not result in more than a 20% increase in the radiation level at any external surface of the package; and
- there will be no changes that would affect the ability of the package to withstand the hypothetical accident conditions tests.

There are three reduced pressure conditions specified in the regulations:

- TS-R-1 Paragraph 643 states: "The containment system shall retain its radioactive contents under a reduction of ambient pressure to 60 kPa."
- TS-R-1 Paragraph 619 states: "Packages containing radioactive material transported by air shall have a containment system able to withstand without leakage a reduction in ambient pressure to 5 kPa."
- 10 CFR 71.71(c)(3) requires the package to withstand a reduced pressure of 25 kPa.

For conservativism, we assume that the external pressure is only 5 kPa.

Also for conservativism, we assume that the package temperature is at 800°C, the hypothetical accident condition temperature, when this reduced pressure occurs.

For this analysis, we have considered the package in four elements: Outer Container, Inner Container Cavity, Inner Container Body, and Containment.

Outer Container

The outer container is open to the atmosphere so there will be no pressure differential within the outer package.

Inner Container Cavity

The inner container cavity (the location where the Special Form capsules are located), although enclosed, is not sealed; no "O"-rings, gaskets or other sealing devices are employed. This cavity is open to the atmosphere. Therefore, there will be no pressure differential within the inner container cavity.

Container Body

The stainless steel housing containing the depleted uranium shield is sealed by means of the welding of the housing. The space between the uranium shield and the housing is filled with air. Under the assumption that the air behaves as an ideal gas, the pressure within this special form capsule would be calculated from:

$$P_2 = \frac{P_1 T_2}{T_1}$$

where:
- P_1: Atmospheric Pressure at the time of sealing (101 kPa)
- P_2: Pressure resulting from the Maximum Hypothetical Accident Temperature
- T_1: Temperature at the time of sealing (20°C or 293°K) (a conservative assumption)
- P_1: Maximum Hypothetical Accident Temperature (800°C or 1,073°K)

From this relationship, the maximum pressure within this space due to the hypothetical thermal accident temperature would be 370 kPa.

This increased pressure within the housing would result in increased stress. We can assume that this space behaves as a thin-wall pressure vessel. The tensile stress induced in a thin-walled pressure vessel from an internal pressure can be described by Barlow's formula (Machinery's Handbook, 22nd Edition, page 327):

$$\sigma = \frac{Pd_i}{2t}$$

where:	P:	Pressure Differential	365 kPa (53 psi)
	d_i:	Inside Diameter	162 mm (6.38 in)
	t:	Wall Thickness	3.09 mm (0.122 in)

From this relationship, the tensile stress generated within the stainless steel housing is 9.57 MPa (1393 psi).

The longitudinal stress for container is calculated from:

$$\sigma_l = \frac{Pd^2}{(d+2t)^2 - d^2}$$

where	σ_l:	Longitudinal Stress
	P_l:	Longitudinal Pressure: (365 kPa or 53 psi)
	d:	Inside diameter of the Cylinder (162 mm or 6.38 in)
	t:	Thickness of the Cylinder (3.09 mm or 0.122 in)

For this stainless steel housing, from this relationship, the longitudinal stress is calculated to be 4.69 MPa (683 psi).

At a temperature of 870° C (1600° F) the yield strength of type 304 stainless steel is 69 MPa (10,000 psi). Therefore, under the conditions of the reduced pressure at the hypothetical thermal accident temperature, the stress generated in the housing is less than 14% of the yield strength of the material at the test temperature.

Containment (Special Form Capsule)

The ASPECT 12K package is designed solely for the transport of Special Form Radioactive Material. These Special Form capsules act as the containment for the radioactive material. The special form capsules are assumed to be filled with air. For this analysis, we assume this volume is filled with air at atmospheric pressure at 20°C. This is a conservative assumption, as during the seal welding process, the temperature of the capsule, and therefore the contained air, would be elevated, thereby reducing the initial pressure. However, for conservativism, no account is taken of this reduced pressure.

It is assumed that during the test, the special form capsule achieves a temperature of 800°C. Under the assumption that the air behaves as an ideal gas, the pressure within this special form capsule would be calculated from:

$$P_2 = \frac{P_1 T_2}{T_1}$$

where:	P_1:	Atmospheric Pressure at the time of sealing (101 kPa)
	P_2:	Pressure resulting from the Maximum Hypothetical Accident Temperature
	T_1:	Temperature at the time of sealing (20°C or 293°K)
	P_1:	Maximum Hypothetical Accident Temperature (800°C or 1,073°K)

From this relationship, the maximum pressure within this capsule due to the hypothetical thermal accident temperature would be 370 kPa.

Although many special form capsules may be used with the ASPECT 12K, the most vulnerable special form capsule to be used with the ASPECT 12K would be fabricated from stainless steel and have an outside diameter of 13 mm and a wall thickness of 0.3 mm. (Titanium has higher yield strength than stainless steel, and therefore a capsule with similar dimensions would be less vulnerable.) The tensile stress induced in a thin-walled pressure vessel from an internal pressure can be described by Barlow's formula (; Machinery's Handbook, 22nd Edition, page 327):

$$\sigma = \frac{Pd_i}{2t}$$

where:	P:	Pressure Differential	365 kPa (53 psi)
	d_i:	Inside Diameter	12.4 mm (0.488 in)
	t:	Wall Thickness	0.3 mm (0.012 in)

From this relationship, the tensile stress generated within the stainless steel capsule is 7.54 MPa (1098 psi).

The longitudinal stress for such a capsule is calculated from:

$$\sigma_l = \frac{Pd^2}{(d+2t)^2 - d^2}$$

where	σ_l:	Longitudinal Stress
	P_l:	Longitudinal Pressure: (365 kPa or 53 psi)
	d:	Inside diameter of the Cylinder
	t:	Thickness of the Cylinder

For this same most vulnerable special form capsule (diameter of 13 mm outside diameter and 0.3 mm wall), from this relationship, the longitudinal stress is calculated to be 3.68 MPa (536 psi).

At a temperature of 870° C (1600° F) the yield strength of type 304 stainless steel is 69 MPa (10,000 psi). Therefore, under the conditions of the reduced pressure at the hypothetical thermal accident temperature, the stress generated in the most vulnerable source capsule is less than 11% of the yield strength of the material at the test temperature.

The evaluation demonstrates that the package satisfies the applicable performance requirements specified in the regulations.

2.12.7 Increased External Pressure

This analysis demonstrates that under the normal condition of transport increased pressure condition, the package will satisfy the applicable performance requirements specified in the regulations:

- there will be no loss or dispersal of contents;
- there will be no structural changes that reduce the effectiveness of components required for shielding, heat transfer, or containment;
- any loss of shielding integrity would not result in more than a 20% increase in the radiation level at any external surface of the package; and
- there will be no changes that would affect the ability of the package to withstand the hypothetical accident conditions tests.

There are two increased pressure conditions specified in the regulations:

- TS-R-1 Paragraph 615 states: "The design of the package shall take into account ambient temperatures and pressures that are likely to be encountered in routine conditions of transport."
- 10 CFR 71.71(c)(3) is more explicit and requires the package to withstand an increased pressure of 140 kPa.

For conservativism, we assume that the external pressure is 140 kPa.

Also for conservativism, we assume that pressure within the sealed volume is 0 kPa.

For this analysis, we have considered the package in four elements: Outer Container, Inner Container Cavity, Inner Container Body, and Containment.

Outer Container

The outer container is open to the atmosphere so there will be no pressure differential within the outer package.

Inner Container Cavity

The inner container cavity (the location where the Special Form capsules are located), although enclosed, is not sealed; no "O"-rings, gaskets or other sealing devices are employed. This cavity is open to the atmosphere. Therefore, there will be no pressure differential within the inner container cavity.

Inner Container Body

The stainless steel housing containing the depleted uranium shield is sealed by means of the welding of the housing. The space between the uranium shield and the housing is filled with air. For the purpose of this analysis, we assume the pressure within the housing is 0 kPa.

We can assume that this space behaves as a cylindrical tube. The collapsing pressure of a tube can be described (Machinery's Handbook, 22nd Edition, page 332) by:

$$P = 3.46x10^8 \left(\frac{t}{d}\right)^3$$

where:	*P*:	Collapsing Pressure in kPa	
	d_i:	Outside Diameter	168 mm (6.63 in)
	t:	Wall Thickness	3.09 mm (0.122 in)

From this relationship, the collapsing pressure of the stainless steel housing is 2.15 MPa (313 psi).

The normal condition of transport increased pressure condition (140 kPa) represents only 6.5% of the collapsing pressure.

Containment (Special Form Capsule)

The ASPECT 12K package is designed solely for the transport of Special Form Radioactive Material. These Special Form capsules act as the containment for the radioactive material. The special form capsules are assumed to be filled with air. For this analysis, we assume the pressure within the capsule is 0 kPa.

Although many special form capsules may be used with the ASPECT 12K, the most vulnerable special form capsule to be used with the ASPECT 12K would be fabricated from stainless steel and have an outside diameter of 13 mm and a wall thickness of 0.3 mm. (Titanium has higher yield strength than stainless steel, and therefore a capsule with similar dimensions would be less vulnerable.)

We can assume that this capsule behaves as a cylindrical tube. The collapsing pressure of a tube can be described (Machinery's Handbook, 22nd Edition, page 332) by:

$$P = 3.46x10^{8}\left(\frac{t}{d}\right)^{3}$$

where:			
	P:	Collapsing Pressure in kPa	
	d:	Outside Diameter	13 mm (0.51 in)
	t:	Wall Thickness	0.3 mm (0.012 in)

From this relationship, the collapsing pressure of the source capsule is 4.25 MPa (619 psi).

The normal condition of transport increased pressure condition (140 kPa) represents only 3.3% of the collapsing pressure.

Therefore the normal condition of transport increased pressure condition (140 kPa) will have no adverse affect on the structure of the package not the containment.

This evaluation demonstrates that the package satisfies the applicable performance requirements specified in the regulations:

- there will be no loss or dispersal of contents;
- there will be no structural changes that reduce the effectiveness of components required for shielding, heat transfer, or containment; and
- there will be no changes that would affect the ability of the package to withstand the hypothetical accident conditions tests.

2.12.8 Immersion - All Packages

This analysis demonstrates that under the hypothetical accident condition of immersion, the package will satisfy the applicable performance requirements specified in the regulations:

- there will be no loss or dispersal of contents;
- there will be no structural changes that reduce the effectiveness of components required for shielding, heat transfer, or containment;
- any loss of shielding integrity would not result in more than a 20% increase in the radiation level at any external surface of the package; and
- there will be no changes that would affect the ability of the package to withstand the hypothetical accident conditions tests.

Paragraph 729 of TS-R-1 (incorporated in Subsection 1(4) of the PTNS Regulations by reference to Paragraph 716 of TS-R-1), and 10 CFR 71.73(c)(6) require an undamaged package to be subjected to water pressure equivalent to immersion under a head of water of at least 15 m (50 ft). This is equivalent to an external water pressure of 150 kPa (21.7 psi).

The ASPECT 12K package is constructed entirely of metallic components and a monolithic thermal ceramic insulator. Prolonged exposure to water will not reduce the shielding efficiency or structural integrity of the package.

For this analysis, we have considered the package in four elements: Outer Container, Inner Container Cavity, Inner Container Body, and Containment.

Outer Container

The outer container is open to the atmosphere so there will be no pressure differential within the outer package.

Inner Container Cavity

The inner container cavity (the location where the Special Form capsules are located), although enclosed, is not sealed; no "O"-rings, gaskets or other sealing devices are employed. This cavity is open to the atmosphere. Therefore, there will be no pressure differential within the inner container cavity.

Container Body

The stainless steel housing containing the depleted uranium shield is sealed by means of the welding of the housing. The space between the uranium shield and the housing is filled with air. For the purpose of this analysis, we assume the pressure within the housing is 0 kPa.

We can assume that this space behaves as a cylindrical tube. The collapsing pressure of a tube can be described (Machinery's Handbook, 22nd Edition, page 332) by:

$$P = 3.46x10^8 \left(\frac{t}{d}\right)^3$$

where:	*P*:	Collapsing Pressure in kPa	
	d_i:	Outside Diameter	168 mm (6.63 in)
	t:	Wall Thickness	3.09 mm (0.122 in)

From this relationship, the collapsing pressure of the stainless steel housing is 2.15 MPa (313 psi).

