LEUPA

Type B(U) Package for Fissile Materials

THERMAL ANALYSIS

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B	References	NG	JLA	JCO	

CONTENTS

1 PURPOSE

1. The purpose of this report, in accordance with the requirements of Standard AR 10.16.1 Rev. 2, is to present the results of the thermal analysis carried out for the LEUPA[2] package.
2. The simulation was performed using finite elements with FLUENT® 6.2 and the results were contrasted with simplified analytical calculations.

2 SCOPE

1. The scope of this report includes the maximum temperatures reached by cadmium contained in the LEUPA package in a condition of exposure during one (1) hour to a fire environment.
2. The temperatures in the container joints were monitored in the finite element simulation.
3. Temperatures were evaluated in a 10-hour range in order to contrast both calculations (simplified analytical calculation and simulation by finite elements), because the analytical calculation is a graphical calculation and it is imprecise at low exposure times.

3 REFERENCES

[1] ARN. *Transport of Radioactive Material.* Standard AR 10.16.1. Rev. 2. Argentina: ARN (Argentine Nuclear Regulatory Authority), 2011.

[2] 0908-LE01-2ASIN-001 “Low Enriched Uranium Package (LEUPA) – Preliminary Design”.

[3] PERRY, Robert H. *Perry’s Chemical Engineers’ Handbook*. Seventh Edition. New York: Mc. Graw Hill, 1997. 2640 pp. ISBN 9780070498419 / 0070498415.

[4] KERN, Donald Q. *Process Heat Transfer.* First Edition. New York: Mc. Graw Hill, 1965. 980 pp. ISBN 9789682610400 / 9682610400.

4 INTRODUCTION

1. The LEUPA package consists of a series of containers, one inside the other, with areas of thermal insulators and neutronic absorbents; see Figure 1: and Figure 2:. For more details, see the preliminary design[2].

Figure 1: Cross-section of the LEUPA package

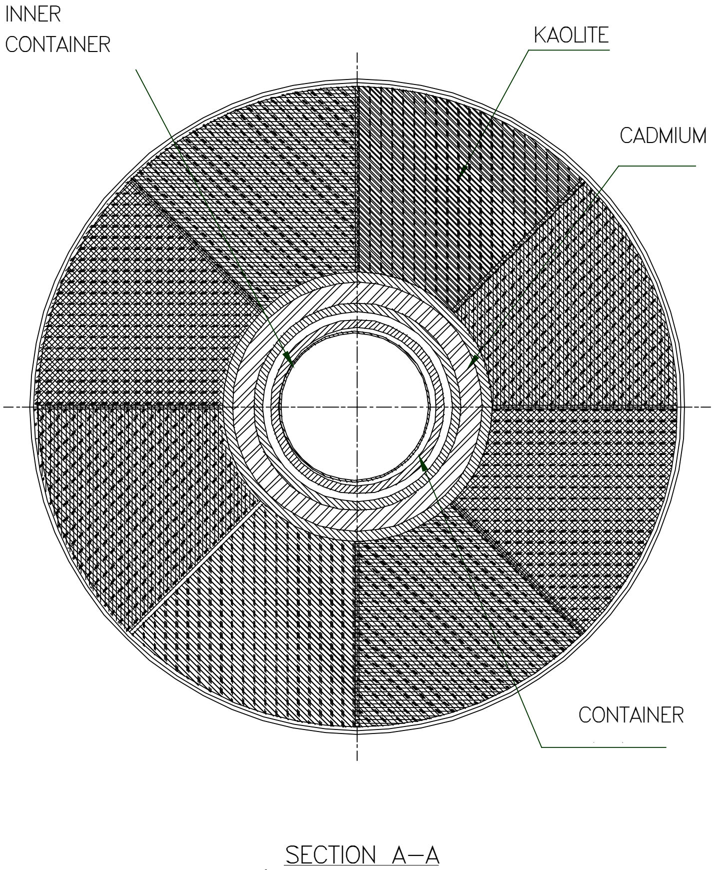


Figure 2: Side view of the LEUPA package

Security-Related Information Figure Withheld Under 10 CFR 2.390.

2. First, analytical calculations were made to determine the maximum temperatures reached by the areas consisting of cadmium.
3. A simulation by finite elements was also carried out to monitor the areas of interest in more detail due to the thermal complexity of the package.

5 THERMAL ANALYSIS

5.1 Analytical Calculation

5.1.1 Calculation Hypothesis

1. Solids composed only of Kaolite 1600 are considered for the estimate.
2. Neither thermal bridges nor metal layers are considered.
3. The cadmium content in the vertical area of the container is treated as a cylinder.
4. The cadmium content in the bottom of the container is treated as a semi-infinite solid.
5. The cadmium content in the container cover is treated as a semi-infinite solid.

6. 900 °C is adopted as the external temperature of the package. This is a conservative value as compared to that set forth by the Standard[1].
7. The external heat transfer coefficient is considered very high, and therefore, for the purposes of the calculations, it is considered infinite.
8. The thermal properties of Kaolite 1600 are evaluated in such a way as to make a conservative estimate:
   a. Minor density.
   b. Thermal conductivity at high temperatures.
   c. Heat capacity considered as the average of the heat capacity of the components evaluated at 100 °C[3].

5.1.2 Calculation Methodology

1. Gurney-Lurie charts[4] were used for analytical calculation (see Figure 3:) with the related equations.
2. The dimensionless groups involved in the calculation are as follows:

$$\frac{4\alpha\theta}{l^2}, Y = \frac{(T_s - t_x)}{(T_s - t_0)}, \frac{1}{Nu} = \frac{2k}{hl}, \frac{2x}{l} (Cylinders)$$

$$\frac{\alpha\theta}{x^2}, Y = \frac{(T_s - t_x)}{(T_s - t_0)}, \frac{k}{hx} (Semi - infinite\ Solids)$$

