SAFETY ANALYSIS AND ASSESSMENT OF CONTAINER FOR RADIOACTIVE MATERIAL TRANSPORTATION

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ABSTRACT

According to IAEA «Regulation for the safe transport of radioactive material», some primary stress analysis about the free falling of the container from the height of 1.2m and 9m have been done in this paper by using the ANSYS program. Then the calculation results are assessed according to material strength relative theories.

Keywords: container for radioactive material transportation, drop, safety analysis

1. INTRODUCTION

Hermetically sealed container for radioactive material transportation has been designed by a subsidiary company of NPIC. According to IAEA «Regulation for the safe transport of radioactive material», it is necessary to test the container’s safety (including normal transport condition and accident transport condition) before the containers are used. So, primary safety has been analyzed in this paper.

2. MODELING OF ANALYSIS

2.1 Container structure

The container is a short cylinder vessel. The diameter is 660mm, and it is 920mm high. It is composed of the main body, shield cover, fireproofing cover, fireproofing lid and the base (see figure 1). The lumen’s diameter and tallness is 164mm, 360mm respectively. It is for the transportation of isotope 60Co. The weight of the container is 3500kg. It is designed according to transportation standard III of GB11806 of China. That means the dose equivalent rate of exterior surface of the container will not be allowed to exceed 2mSv/h.

The main body is made of different thickness steel plates, which are made of 1Cr18Ni9Ti. The thickness of exterior shell, inside shell, top plate, and base plate are 6mm, 5mm, 30mm, and 20mm respectively. The space between the exterior shell and inside shell is full filled with lead. The thickness of lead is 245mm. The heat-transferring sheets are distributed equally around the exterior shell. The shield cover is also made of steel plate and is filled with lead to prevent radioactivity from revealing. The fireproofing cover is made of steel plates and is filled with heat insulation material. The base is made of angle iron with equal sides.

2.2 Models for analysis

In this job, the most important thing that we should take care of is the destruction of container. The mathematic model is composed of element solid 164 and element shell163. The total number of nodes is 4061, and the total number of elements is 14550, see figure 2.

2.3 Boundary and loads conditions

In this analysis, the target plate is assumed rigid entirely, and the container free falls to the target plate, ignoring the effect of air resistance.

2.4 The properties of materials

The materials in this analysis include 1Cr18Ni9Ti, Pb-6, 2Cr13. The materials mechanical properties of those can be seen in table 1. The Bilinear Kinematics was chosen as the material mode in the analysis. The static friction coefficient is 0.25; the dynamic friction coefficient is 0.2.
Table 1 the characteristic of materials

<table>
<thead>
<tr>
<th>Materials</th>
<th>1Cr18Ni9Ti</th>
<th>Pb-6</th>
<th>2Cr13</th>
</tr>
</thead>
<tbody>
<tr>
<td>ρ (kg/m³)</td>
<td>7920</td>
<td>11340</td>
<td>7750</td>
</tr>
<tr>
<td>E (MPa)</td>
<td>1.84×10⁵</td>
<td>16.68×10³</td>
<td>2.23×10⁵</td>
</tr>
<tr>
<td>µ</td>
<td>0.243</td>
<td>0.42</td>
<td>0.297</td>
</tr>
<tr>
<td>σ₀ (MPa)</td>
<td>382</td>
<td>4.6</td>
<td>563</td>
</tr>
<tr>
<td>σₘ (MPa)</td>
<td>637</td>
<td>23.3</td>
<td>747</td>
</tr>
<tr>
<td>δ (%)</td>
<td>69</td>
<td>48</td>
<td>22</td>
</tr>
</tbody>
</table>

3 CONTENTS OF ANALYSIS

- Free falling from the height of 1.2m: Container falls freely to the target plate from the height of 1.2m in 5 cases, case 1, the bottom of a container impacting target plate; case 2, the top of a container impacting target plate; case 3, the side surface of a container impacting target plate; case 4, the bottom of a container impacting target plate aslant with 45 degrees; case 5, the top of container impacting the target plate aslant with 45 degrees.
- Free falling from the height of 9m: Container falls freely to the target plate from the height of 9m in 5 cases, as mentioned above.

The analysis for the free falling of the container from the height of 1.2m and 9m were done using LS-DYNA module of ANSYS program.