The increased pressure resulting from this immersion condition (150 kPa) represents only 7% of the collapsing pressure. Therefore, this immersion pressure will have no adverse affect on the structural integrity of the inner container body.

Containment (Special Form Capsule)

The ASPECT 12K package is designed solely for the transport of Special Form Radioactive Material. These Special Form capsules act as the containment for the radioactive material. The special form capsules are assumed to be filled with air. For this analysis, we assume the pressure within the capsule is 0 kPa.

Although many special form capsules may be used with the ASPECT 12K, the most vulnerable special form capsule to be used with the ASPECT 12K would be fabricated from stainless steel and have an outside diameter of 13 mm and a wall thickness of 0.3 mm. (Titanium has higher yield strength than stainless steel, and therefore a capsule with similar dimensions would be less vulnerable.)

We can assume that this capsule behaves as a cylindrical tube. The collapsing pressure of a tube can be described (Machinery's Handbook, 22nd Edition, page 332) by:

$$P = 3.46x10^{8}\left(\frac{t}{d}\right)^{3}$$

where:	*P*:	Collapsing Pressure in kPa	
	d:	Outside Diameter	13 mm (0.51 in)
	t:	Wall Thickness	0.3 mm (0.012 in)

From this relationship, the collapsing pressure of the source capsule is 4.25 MPa (619 psi).

The increased pressure resulting from this immersion condition (150 kPa) represents only 3.5% of the collapsing pressure. Therefore, this immersion pressure will have no adverse affect on the structural integrity of the most vulnerable special form capsule which serves as the containment.

2.12.9 **Lifting Handles Test**

Test Report

By: Krissie Zambrano

Date: 22 January 2014

Subject: **Lifting Handles Test**

The objective of this test is to determine whether the lifting handles of the ASPECT 12K package meet the requirement that they be designed with a minimum safety factor of three against yielding when used to lift the package in the intended manner.

The total weight required for the test is 447 kg (984lb), which is three times the maximum package weight of 149kg (328lb). Commercially available lifting handles are provided as a convenience on the package configuration. The package lifting handles are the only components designed to lift the package. The total weight of the package plus the dead weight that was distributed uniformly on top of the package was equal to 603.7kg (1331lb).

Straps were used to connect the handles to a forklift. The forklift was used to lift the package and weights about 2in off the ground for a full minute (See Figure 1). The package was suspended from a single point approximately in the center of each one of the lifting handles. The handles supported the weight without any deformation or damage (See Figure 2) in compliance with 10 CFR 71.45 (a). In addition, if the handles became separated from the package, they would not impair the ability of the package to meet other requirements. There are no other attachments or other features that could reasonably be used to lift the package.

Figure 1: Lifting Configuration

Figure 2: Drum With Handles Intact After Test

3.0 Thermal Evaluation

This chapter identifies and describes the principal thermal design features of the ASPECT 12K packaging that are important to safety. The thermal evaluations of the package under the Normal Conditions of Transport and under the Hypothetical Accident Condition were performed by CAE Associates using the ANSYS CFD thermal simulation software. All simulations were performed using a simplified two-dimensional axisymmetric model of the Aspect 12K package. As described below, this analytical model demonstrates compliance with the applicable performance requirements of Canadian Nuclear Safety Commission (CNSC) Packaging and Transport of Nuclear Substances (PTNS) Regulations, SOR/2000-208, International Atomic Energy Agency (IAEA) Regulations for the Safe Transport of Radioactive Material TS-R-1, 1996 Edition (Revised), and the United States Nuclear Regulatory Commission (USNRC) regulation Packaging and Transportation of Radioactive Materials (10 CFR Part 71) under the normal conditions of transport (§71.71) and the hypothetical accident conditions (§71.73). The thermal evaluations demonstrate that the maximum temperatures of all components of the package remain below their respective temperature limits under both normal conditions of transport and the hypothetical accident conditions. Further, the package is designed, constructed, and prepared for transport such that in still air at 38°C and in the shade, no accessible surface of the package has a temperature exceeding 50°C. These results assure that the thermal performance of the package will not cause any loss or dispersal of radioactive contents, and no loss of shielding integrity which would result in more than a 20% increase in the radiation level at any external surface of the package, in accordance with the requirements of IAEA paragraph 646.

3.1 Description of Thermal Design

The ASPECT 12K is a completely passive thermal device and has no mechanical cooling system or relief valves. All cooling of the package is through free convection and radiation.

3.1.1 Design Features

The ASPECT 12K is a cylindrical container with diameter of 394 mm (15.5 in) and height of 547 mm (21.6 in). The package contains one of three possible inner containers, each cylindrical in shape. Each utilizes a depleted uranium shield that is encased in a stainless steel housing. Copper and brass are used to separate the depleted uranium from the stainless steel to preclude the possibility of the formation of an iron-uranium eutectic alloy at temperatures below the thermal test condition.

The inner container is surrounded by a lightweight, low thermal conductivity, monolithic thermal ceramic insulator which provides impact protection during the hypothetical free fall accident condition and thermal insulation during the normal and hypothetical thermal accident conditions.

There are no cooling fins associated with the package, nor are there any coolants used.

3.1.2 Decay Heat of Contents

The ASPECT 12K may contain one of three separate inner containers. The contents, capacities and decay heat loads for each is described in the following table 3.1.

Table 3.1 Content and Heat Load for maxiBulk Inner Container

		maxiBulk			miniBulk			10-Channel		
		Max Activity		Pwr	Max Activity		Pwr	Max Activity		Pwr
Radionucide	**mW/Ci**	**TBq**	**Ci**	**W**	**TBq**	**Ci**	**W**	**TBq**	**Ci**	**W**
^{192}Iridium	8.59	250	6,750	58	81	2,200	19	56	1,500	13
^{75}Selenium	5.12	370	10,000	51	370	10,000	51	56	1,500	8
^{192}Ytterbium	5.38	56	1,500	8	56	1,500	8	56	1,500	8
^{137}Cesium	6.97	250	6,750	47	5.6	150	1	19	500	3.5
^{60}Cobalt	16.7	0.022	0.6	0.01	0.003	0.08	0.001	0.03	0.8	0.013

The maximum heat source, of all of these possibilities, is the maxiBulk container with 250 TBq (6,750 Ci) of ^{192}Iridium which generates 58 W of decay power. Therefore, this configuration, being the most severe case, was used in this evaluation.

3.1.3 Summary Tables of Temperatures

A summary of the maximum package temperatures resulting from the normal conditions of transport heat conditions that affect structural integrity, containment, and shielding are presented in Table 3.2. As a conservative approach, we employ a steady-state analysis in which all components reach their maximum temperatures. Therefore, no temporal results are presented.

The package has considerable thermal margin for normal conditions of transport heat condition.

We have chosen to apply the minimum ambient temperature, -40°C, to all package components with no consideration to the effect of the decay heat load in limiting this minimum temperature.

A significant thermal margin exists for all package components.

Table 3.2 Summary of Package Temperatures

Component	Maximum Temperature			
	38 °C ambient temperature without solar insolation (°C)	38 °C ambient temperature with solar insolation (°C)	800 °C Accident (°C)	Temperature Limit (°C)
Bulk Capsule	197.3	237.8	274.1	1,427
Uranium Shield	180.5	220.8	257.1	1,130
Shell	170.4	210.4	246.5	1,427
Insulation	170.0	209.9	799.2	870*
Drum (outer)	47.7	107.5	799.6	1,427
Drum (Bottom)	49.0	70.1	799.6	1,427

*Recommended service temperature (not melting temperature)

3.1.4 Summary Table of Pressures

A summary of the maximum internal pressures resulting from the hypothetical accident condition that affect structural integrity, containment, and shielding is presented in Table 3.3. The pressure limit is expressed as the pressure that would result in the stress of the component being equal to the yield strength of the material at the specific temperature. Since the maximum internal pressures during the hypothetical accident conditions do not exceed the pressure limits, it can be assumed that the internal pressures under normal conditions also would not exceed the pressure limits.

Table 3.3 Summary of Maximum Package Pressures

	Hypothetical Accident Condition	Pressure Limit
Bulk Capsule	0.37 MPa	3.38 MPa
Inner Container Cavity	0 MPa	N.A.
Inner Container Body	0.37 MPa	2.74 MPa
Outer Container	0 MPa	N.A.

3.2 Material Properties and Component Specifications

3.2.1 Material Properties

The package is fabricated primarily from depleted uranium, stainless steel Type 304, copper, brass, carbon steel, and monolithic thermal ceramic insulator. The thermal properties of these materials are presented in Table 3.4.

Table 3.4 Summary of Material Properties

Material	Melting Point (°C)	Thermal Conductivity (W/m-°C)	Specific Heat (J/kg-°C^{-1})	Density (g/cm^3)	Emissivity	Coefficient of Thermal Expansion (°C^{-1})	Modulus of Elasticity (GPa)
Uranium	1130	27.5	120	19.0	0.15	2.05 E-05	205
Copper	854	390	390	8.9	0.65	2.40 E-05	110
Brass	888	110	390	8.5	0.22	1.80 E-05	100
Stainless Steel	1,427	16	500	8.0	0.36	1.80 E-05	190
Monolithic Thermal Ceramic Insulator (Kaolite 1600)	870*	0.147	837	0.36	0.94	9.07 E-06	0.2
Carbon Steel	1510	52	490	7.9	0.92	1.17 E-05	210

*: Maximum Recommended Use Temperature

An analysis of the effect of uncertainties in these material properties on the resultant package temperatures is presented in Appendix 3.6.2

3.2.2 Component Specifications

The technical specifications of the components important to the thermal performance of the package include the allowable service temperatures and pressures for the normal conditions of transport and the hypothetical accident condition. The allowable service temperatures for all components encompass the maximum and minimum temperatures anticipated during normal conditions of transport and the hypothetical accident condition. The minimum service temperature for all package components is less than or equal to -40°C. The maximum service temperatures of the package components are based on the component's functional requirements for the service conditions. The maximum service temperature for metallic structural components is limited to the melting temperature of the material.

The monolithic thermal ceramic insulator material that fills the space between the outer container and the inner container has a maximum recommended use temperature of 870°C.

3.3 General Considerations

3.3.1 Evaluation by Analysis

The thermal analysis was performed by CAE Associates using ANSYS CFD thermal simulation software and using very conservative simplifying assumptions. Heat transfer from the package is assumed to occur by convection and/or radiation under very conservative boundary conditions.

For the normal conditions, as a conservative approach, we employ a steady-state analysis in which all components reach their maximum temperatures. No consideration is made for the temporal response that would result in lower package temperatures.

For the Hypothetical Accident Condition, we employ a transient analysis and we follow the temperatures of the critical components for a period of time after removal from the hypothetical thermal environment.

Package Calculational Model

For calculational efficiency, the model used was a simplification of the package design. The package contained a single, simplified, cylindrical version of the SPEC Bulk Source Capsule (IAEA Certificate of Competent Authority Special Form Radioactive Materials Certificate USA/0786/S-96, Revision 0), containing 6,764 Ci of ^{192}Iridium. The associated decay power was deposited completely as heat within the ^{192}Iridium contents (58.1 W). We contend that these are conservative assumptions, as in actual use, not all of the decay power would be completely deposited as heat in the source capsule; much of the gamma decay power would be distributed beyond the capsule to be deposited in the uranium shield.

This source capsule is positioned within a stainless steel spacer inside the cavity of the uranium shield. The shield is positioned by means of brass support rings, mounted on both ends, inside the stainless steel container shell (diameter of 168 mm, height of 260 mm and a wall thickness of 3.0 mm). This geometry is shown in Figure 3.2

The material properties used were those presented in Table 3.4.

Figure 3.2: Calculational model of the Aspect 12K maxiBulk inner package, consisting of one contained SPEC Bulk Source Capsule containing 6,764 Ci of ^{192}Iridium positioned within a stainless steel spacer which is located inside the cavity of the uranium shield, which is positioned by means of brass support rings, mounted on both ends, inside the stainless steel container shell (diameter of 168 mm, height of 260 mm and a wall thickness of 3.0 mm.