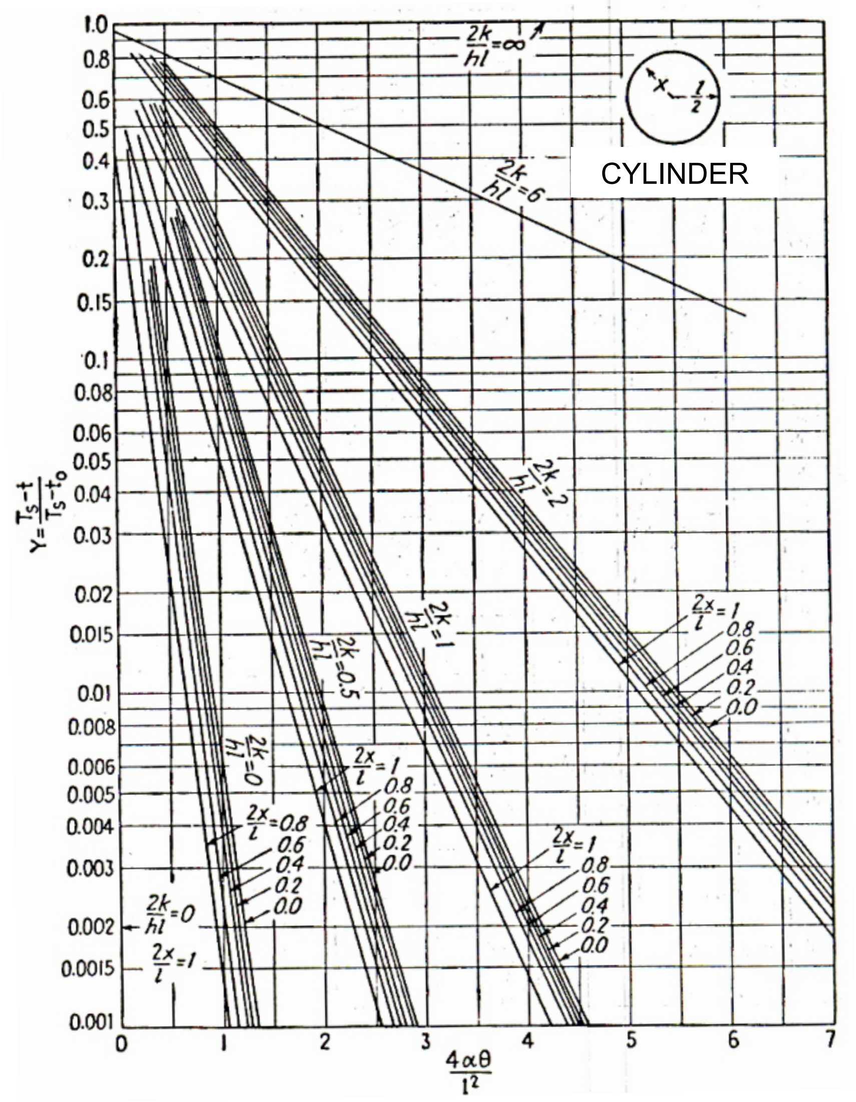
With:

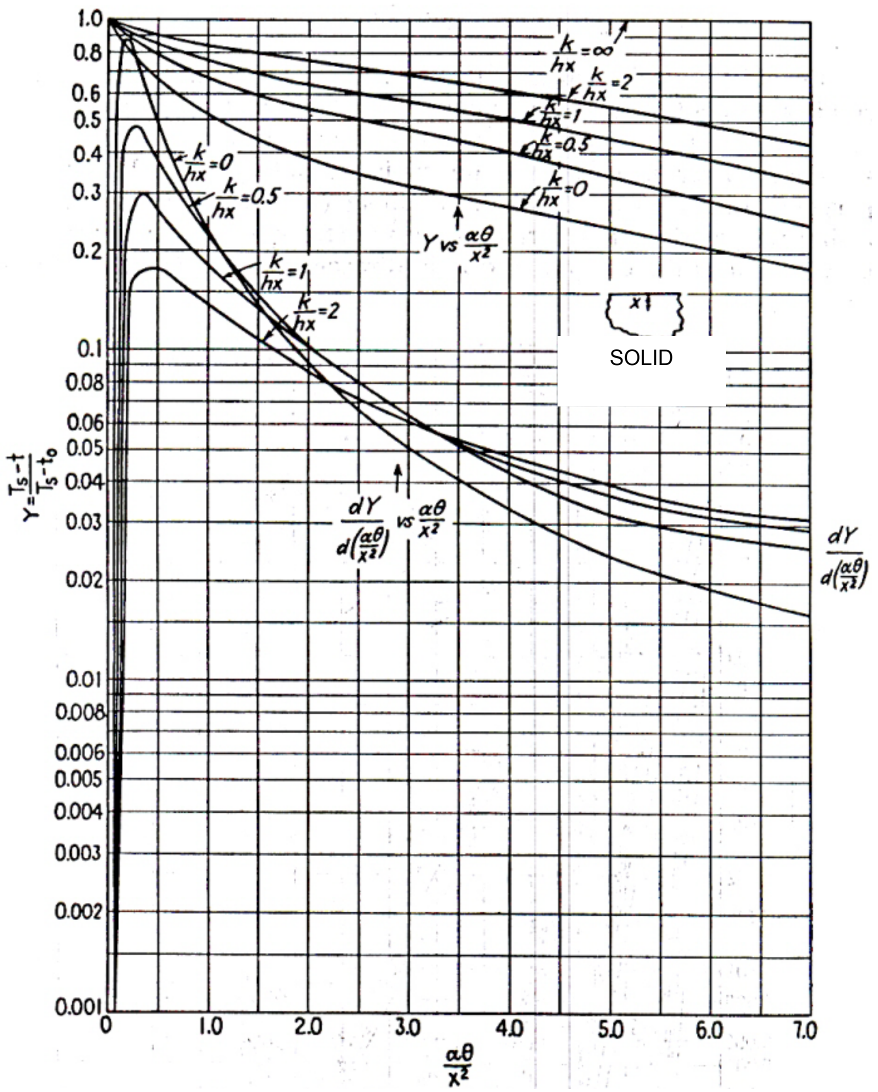
$$\alpha = \frac{k}{C_p \rho}$$

Where:

k	=	Thermal Conductivity [W/m*K]
Cp	=	Heat Capacity [J/kg*K]
ρ	=	Density [kg/m^3]
θ	=	Time [s]
l	=	Depth or Main Diameter [m]
T_s	=	Outside Surface Temperature [°C]
t_0	=	Initial Temperature [°C]
t_x	=	Temperature at Distance x [°C]
h	=	Heat Transfer Coefficient [W/m^2 K]
x	=	Distance Evaluated [m]