The maxiBulk container is transported inside the outer container. The outer container was simulated as a carbon steel cylindrical shell with a diameter of 400 mm, height of 540 mm and a wall thickness of 2 mm. The maxiBulk is located in the center of the outer container, surrounded by an alignment sleeve. The space around the alignment sleeve and above the maxiBulk container is filled with monolithic thermal ceramic insulator material. This model geometry is shown in Figure 3.3:

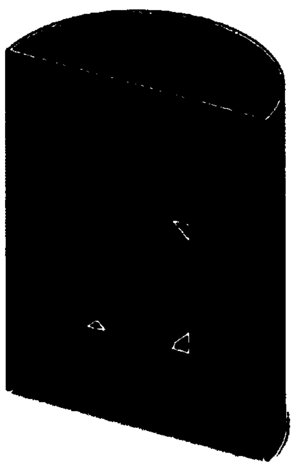

Figure 3.3: Calculational model of the Aspect 12K package, consisting of an inner container (maxiBulk, described in Figure 3.2) surrounded by an alignment sleeve, and an outer container simulated as a carbon steel cylindrical shell with a diameter of 400 mm, height of 540 mm and a wall thickness of 2 mm. The space between the alignment sleeve and the outer container was filled with a monolithic thermal ceramic insulator material.

These thermal analyses demonstrate that the maximum temperatures of all components of the package remain below their respective temperature limits under the normal conditions of transport. Further, the package is designed, constructed, and prepared for transport such that, in still air at 38°C and in the shade, no accessible surface of the package has a temperature exceeding 50°C. These results assure that the thermal performance of the package will not cause any loss or dispersal of radioactive contents, and no loss of shielding integrity which would result in more than a 20% increase in the radiation level at any external surface of the package, in accordance with the requirements of IAEA paragraph 646.

Under the hypothetical accident conditions, the possibility of oxidation of the depleted uranium shield has been taken into account. This analysis demonstrated that under the hypothetical thermal accident condition, there will be no release of the radioactive contents and that the radiation levels associated with the package remain well below the regulatory limit.

3.3.2 Evaluation by Test

The results of two thermal analyses were validated by physical test.

To verify that there would be no reduction in safety as a result of the cold temperature limit and brittle fracture, a physical test was performed using a full scale package as described in Section 3.4.1.

To verify that oxidation of the surface of the uranium shield under the hypothetical thermal accident condition would not cause an increase in the radiation levels prescribed by IAEA Paragraph 651 and to verify that the test temperature would not result in thermal stresses that would compromise the package safety, a physical test was performed using a reduced scale model as described in Section 3.5.3, 3.5.4 and 3.6.6.

3.4 Thermal Evaluation under Normal Conditions of Transport

This section describes the thermal evaluation of the package under normal conditions of transport. The evaluation is conducted using analytical methods for the applicable thermal loads. The results are compared with the allowable limits of temperature and pressure for the package components.

As described in Section 3.3.1, the thermal analysis was performed by CAE Associates using ANSYS CFD thermal simulation software and using very conservative simplifying assumptions. Heat transfer from the package is assumed to occur by convection and radiation under very conservative boundary conditions. As a conservative approach, we employ a steady-state analysis in which all components reach their maximum temperatures. No consideration is made for the temporal response that would result in lower temperatures.

The package model used in this analysis is described in Section 3.3.1.

The heat source for the ASPECT 12K is a maximum of 6,764 Ci of ^{192}Iridium. The ^{192}Iridium decays with a total energy liberation of 1.45 MeV per disintegration or 8.59 mW/Ci. Assuming that all decay energy is transformed into heat, the heat generation rate for the 6,764 Ci of ^{192}Iridium would be 58.1 W.

These thermal analyses demonstrate that the maximum temperatures of all components of the package remain below their respective temperature limits under the normal conditions of transport. Further, the package is designed, constructed, and prepared for transport such that, in still air at 38°C and in the shade, no accessible surface of the package has a temperature exceeding 50°C. These results assure that the thermal performance of the package will not cause any loss or dispersal of radioactive contents, and no loss of shielding integrity which would result in more than a 20% increase in the radiation level at any external surface of the package, in accordance with the requirements of IAEA paragraph 646.

3.4.1 Heat and Cold

The thermal evaluations of the package under normal conditions of transport are conducted using a steady-state analysis methodology. To assure conservativism, no temporal effects are considered.

For the normal conditions of transport heat evaluation, the package is assumed to be subjected to a constant ambient temperature of 38°C.

An analysis of the maximum temperatures of the components of the package, in the shade, as a result of the decay heat generation is presented in Appendix 3.6.1. Heat transfer from the package is assumed to occur by convection and radiation under very conservative boundary conditions. The maximum temperatures of the package components are presented in Table 3.2. As described in Section 3.5.4, these temperatures will not generate any stresses in the package that would reduce the structural integrity of the package.

The maximum outer container surface temperature was 49.0°C. This demonstrates that the package will satisfy the regulatory requirement that in still air at 38°C and in the shade; no accessible surface of the package has a temperature exceeding 50°C.

An analysis of the maximum temperature of the components of the package as a result of solar insolation in addition to decay heat generation is also presented in Appendix 3.6.1. For this analysis, we conservatively assume that the entire decay heat load (58.1 W) is deposited within the package. The package is insolated at the rate of:

800 W/m^2 to the top
400 W/m^2 to the sides

The package is analyzed under steady state conditions. For conservativism, diurnal insolation is not considered. Heat transfer from the package is assumed to occur by convection and radiation under very conservative boundary conditions.

The maximum temperatures of the package components under this condition are also presented in Table 3.2. As described in Section 3.5.4, these temperatures will not generate any stresses in the package that would reduce the structural integrity of the package.

The outer container is open to the atmosphere so there will be no pressure build-up within the package due to this temperature. There will be no reduction in the structural integrity of the outer container at this temperature. The inner container has been shown, in Section 3.5.4, to be able to withstand this temperature with no loss of containment, reduction of the structural integrity or reduction of shielding efficiency of the package.

For the cold analysis, we again used a steady state analysis. For conservativism, we have chosen to apply the minimum ambient temperature, -40 °C, to all package components with no consideration to the effect of the decay heat load in limiting this minimum temperature. The steady state model therefore resulted in all components of the package reaching a temperature of -40 °C, which are within the operating range of all of the materials of the package.

The possibility of brittle fracture under these temperature conditions was evaluated by test. As described in Section 2.7.1, prior to the performance of the hypothetical free fall accident test, the package was buried in dry ice for a period of 17 hours until the temperature of the inner package reached -40°C. The outer package was at a temperature of -75°C. The package was removed from the dry ice and immediately subjected to the 9 meter hypothetical free fall accident condition. No brittle fracture of the stainless steel outer container or stainless steel inner container was observed. As noted in Section 2.7.1, the results of that test demonstrate that the package satisfactorily meets the requirements for the hypothetical free fall accident. There were no stress-related failures as a result of this cold temperature. The inner container maintained its integrity with no loss or dispersal of radioactive contents, and no loss of shielding integrity which would result in more than a 20% increase in the radiation level at any external surface of the package. A report of this test is included in Appendix 2.12.2.3.

3.4.2 Temperatures Resulting in Maximum Thermal Stresses

The maximum temperatures encountered under the normal conditions of transport will have no adverse effect on the structural integrity or shielding efficiency of the package. The maximum temperatures of the package components are presented in Table 3.2. All temperatures are far below 800°C.

In Sections 3.5.3 and 3.5.4, the maximum stresses generated in the package at a temperature of 800°C were shown to result in stresses less than 11% of the yield strength of the material. Clearly, the pressures and stresses resulting from these significantly lower temperatures will be less severe.

There will be no thermal stress as a result of differential thermal expansion of the materials of the inner container as described in Section 3.5.4.

3.4.3 Maximum Normal Operating Pressure

In Sections 3.5.3 and 3.5.4, the maximum pressures generated in the package at a temperature of 800°C were shown to be 374 kPa. These pressures were shown to result in stresses less than 11% of the yield strength of the material. Clearly, the pressures and stresses resulting from these significantly lower temperatures will be less severe.

The external container, although enclosed, is not sealed. Therefore, there will be no pressure build up in this container during the normal conditions of transport.

3.5 Thermal Evaluation under Hypothetical Accident Conditions

This section presents the predicted system temperatures and pressures for the package under the hypothetical thermal accident condition specified in IAEA Paragraph 656. As described in Section 3.3.1, the thermal analysis of the package is performed by CAE Associates using ANSYS CFD thermal simulation software using very conservative simplifying assumptions.

The analysis demonstrates that as a result of the hypothetical thermal accident, there would be no release of the radioactive contents and the radiation exposure rate at a distance of one meter from the surface of the package would not exceed 10 mSv/hr as prescribed by IAEA Paragraph 656.

3.5.1 Initial Conditions

During the hypothetical free fall accident test, the outer stainless steel container was slightly deformed and the monolithic thermal ceramic insulator material was essentially undamaged, as described in Section 2.7.1.

3.5.2 Fire Test Conditions

Because of the limited deformation and displacement described above, we have assumed that the package was undamaged for the thermal analysis.

3.5.3 Maximum Temperatures and Pressure

The analysis of the performance of the ASPECT 12K under the hypothetical accident conditions is presented in Appendix 3.6.7. The maximum temperatures achieved by the various components of the package were presented in Table 3.2.

Notwithstanding these results, our subsequent analyses of the performance of the containment and shielding of the package, presented in Appendix 3.6.4 and 3.6.5, are based on the conservative assumption that all components of the package reach a temperature of 800°C.

The ASPECT 12K package is designed solely for the transport of Special Form Radioactive Material. As described in Appendix 3.6.5, at a temperature of 800°C, the maximum pressure generated within this Special Form Capsule is 370 kPa.

The inner container cavity, although enclosed, is not sealed; no "O"-rings, gaskets or other sealing devices are employed. This cavity is open to the atmosphere. Therefore, there will be no pressure build up in this cavity during normal operation.

The stainless steel housing containing the depleted uranium shield is sealed by means of the welding. The space between the uranium shield and the housing is filled with air. As described in Appendix 3.6.4, at a temperature of 800°C, the maximum pressure generated within this space is also 370 kPa.

At a temperature of 800°C, the surface of the uranium shield would be expected to oxidize. As described in Section 3.5.4, due to the limited oxygen in this sealed space, this oxidation is expected to result in less than 1% increase in the radiation intensity surrounding the package. A physical test to verify this analysis was performed using a reduced scale model as described in Appendix 3.6.6.

The external container, although enclosed, is not sealed.

3.5.4 Maximum Thermal Stresses

As noted above in Section 3.5.3, the ASPECT 12K package is designed solely for the transport of Special Form Radioactive Material. The Special Form capsules provide the primary containment for the radioactive material. It is assumed that the special form capsule achieves a temperature of 800 °C.

As was demonstrated in Section 3.5.3, above, the maximum pressure inside the capsule at that temperature is 370 kPa. As described in Appendix 3.6.5, the maximum stress generated within the stainless steel capsule is 5.68 MPa (871 psi), which is less than 9% of the yield strength of the stainless steel capsule material at that temperature.

In addition to this analysis, all special form source capsules authorized to be transported in the ASPECT 12K will have been successfully subjected to the Special Form thermal test of 800 °C.

As noted above in Section 3.5.3, the maximum pressure generated within the space between the uranium shield and the housing is also 370 kPa from this temperature. As described in Appendix 3.6.4, the maximum stress generated within the stainless steel housing is 7.05 MPa, which is less than 11% of the yield strength of stainless steel at that temperature.

As described in Appendix 3.6.4, there will be no thermal stress as a result of differential thermal expansion of the materials of the inner container. A physical test to verify this analysis was performed using a reduced scale model as described in Appendix 3.6.6.

3.5.5 Fuel/Cladding Temperatures for Spent Nuclear Fuel

Not Applicable

3.5.6 Hypothetical Accident Conditions for Fissile Material Packages for Air Transport

Not applicable.