Figure 3: Gurney - Lurie charts





5.1.3 Input Data

1. Thermal properties of Kaolite 1600:

   k = 0.173 W/m*K

   Cp = 991.58 J/kg*K

   ρ = 320 kg/m^3

2. Additional data:

   θ = 0 – 10 h = 0 – 36000 s

   l = 0.526 m

   T_s = 900 °C

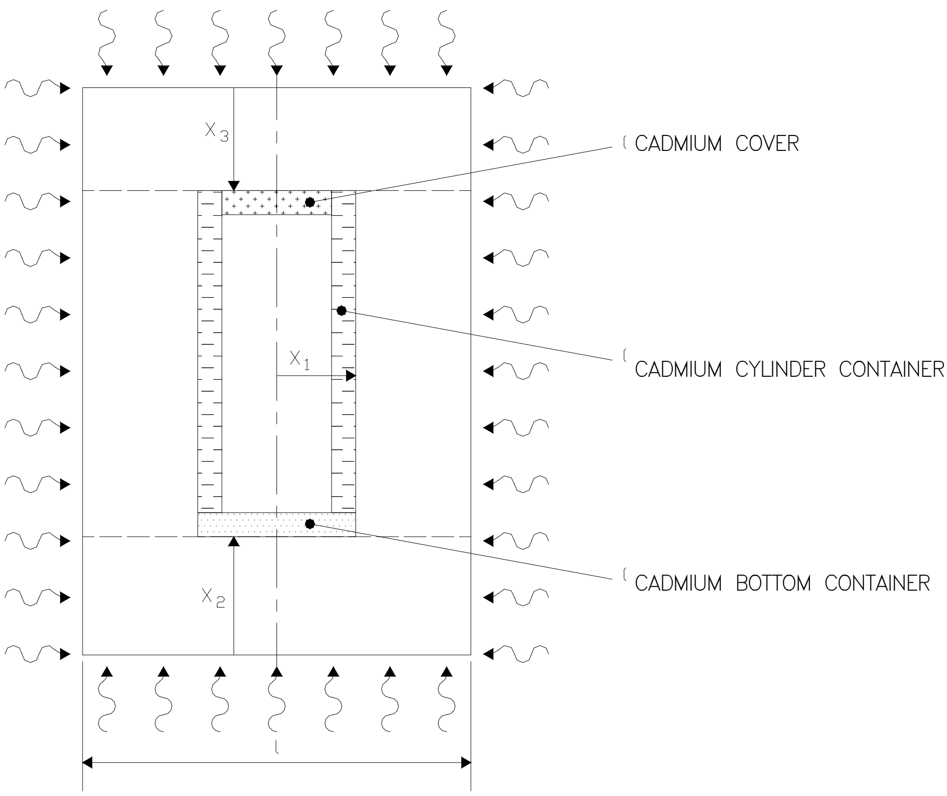
   t_0 = 38 °C

   x_1 = 0.101 m (for the Cd content in the vertical area of the container)

   x_2 = 0.159 m (for the Cd content in the bottom of the container)

x_3 = 0.206 m (for the Cd content in the container cover)

Figure 4: Scheme for the estimate analytical calculation



5.1.4 Results

1. According to the input data, temperature values are calculated for a 10-hour range.
2. The value of α = 5.45 E-7 m^2/s.
3. The values for the different areas with cadmium content are as follows:
   a. Cadmium content in the vertical area of the containerfor a value of$\frac{2x}{l} = 0.38$and $\frac{2k}{hl} = 0.$

Table 1: Data for the vertical area of the container

$\theta\ T\ [h]$	$\theta\ s\ [h]$	$4\alpha\theta/l^2$	Y	t_x[°C]
1	3600	0,028	0,930	98
2	7200	0,057	0,800	210
3	10800	0,085	0,670	322
4	14400	0,114	0,580	400
5	18000	0,142	0,480	486
6	21600	0,170	0,400	555
7	25200	0,199	0,360	590
8	28800	0,227	0,300	641

9	32400	0,255	0,250	685
10	36000	0,284	0,205	723

b. Cadmium content in the bottom of the container for a value of $\frac{k}{hl} = 0$.

Table 2: Data for the bottom of the container

$\boldsymbol{\theta\, T}\ [\boldsymbol{h}]$	$\boldsymbol{\theta\, s}\ [\boldsymbol{h}]$	$\boldsymbol{\alpha\theta}/_{\boldsymbol{x}^2}$	$\boldsymbol{Y}$	$\boldsymbol{t_x}[°C]$
1	3600	0,078	0,916	110
2	7200	0,155	0,848	169
3	10800	0,233	0,792	217
4	14400	0,311	0,744	258
5	18000	0,388	0,704	293
6	21600	0,466	0,668	324
7	25200	0,543	0,637	351
8	28800	0,621	0,609	375
9	32400	0,699	0,585	396
10	36000	0,776	0,563	415

c. Cadmium content in the cover of the container for a value of $\frac{k}{hl} = 0$.

Table 3: Data for the cover of the container

$\boldsymbol{\theta\, T}\ [\boldsymbol{h}]$	$\boldsymbol{\theta\, s}\ [\boldsymbol{h}]$	$\boldsymbol{\alpha\theta}/_{\boldsymbol{x}^2}$	$\boldsymbol{Y}$	$\boldsymbol{t_x}[°C]$
1	3600	0,046	0,948	83
2	7200	0,093	0,902	122
3	10800	0,139	0,862	157
4	14400	0,185	0,826	188
5	18000	0,231	0,793	216
6	21600	0,278	0,764	242
7	25200	0,324	0,737	265
8	28800	0,370	0,713	286
9	32400	0,416	0,690	305
10	36000	0,463	0,670	323