3.6 Appendices

3.6.1 ASPECT 12K Type B(U) Thermal Analysis Under the Normal Conditions of Transport

3.6.1.1 Analysis of the Package Temperatures at 38°C in the Shade: Assessment of Two Different Inorganic Insulation Materials; CAE Associates Report dated 30 October 2013

3.6.1.2 Analysis of the Package Temperatures at 38°C in the Shade: Assessment of Maximum Permissible Decay Heat Load; CAE Associates Report dated 06 November 2013

3.6.1.3 Analysis of the Package Temperatures at 38°C with Solar Insolation; CAE Associates Report dated 12 November 2013

3.6.1.4 3.6.1.4 CAE Supplement (Package Geometry and Materials); CAE Associates Report dated 30 January 2014

3.6.1.5 CAE Supplement ANSYS CFD Output File

3.6.2 ASPECT 12K Type B(U) Thermal Analysis Under the Normal Conditions of Transport

3.6.2.1 ASPECT 12K Analysis of the Effect of the Uncertainties in the Package Conditions and Properties on the Resultant Surface Temperature under the IAEA Normal Thermal Condition

3.6.2.2 Analysis of the Package Temperatures at 38°C in the Shade: Assessment of Two Disparately Different Values of Emissivity; CAE Associates Report dated 23 December 2013

3.6.3 Analysis of the Package Temperatures under the Hypothetical Accident Thermal Condition; CAE Associates Report dated 16 December 2013

3.6.4 Aspect 12K Type B(U) Thermal Analysis: Maximum Pressures and Stresses

3.6.5 Aspect 12K Type B(U) Thermal Analysis in accordance with 10CFR71.73(c)(4) and TSR1 Paragraph 728 (Special Form Capsule Under the Hypothetical Accident Fire Condition)

3.6.6 Test Report of the Verification of the Oxidation of the Uranium Surface and the Thermal Stress

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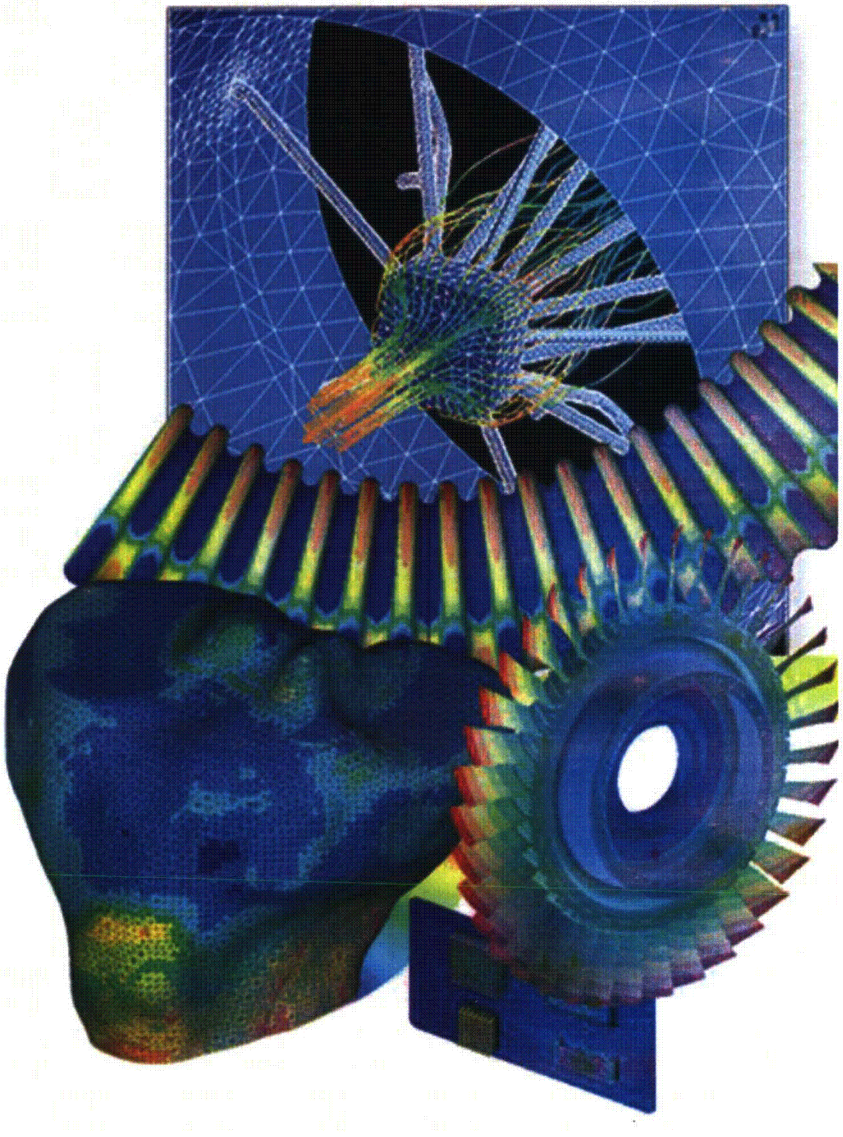
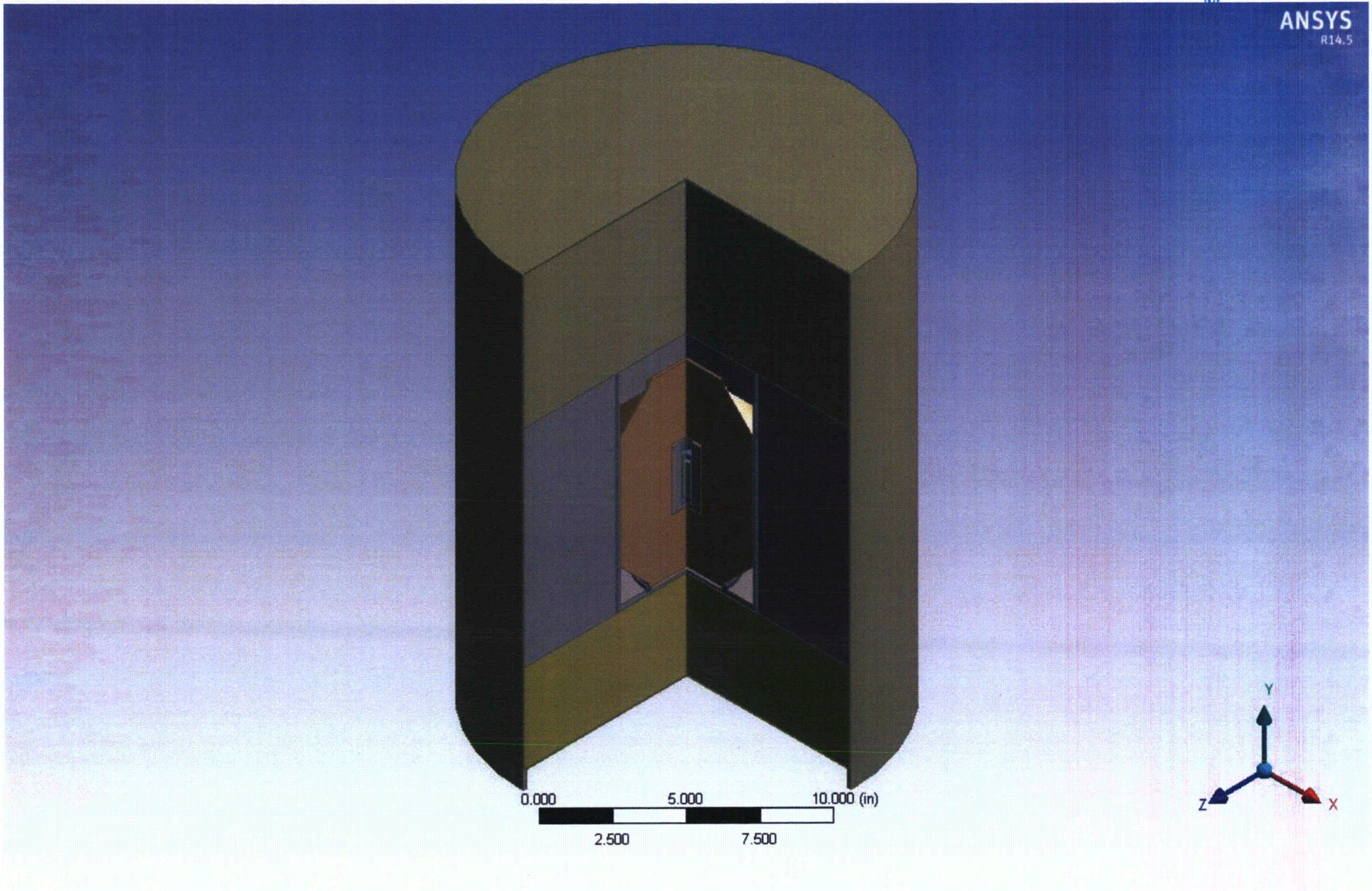


Aspect Transport Package Thermal Analysis

October 30, 2013

Radioactive Material Transport Package



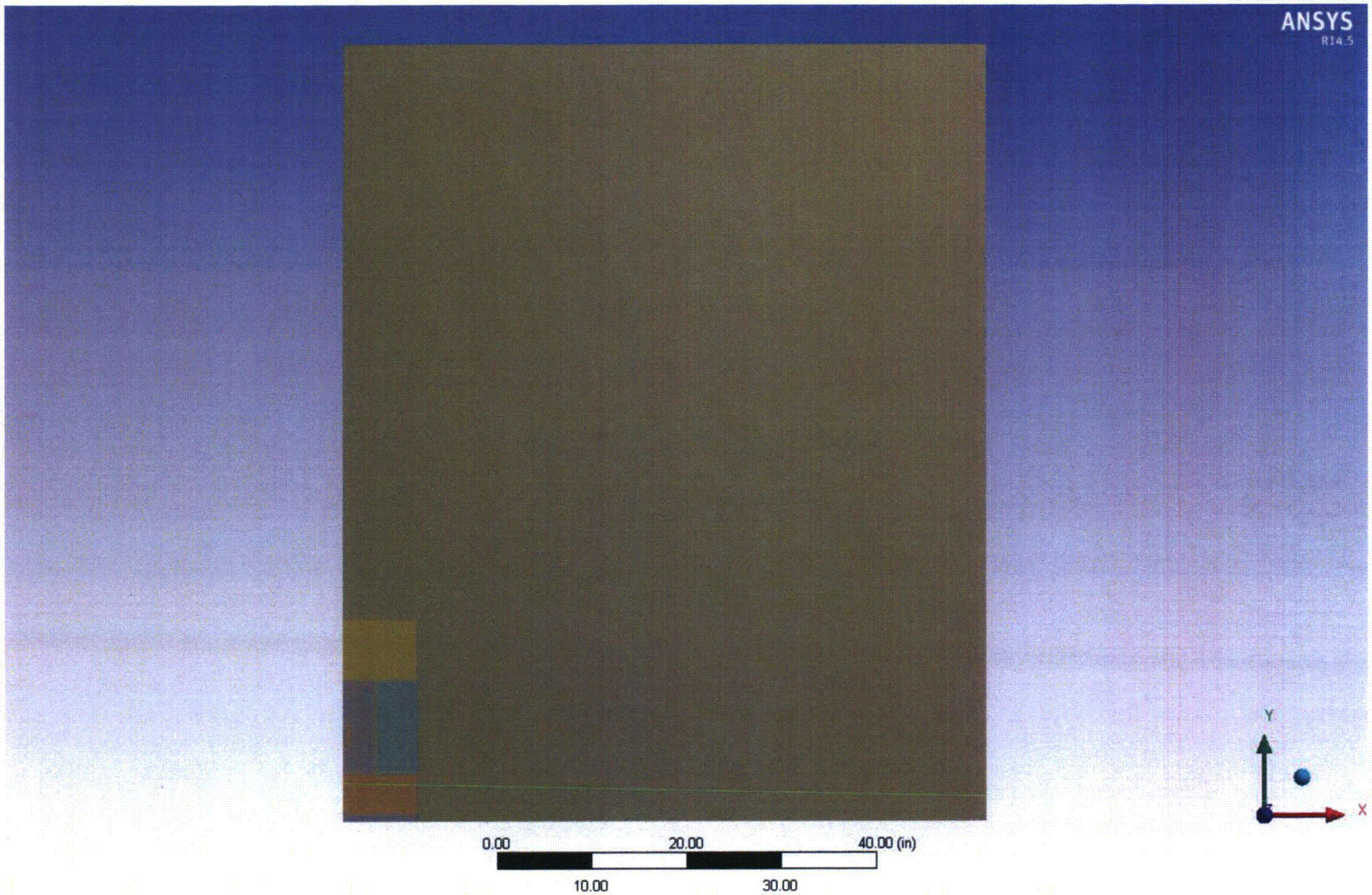
CFD Analysis

- CAEA has previously analyzed Aspect's radioactive transport package for the three thermal conditions required under 10 CFR 71 for a Type B(U) package, shown below.
- The thermal loads of condition 10CFR 71.71c1 (condition 2) result in local temperatures in the foam insulation that exceed the manufacturers maximum working temperature.
- Aspect is interested in modeling a redesigned radioactive transport package with non-organic insulation under condition 10CFR 71.71c2 (condition 1). The behavior of the package will be assessed using two different insulation materials for an Iridium heat generation rate of 44.3 W. The initial goal is to determine which of the two non-organic insulation materials exhibits superior performance.