5.2 Simulation Using Finite Elements

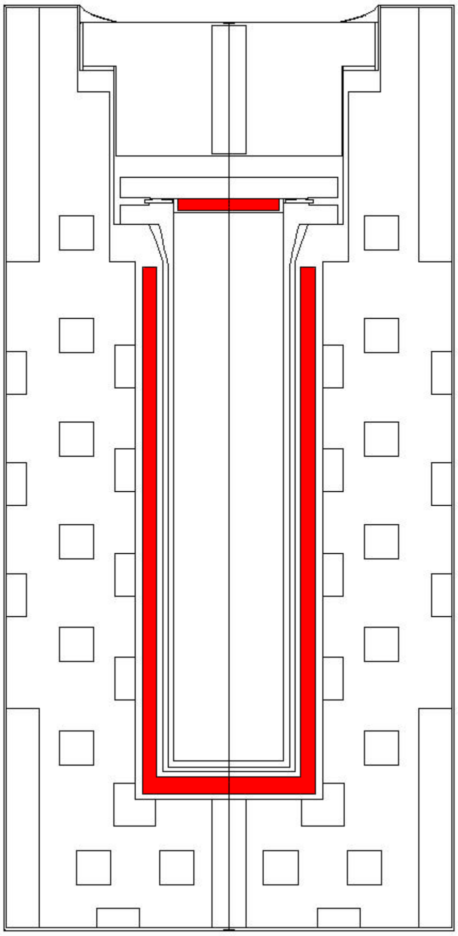
5.2.1 Hypothesis of the Simulation

1. Only one-eighth (1/8) of the actual geometry is simulateddue to the symmetry of the problem.
2. Only conduction heat is considered for the calculation using finite elements.
3. Conservatively, elastomer connections and graphite as steel are considered.
4. The geometry of the model is slightly different from the prototype but not significantly.
5. Air gaps are considered a solid with the thermal properties of air.
6. All prototype thermal bridges are considered.
7. Conservatively, two structural reinforcements (thermal bridges in the case of the simulation) instead of one on the cover filled with Kaolite 1600.
8. 900° C is adopted as the external temperature of the package. This is a conservative value as compared to that set forth by the Standard[1].
9. The cover of the external container and the double bottom do not provide thermal insulation, and therefore are not considered in the simulation; the external cover filled with Kaolite 1600 as well as the inside bottom of the container have a surface temperature of 900 °C as well as the walls of the outside container.
10. The thermal properties of Kaolite 1600 are evaluated in such a way as to make a conservative estimate:
    a. Minor density.
    b. Thermal conductivity varying according to the temperature.
    c. Heat capacity considered as the average of the heat capacity of the components evaluated at 100 °C[3].

5.2.2 Geometry of the Model

1. Below is an outline of the simulated model. The areas colored in red represent cadmium:

Figure 5: Geometry simulated by finite element



5.2.3 Input Data

1. Thermal properties of the compounds used:

Table 4: Thermal properties

Compound	Density [kg/m^3]	Heat Capacity [J/kg*K]	Thermal Conductivity [W/m*K]
Kaolite 1600	320	991.58	0.13082 + 3.571E-9 T
Cadmium	8650	203.362 + 0.09185 T	102.0083 – 0.031202 T
Steel	8030	502.48	16.27
Pseudo Air	0.6 (300 °C)	1006.43	0.002619 + 8.15E-5 T + 9.05E-9 T^2 – 4.87E-12 T^3

2. Temperature of the package surface:

   T_s = 900 °C

3. Initial temperature:

   t_0 = 38 °C

5.2.4 Results

1. Heat transient was simulated every ten (10) hours at one (1) minute intervals.
2. Below are the average and maximum temperature for each interest component after one (1) hour:

   Cadmium content in the container:

   $\bar{T}$ = 73.45 °C

   T_{max} = 79.98 °C

   Cadmium content in the cover of the container:

   $\bar{T}$ = 68.25 °C

   T_{max} = 68.54 °C

   Internal elastomeric gasket:

   $\bar{T}$ = 814.62 °C

   T_{max} = 820.49 °C

   Graphite spiralledgasket:

   $\bar{T}$ = 71.20 °C

   T_{max} = 72.44 °C

3. Below are the graphs of Temperature vs. Time, for the different components, after one (1) hour:

Figure 6: Cadmium content in the container

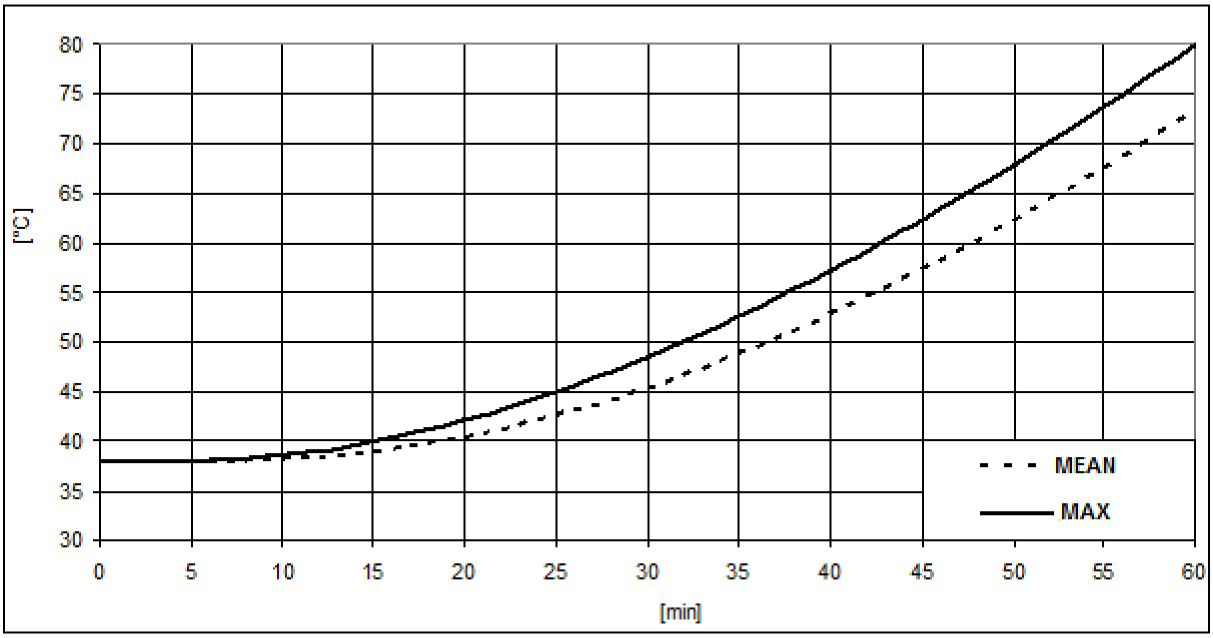


Figure 7: Cadmium content in the cover of the container

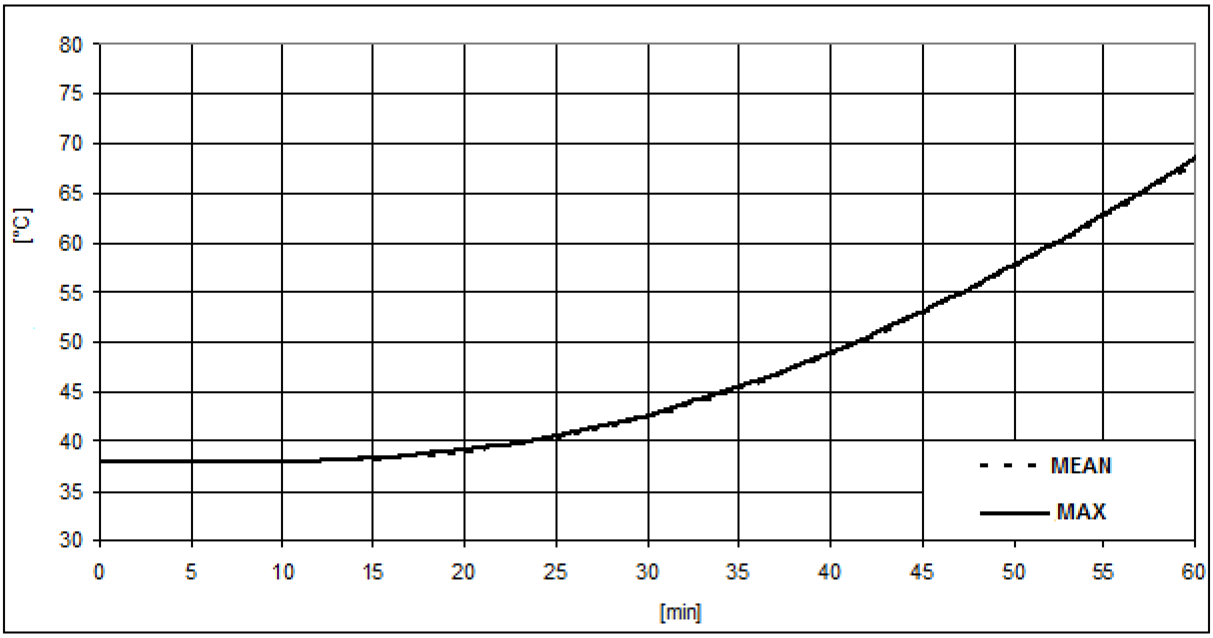


Figure 8: Internal elastomeric gasket

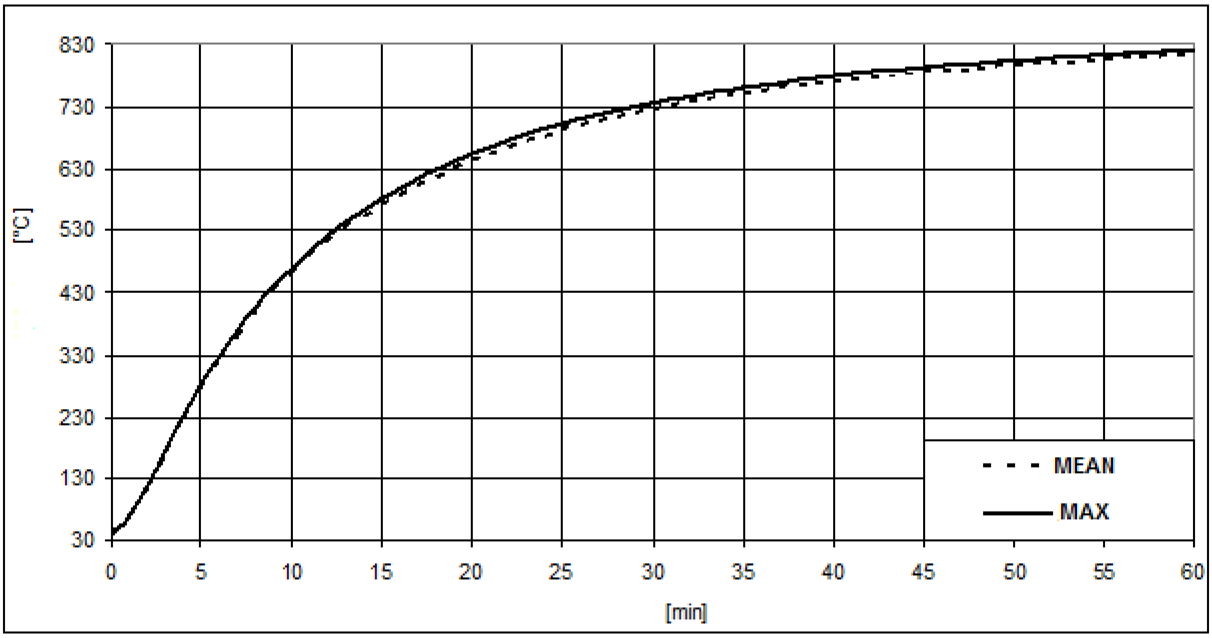
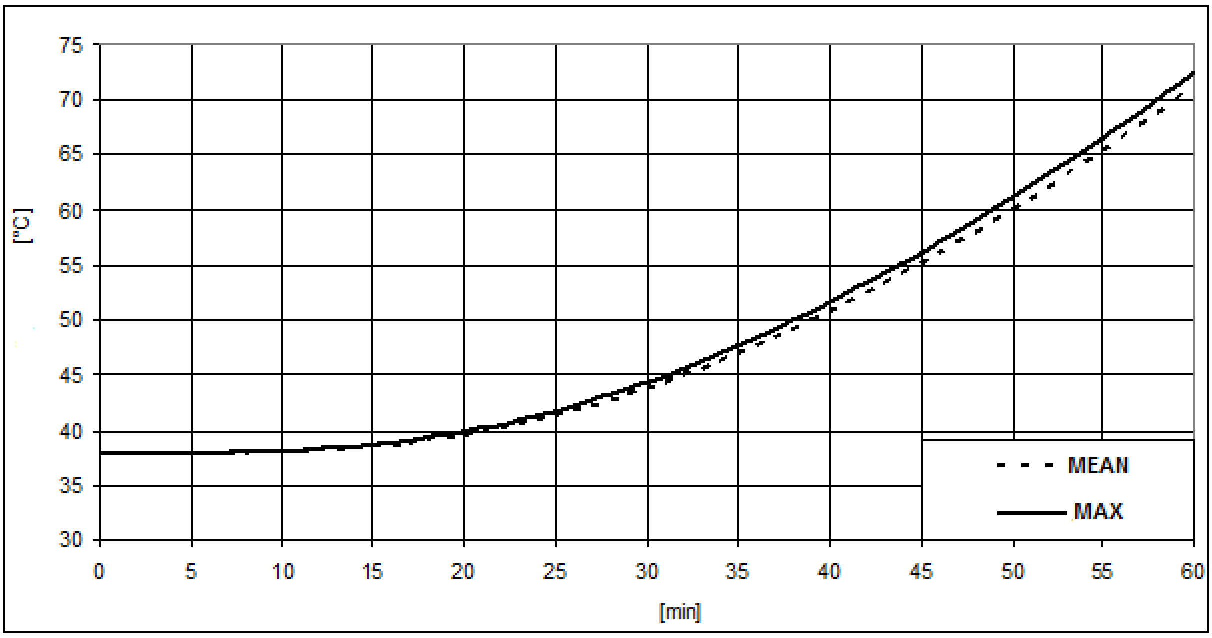
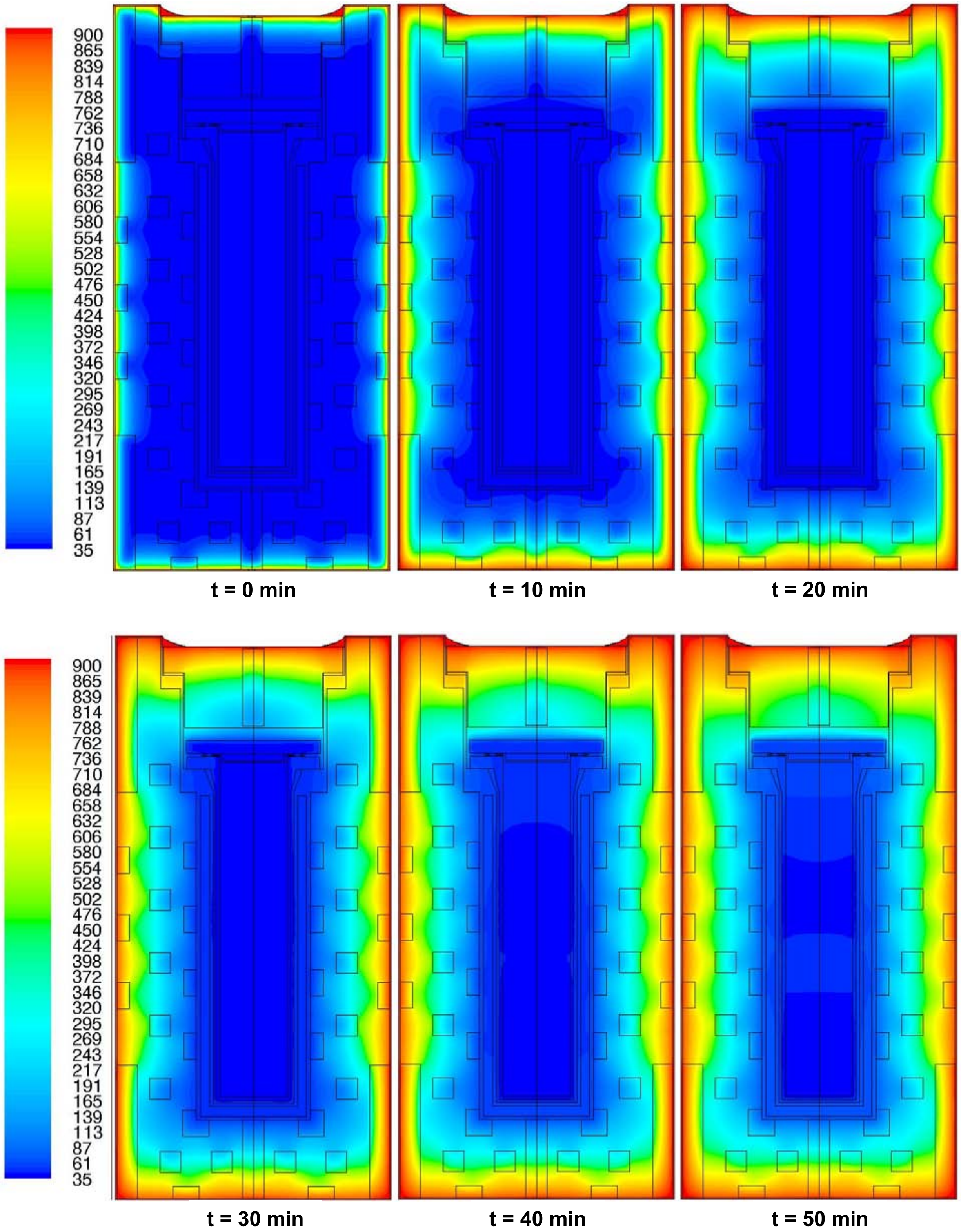