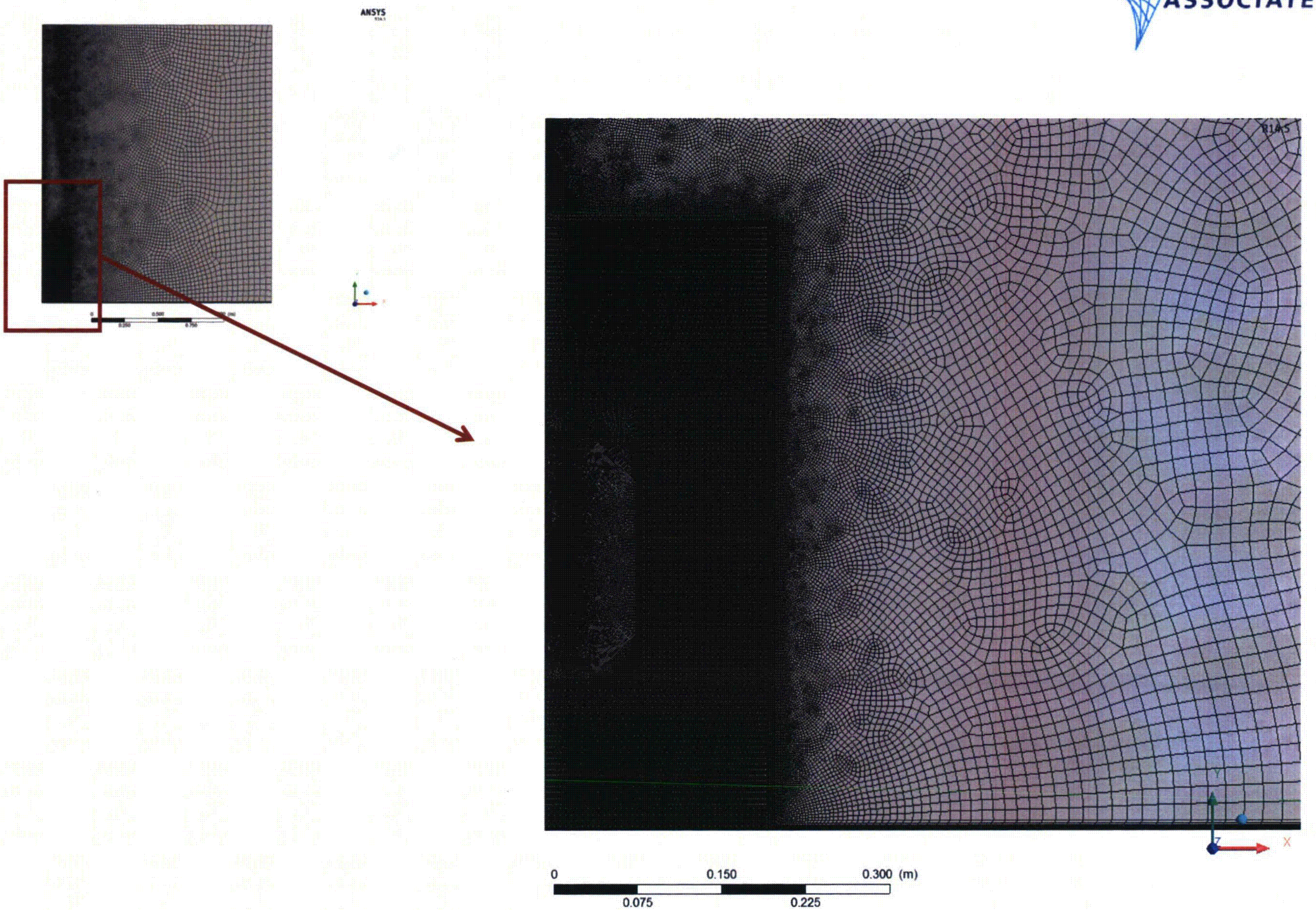
10 CFR 71.43g 10 CFR 71.71 c2	A package must be designed, constructed, and prepared for transport so that in still air at 38 deg C (100 deg F) and in the shade, no accessible surface of a package would have a temperature exceeding 50 deg. C (122 deg. F) in a nonexclusive use shipment.
10CFR 71.71c1 TSR1 651, 652, 653, 654	The package design shall be designed so that under ambient conditions (temperature 38C (100F) and solar insolation conditions), heat generated by the radioactive material shall not under normal conditions of transport adversely affect the package in such a way that it would fail to meet containment and shielding requirements if left unattended for a week. Insolation data is as follows: Surface Form / Location Insolation for 12 hrs/day Flat surface transported horizontally - Base None - Other Surfaces 800 W/m^2 Flat surface not transported horizontally -Each surface 200 W/m^2 Curved Surfaces 400 W/ m^2
10 CFR 71.73c4 (Hypothetical Accident Conditions) TSR1 728	Under the conditions of the hypothetical thermal accident condition (800oC for one hour), there would be no escape of radioactive material and no external radiation dose rate exceeding 10 mSv/h (1 rem/h) at 1 m (40 in) from the external surface of the package. This would require calculating the most severe thermal stress conditions that result during the fire test and subsequent cooldown.

Flow Domain

- The flow domain was extracted based on an axisymmetric representation of the transport package.

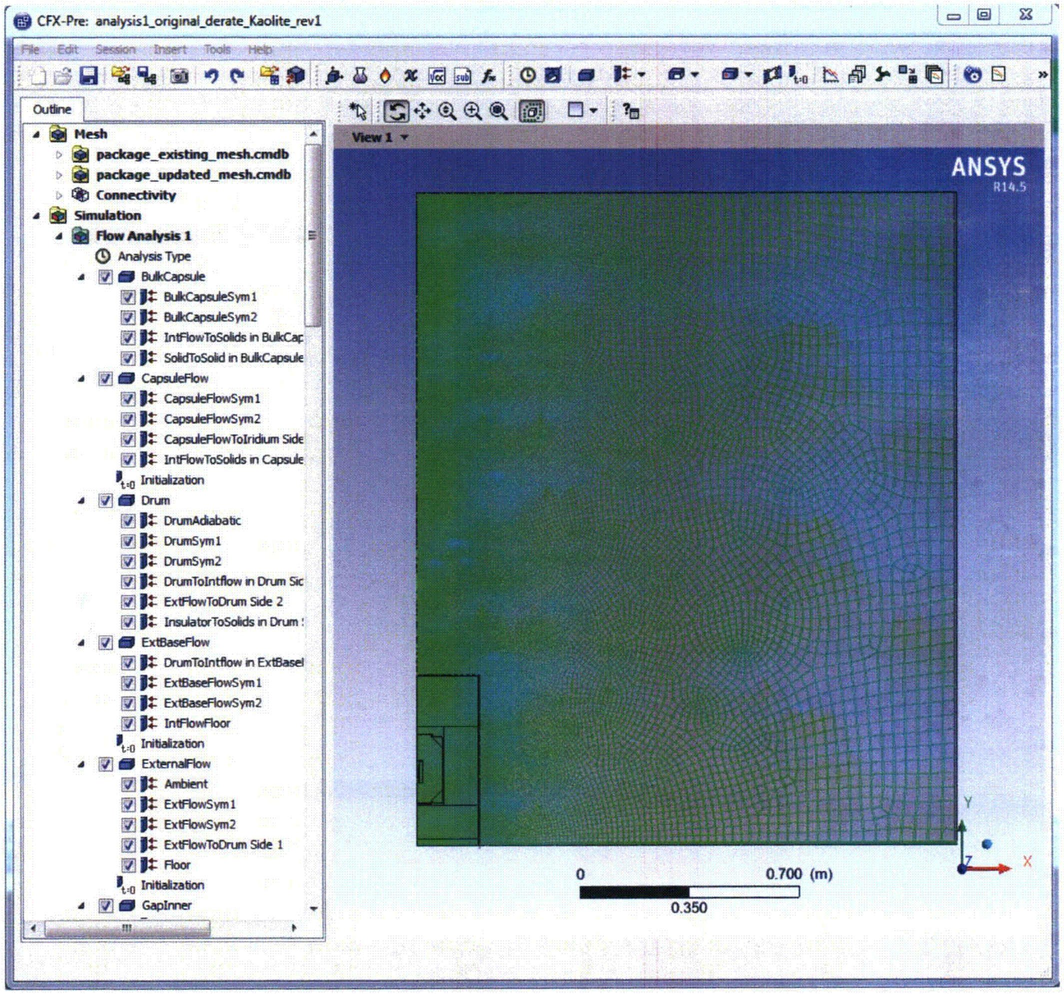


Mesh



CFD Model – Condition 1

- 2D, Steady State, Conjugate Heat Transfer, Internal and External Radiation
- Boundary Conditions:
  - External Air at 38°C
  - Iridium internal heat generation of 44.3 W
  - Package sits atop a flat surface at 38°C
- Insulation Materials:
  - The simulation is run with each insulation material:
    - Thermo 12
    - Kaolite 1600



Insulation Material Properties

- Thermo 12
  - Density: 230 kg/m^3
  - Specific Heat Capacity: 1005 J/kg*K
  - Thermal Conductivity:

Temperature (°C)	38	93	149	204	260	316	371
W/m*K	0.053	0.058	0.064	0.071	0.079	0.087	0.096

  - Emissivity: 0.85

- Kaolite 1600
  - Density: 400.5 kg/m^3
  - Specific Heat Capacity: 836.8 J/kg*K
  - Thermal Conductivity:

Temperature (°C)	20	100	200	300	600
W/m*K	0.193	0.189	0.168	0.150	0.170

  - Emissivity: 0.94

Component Temperatures

	Thermo 12		Kaolite 1600	
Component	Average Temperature [°C]	Maximum Temperature [°C]	Average Temperature [°C]	Maximum Temperature [°C]
Bulk Capsule	297.5	303.6	153.0	159.0
Uranium Shield	285.5	290.6	141.0	146.0
Shell	279.7	283.1	134.9	138.3
Insulator	107.7	282.8	65.0	138.0
Drum (Internal)	43.5	46.2	43.5	46.5
Drum (Outer Surface)	43.7	45.8	43.6	45.6
Drum (Bottom Outer Surface)	43.0	46.2	43.3	46.5

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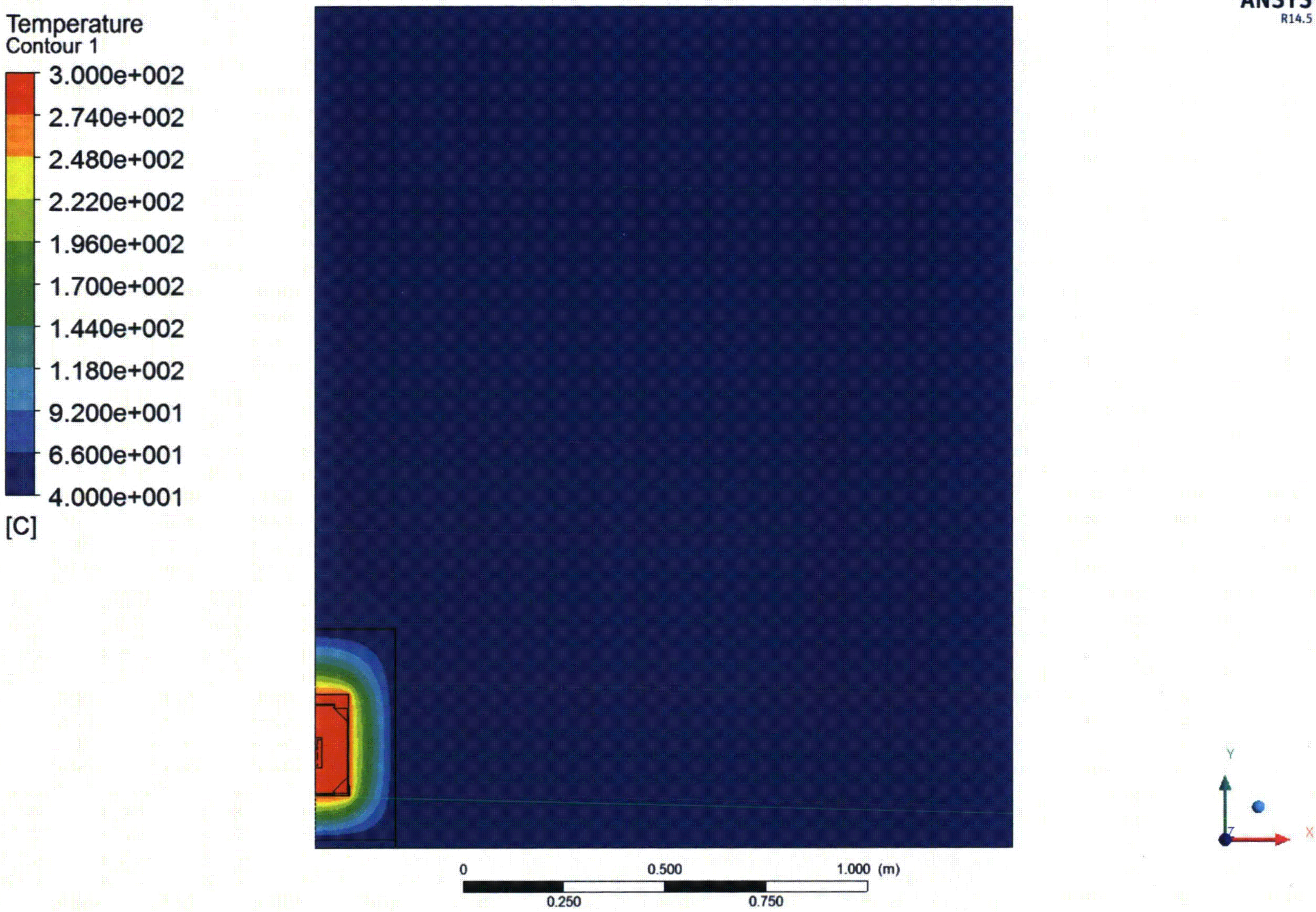
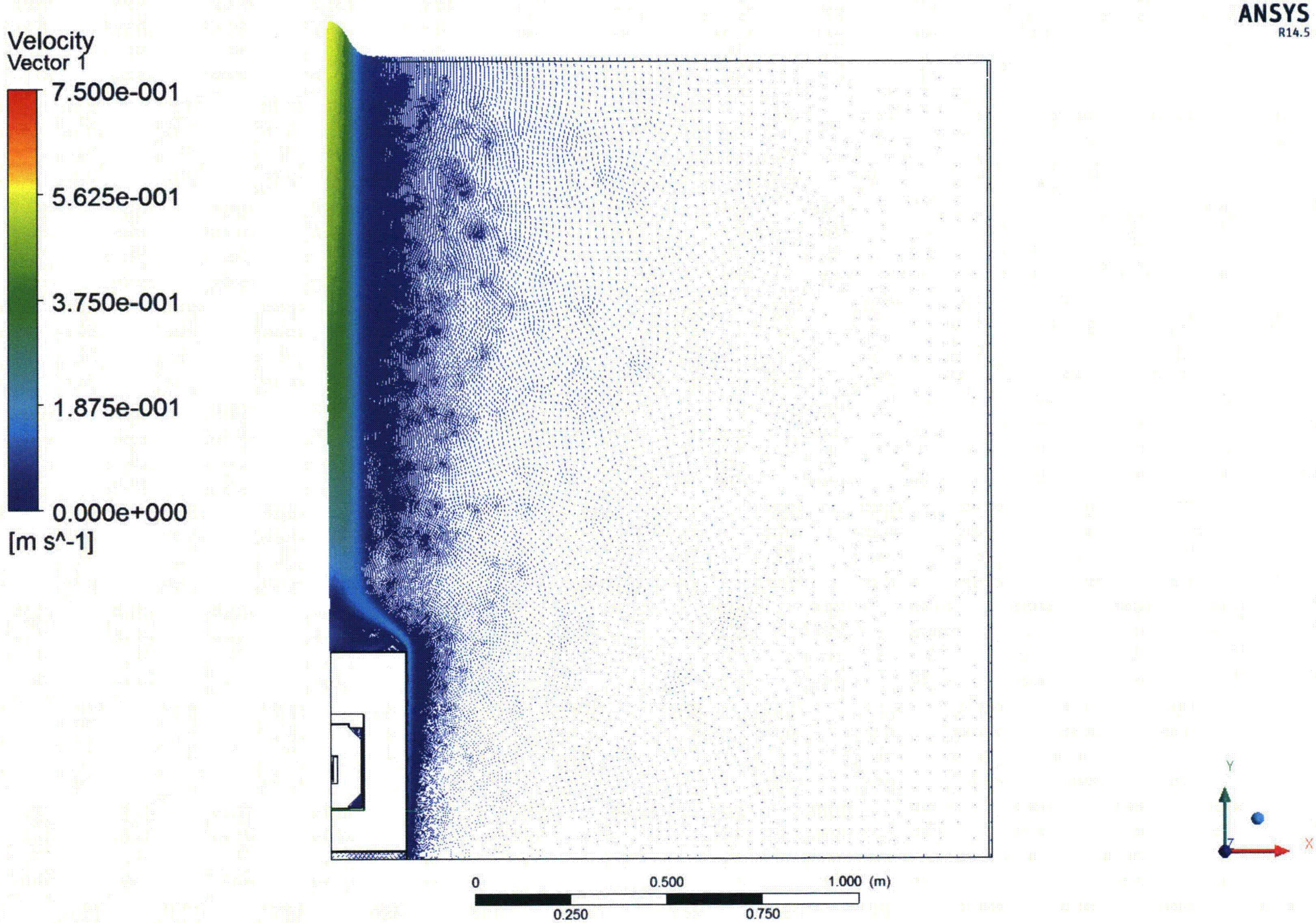
Condition 1

Thermo 12

Temperature Contours



Velocity Vectors



Streamlines – External Flow

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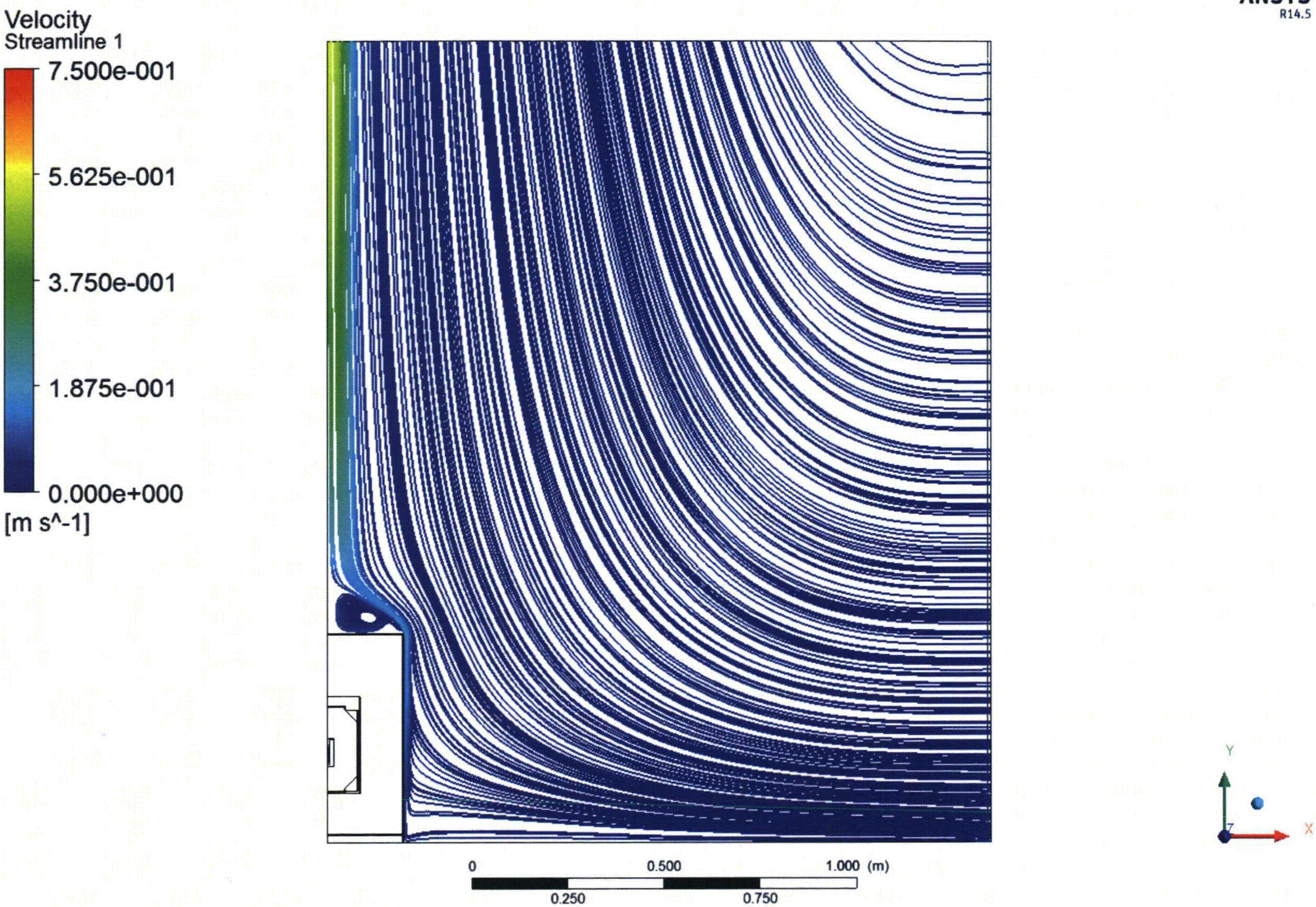