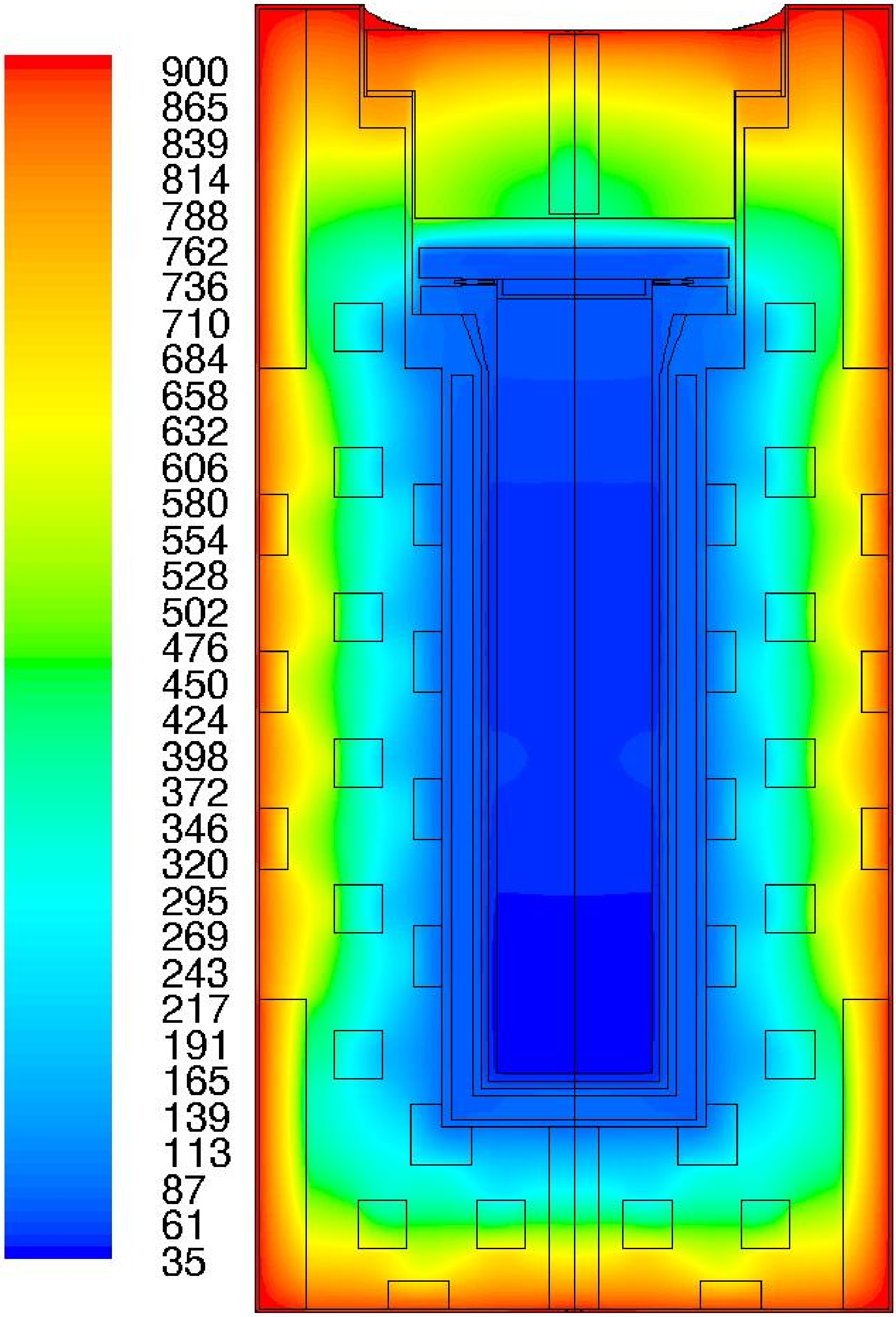
Figure 9: Graphite spiralled gasket



4. Below are profiles of temperature for ten-minute intervals. Temperatures are stated in °C:

Figure 10: Temperature profiles at ten (10) minutes intervals





t = 60 min

5. The results of the simulation in the full span of ten (10) hours are presented in a summarized table:

Table 5: Thermal simulation results

Area	Cd Container		Cd Cover		Graphite Gasket		Elastomer Gasket	
$\theta\ T\ [h]$	$\bar{T}$ [°C]	T_{max}[°C]	$\bar{T}$ [°C]	T_{max}[°C]	$\bar{T}$[°C]	T_{max}[°C]	$\bar{T}$ [°C]	T_{max}[°C]
0	38.0	38.0	38.0	38.0	38.0	38.0	38.0	38.0
1	73.5	80.0	68.3	68.5	71.2	72.4	814.6	820.5
2	159.5	169.8	154.1	154.3	157.8	159.3	855.6	858.9
3	250.0	261.3	246.4	246.6	249.8	251.2	866.9	869.5
4	331.9	342.5	331.0	331.2	334.1	335.1	872.3	874.5
5	404.2	413.6	405.6	405.8	408.2	409.1	876.0	877.9
6	467.6	475.9	470.6	470.8	472.8	473.5	879.1	880.7
7	523.2	530.6	527.1	527.2	529.0	529.5	881.7	883.1
8	571.7	578.3	576.1	576.2	577.7	578.1	884.0	885.3
9	614.0	619.8	618.6	618.7	620.0	620.3	886.0	887.1
10	650.8	655.8	655.3	655.4	656.6	656.9	887.8	888.8

5.3 Comparison of Results

1. Below are the comparisons of the results for the ten-hour period of the temperatures resulting from the scheduled thermal calculation and the thermal simulation using finite elements:

Figure 11: Comparison of cadmium in the vertical area of the container

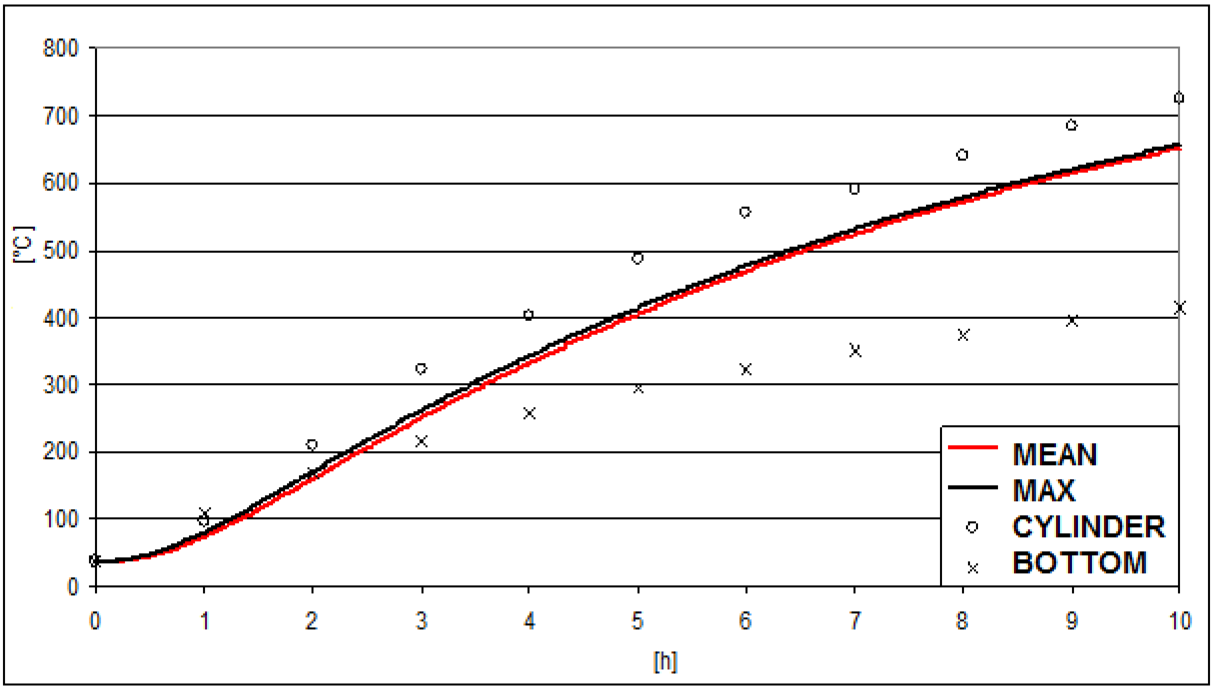
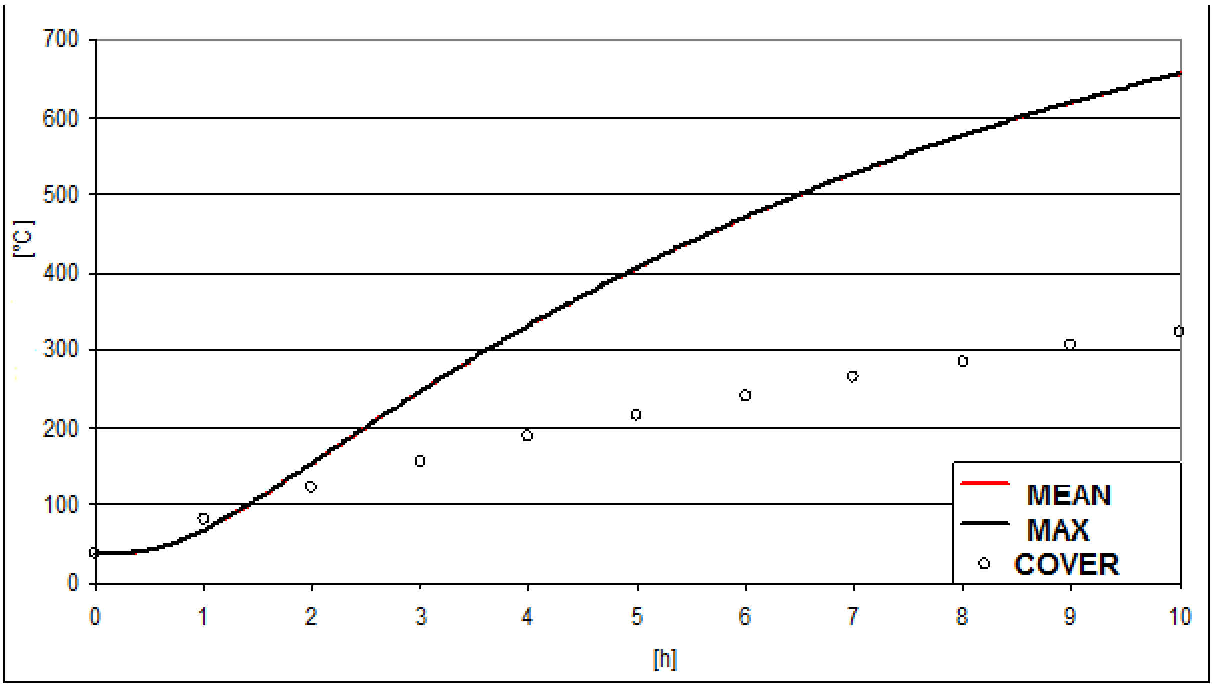


Figure 12: Comparison of cadmium in the cover of the container



2. In the first chart (Figure 11:), representing heating with large periods of exposure of the cadmium content in the container, it is observed that:
   a. The model of finite element predicts a temperature in the bottom which is greater than that calculated by the approximate chart. This may be because the approximate calculation does not provide for the heating from the sides or the thermal bridges.
   b. In the case of cadmium content in the vertical area of the container using finite elements predicts a temperature below that calculated using the approximate graph method. This may be because the estimate does not provide for the heat absorbed by the large metal masses adjacent to cadmium in the vertical area.
3. The second graph (Figure 12:), representing heat with large periods of exposure of the cadmium content in the container cover. It is observed that the model using finite element predicts a temperature much higher than that calculated by the approximate chart method. This is due to the fact that the estimate does not provide for the heating from all sides; even thermal bridges in this case acquire a greater preponderancein the case of cadmium content in the bottom of the container.

6 CONCLUSIONS AND RECOMMENDATIONS

1. No hot spots with temperatures above the melting temperature (320.9 °C) were observed for the Cadmium in the container and the cover. Still it is not recommended to reduce the thickness of thermal insulation to have an appreciable safety margin.
2. No limit temperatures are observed in the graphite spiral connection.
3. It is also recommended to place a ceramic blanket-type concrete disk between the outside of the container cover and the cover filled with Kaolite 1600.
4. Elastomeric connections would be carbonized.
5. If it were necessary to obtain a higher resistance to impacts, it is possible to double the number of radial reinforcements without making a new simulation, since the thermal bridges these would cause have not much influence on radial thermal transfer. A new simulation shall be carried out to make more radical changes.