Temperature Contours – External Flow

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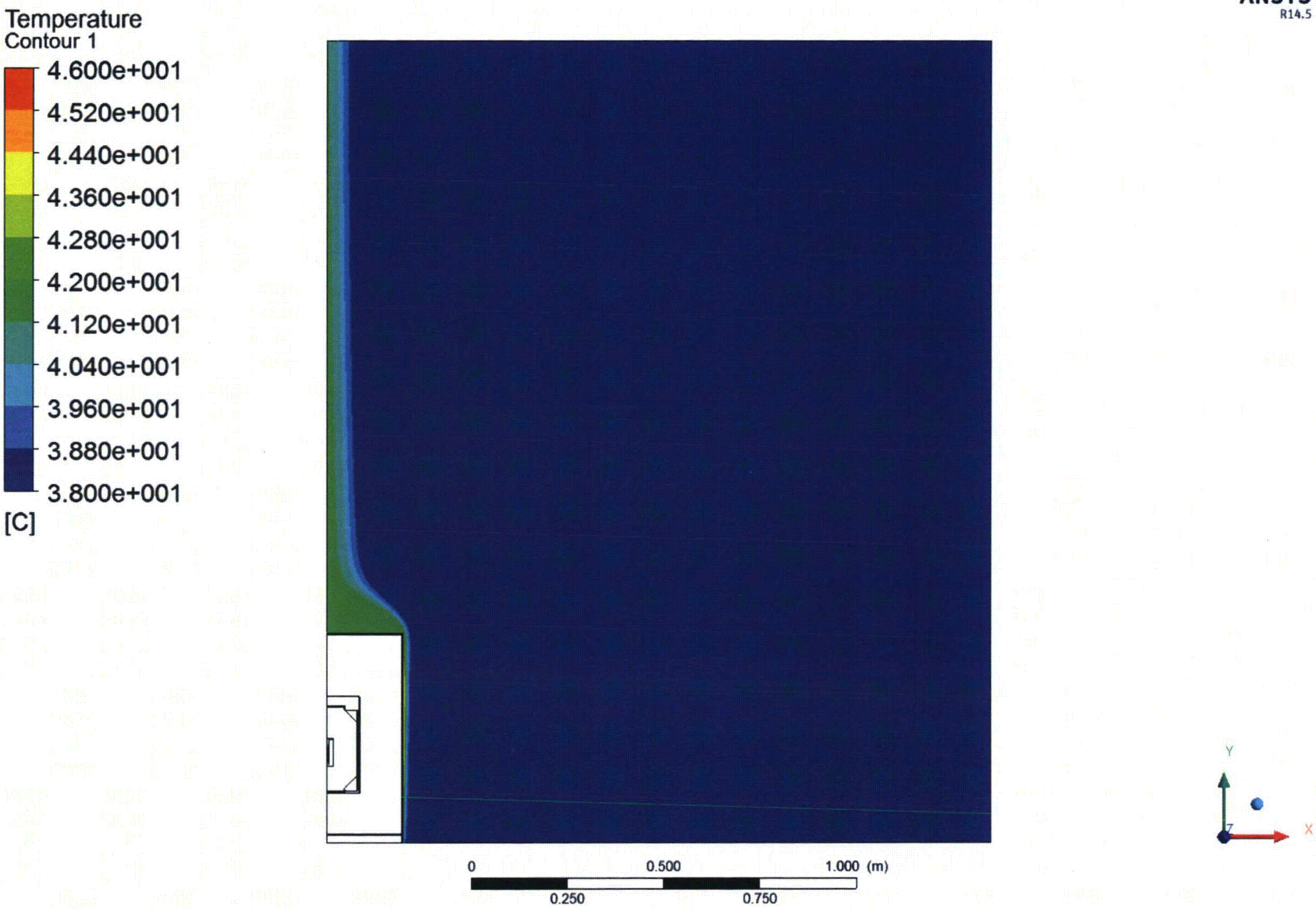
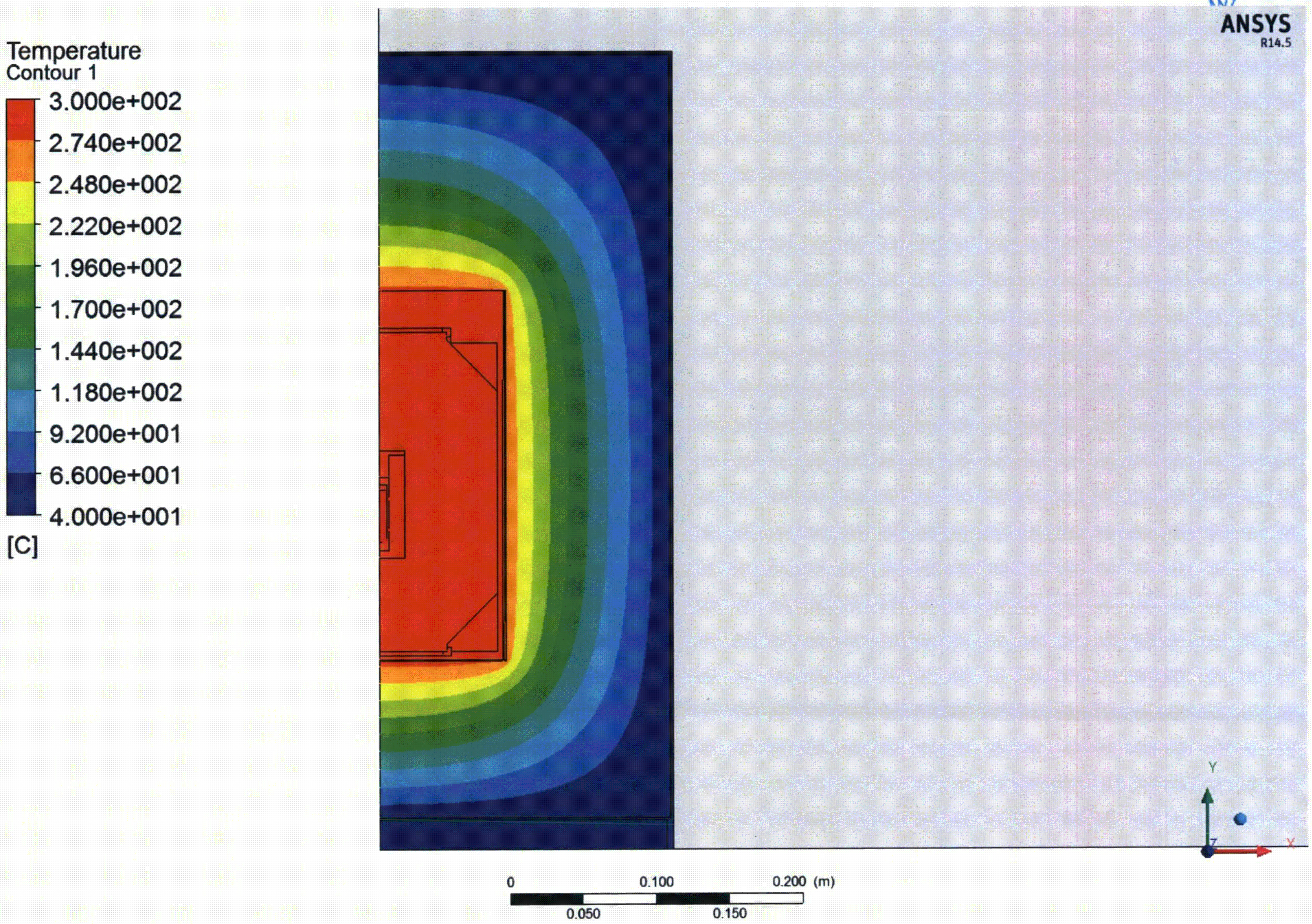


Temperature Contours – Interior



Temperature Contours – Bulk Capsule

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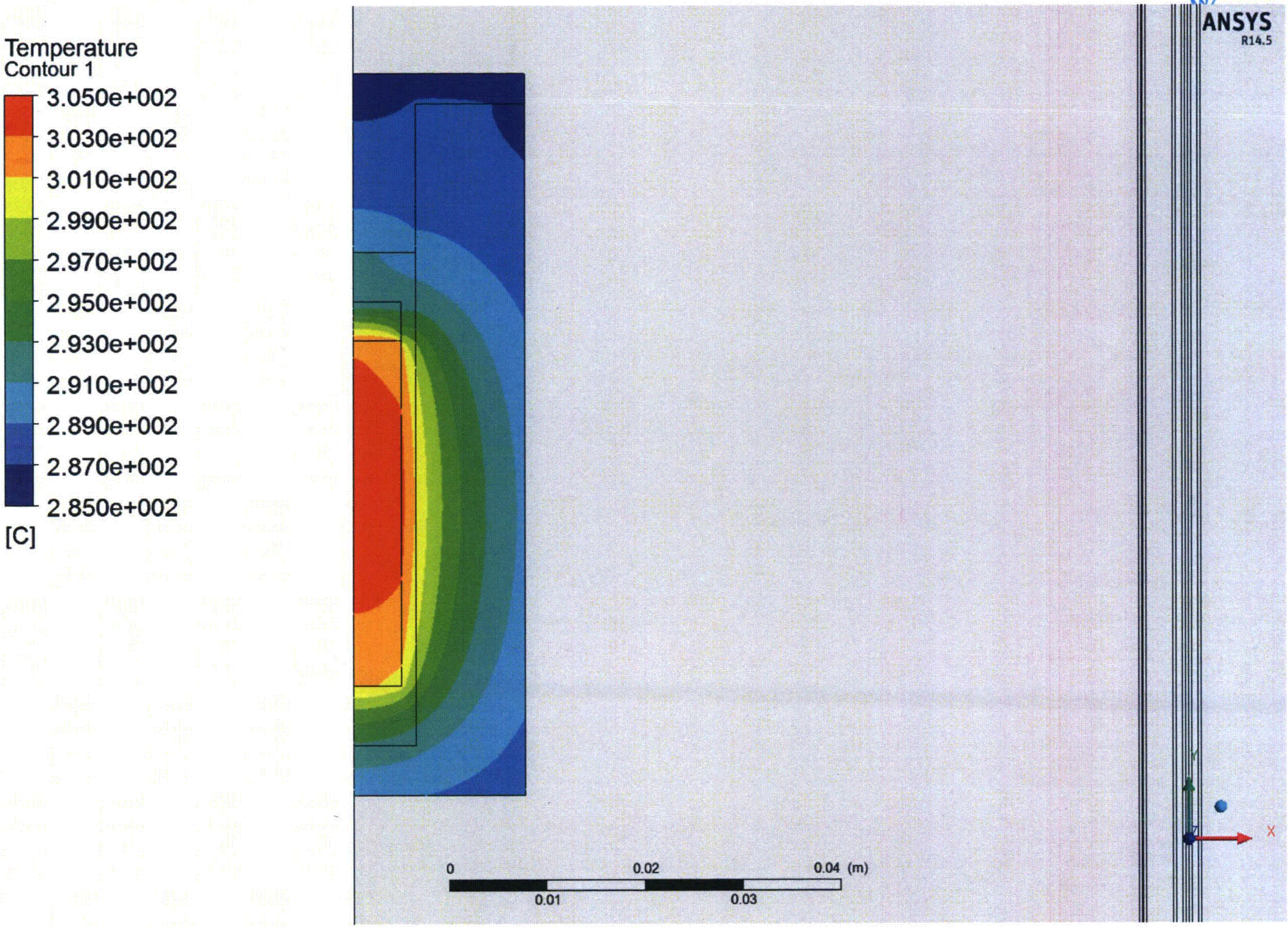
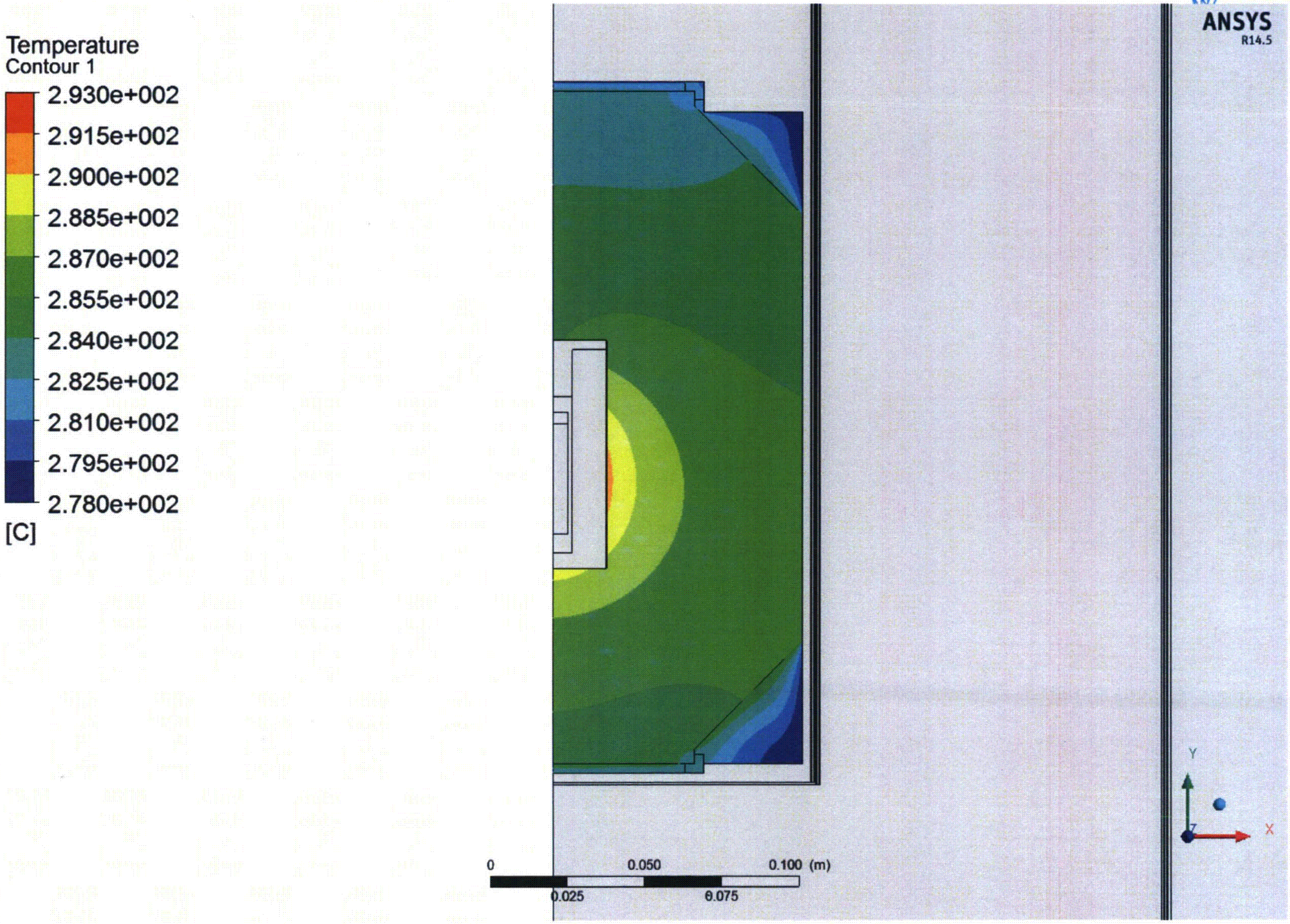
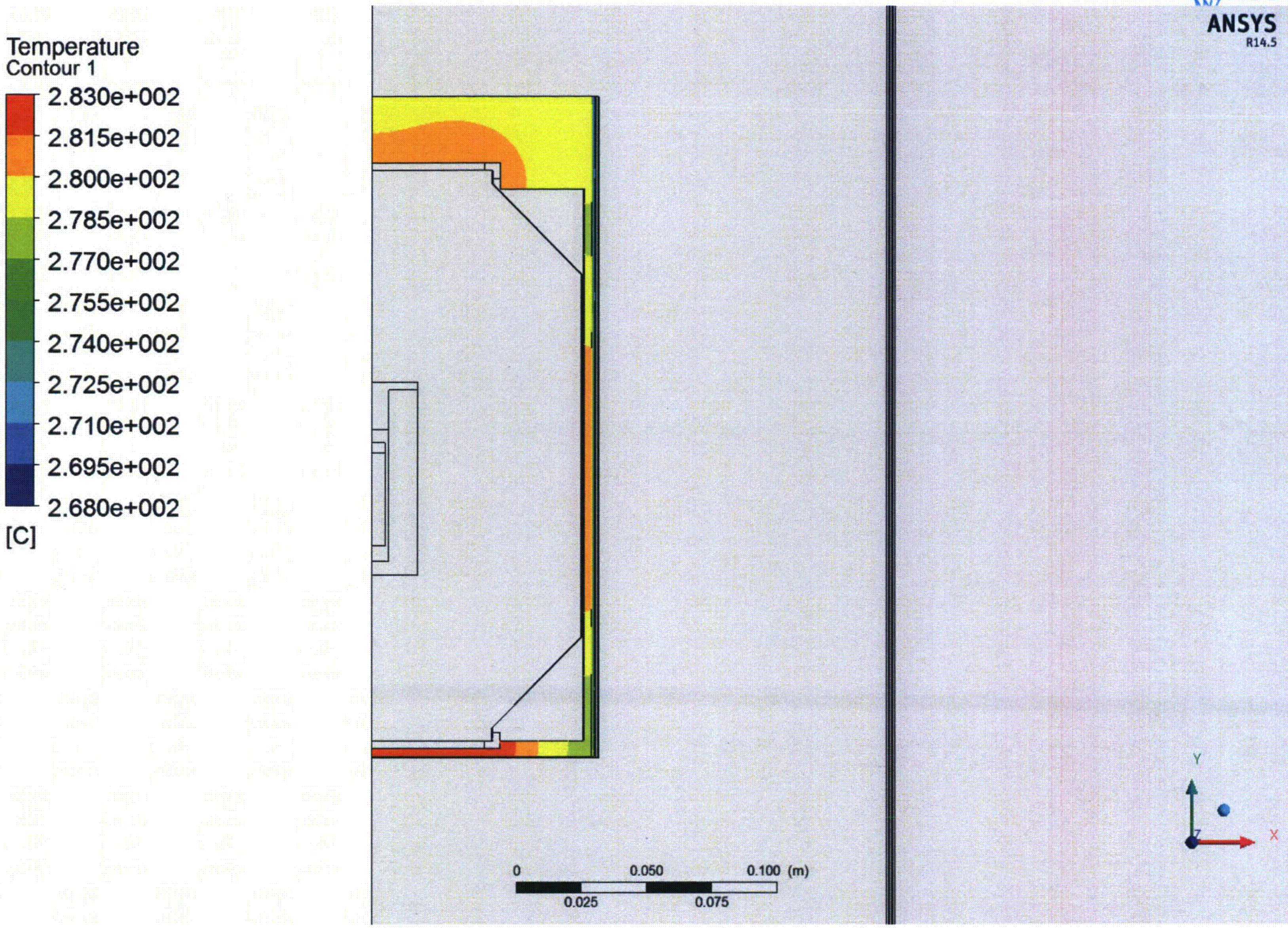


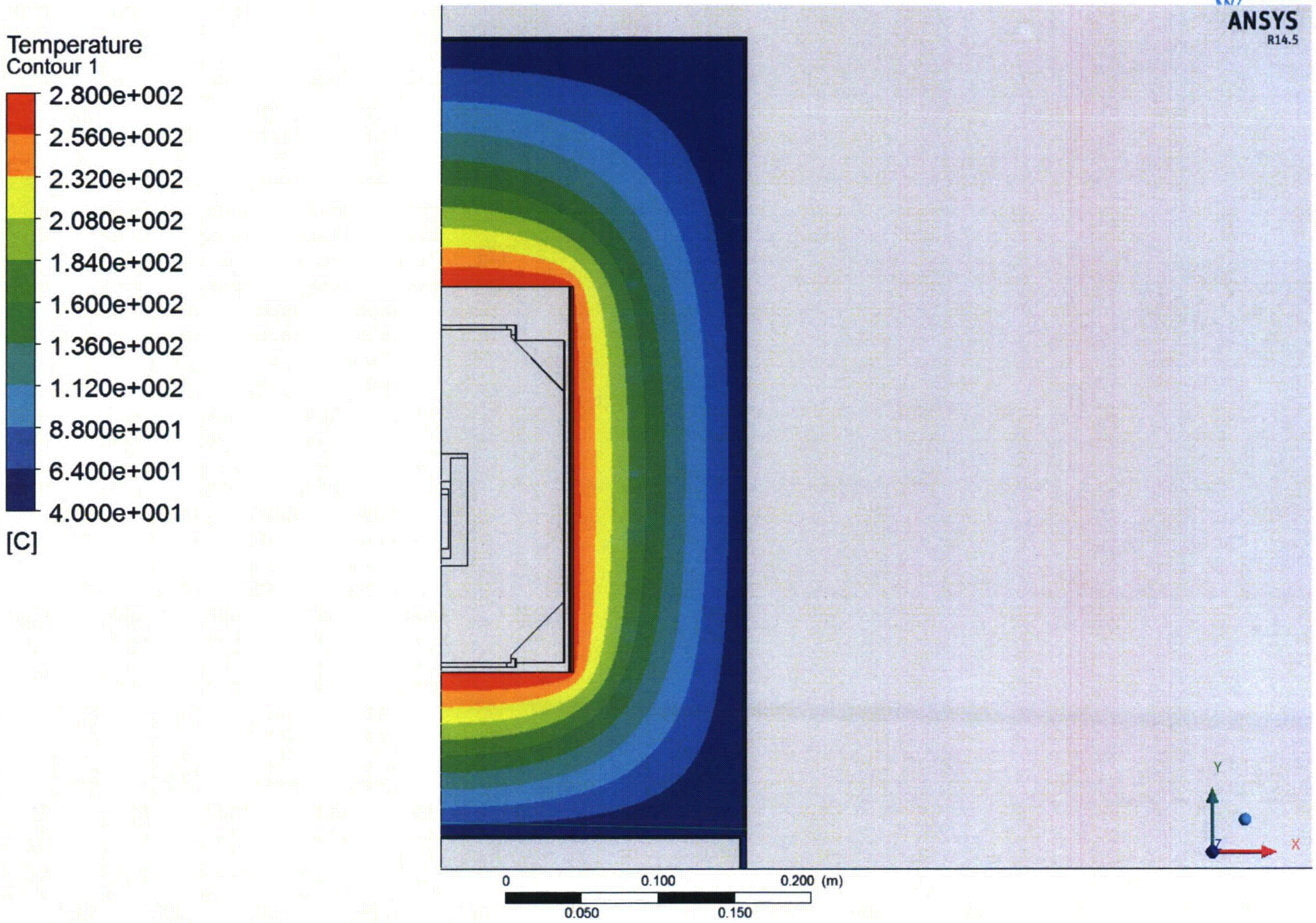
Temperature Contours – Uranium Shield



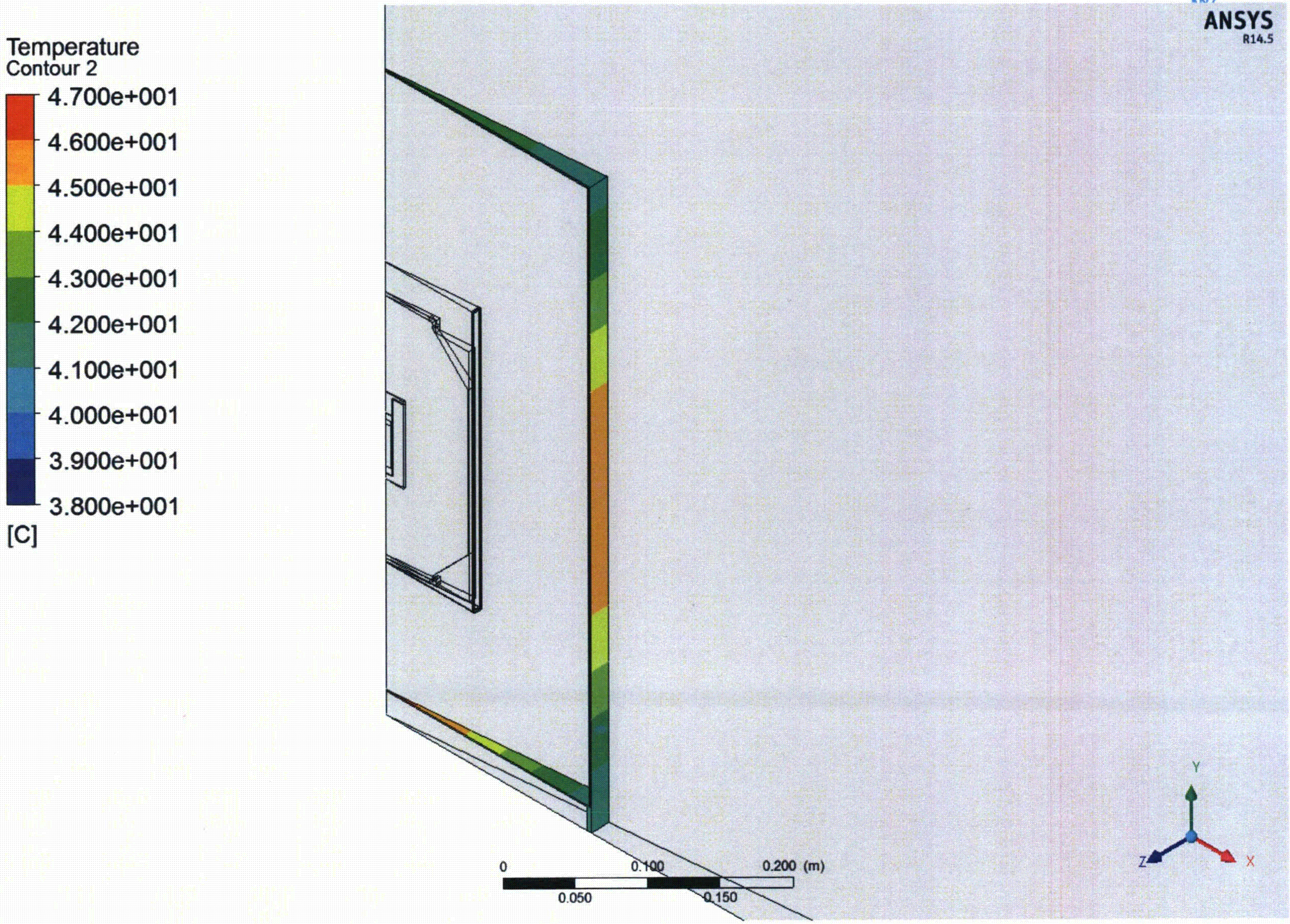
Temperature Contours - Shell



Temperature Contours – Insulation



Temperature Contours – Drum



Temperature Contours – Drum