4 STRENGTH LIMITATIONS

At present, there is no relative criterion for drop analysis, so the calculation results are assessed according to material strength correlative theories:

- the main body of the container(1Cr18Ni9Ti): Adopting plastic strain limitations, that is, the maximum plastic strain will not be allowed to exceed δ of its material.
- Bolts(2Cr13): Adopting extremum stress limitation, refer to <criterion of the manufacture of national defense warship in Germany>, it is said that the bolts will suffer the tensile force, bending loads and shearing force, the comparative stress \( \sigma_v = \sqrt{\sigma^2 + 3 \cdot \tau^2} \), and \( \sigma \) represents the normal stress, \( \tau \) represents shearing stress. Comparative stress \( \sigma_v \) will not be allowed to exceed static yield limitation. But in this paper, we use the strength limitation instead of static yield limitation, because we just take that whether the radioactive material will be leaked as a result of the destruction of the container or not into account.

Generally, the strength of material will be enhanced greatly in impacting condition. Because there is not any information about the characteristic of 2Cr13 in impacting condition, so we conclude the strength limitation (in impacting condition) of it conservatively according to the close material of 2Cr13, see table 2.

Table 2 the strength limitation of material

<table>
<thead>
<tr>
<th>Materials</th>
<th>Impacting condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 steel</td>
<td>1667</td>
</tr>
<tr>
<td>40 steel</td>
<td>1800</td>
</tr>
<tr>
<td>2Cr13</td>
<td>≥ 1800</td>
</tr>
</tbody>
</table>

5 THE CALCULATION RESULTS AND SAFETY ASSESSMENT

5.1 Analysis of falling from the height of 1.2m

The container falls freely to the target plate from the height of 1.2m, and the target plate is rigid. The results can be seen from table 3 and figures 3~7 (the data in table 3 reveal the main body of container’ strain results which has been get rid of the base, the fireproofing cover, the heat transferring sheets and the fireproofing lid, while those in figures 3~7 represent the whole container’s strain results. So if the maximum strain doesn’t occur at the main body of container, the data in figures will be different from those in table 3. For example, in the case of case 2, the maximum plastic strain of main body is 0.159, while that of total container is 0.507, which occur at the fireproofing lid).
It can be seen from the results, the maximum plastic strain is 0.235, which occur in the case 1. It is less than the material plastic strain limitation, so the container is safe enough. The maximum stress is 442 MPa, which is also less than material strength limitation.

8 bolts of M16 connect the shield cover and the container tightly. So it is necessary to do some strength assessment for these bolts. The shield cover is embedded in the top plate of the container; so the bolts just suffer tensile stress. We acquire the relative acceleration between the shield cover and the main body of the container, then, the tensile stress, which the bolts suffered, is: \( \sigma = \frac{ma}{A} \) (see table 4).

\( m \) — mass of shield cover, \( A \) — the section area

It can be seen from table 4, the maximum tensile stress is 263.02 MPa, which occur in the case 4. It is less than the material strength limitation, so the bolts are safe enough (in this paper, the acceleration curve of angle \( \theta \) was shown, see figure 8).

### Table 4 the tensile stress of bolts

<table>
<thead>
<tr>
<th>Cases</th>
<th>Acceleration (m/s(^2))</th>
<th>Tensile stress (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1095.92</td>
<td>77.7</td>
</tr>
<tr>
<td>2</td>
<td>1198.42</td>
<td>84.9</td>
</tr>
<tr>
<td>3</td>
<td>2372.20</td>
<td>168.13</td>
</tr>
<tr>
<td>4</td>
<td>3711.14</td>
<td>263.02</td>
</tr>
</tbody>
</table>

#### 5.2 Analysis of falling from the height of 9m

The container fall freely to the target plate from the height of 9m, and the target plate is rigid plane. The results can be seen from table 5 and figures 9–13 (Some data in table 5 are different from those in figures 9–13. The reasons of that are same with the 1.2m.)

It can be seen from the results, the maximum plastic strain is 0.494, which occur in the case 4. It is less than the material plastic strain limitation, the maximum plastic strain of total container is 0.600 (see figure 12), and so the container is safe enough.

It is necessary to do some strength assess of these bolts also. The shield cover is embedded in top plate of the container; so the bolts just suffer tensile stress. We acquire the relative acceleration between the shield cover and the main body of the container, then, the tensile stress, which the bolts suffer, is: \( \sigma = \frac{ma}{A} \) (see table 6).

It can be seen from table 6, the maximum tensile stress is 424.87 MPa, which occur in the case of case 5. It is less than the material strength limitation, so the bolts are safe enough.
Table 6 the tensile stress of bolts

<table>
<thead>
<tr>
<th>Cases</th>
<th>Acceleration (m/s²)</th>
<th>Tensile stress (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1755.94</td>
<td>124.45</td>
</tr>
<tr>
<td>2</td>
<td>5740.53</td>
<td>406.85</td>
</tr>
<tr>
<td>3</td>
<td>5590.25</td>
<td>396.20</td>
</tr>
<tr>
<td>4</td>
<td>5990.29</td>
<td>424.55</td>
</tr>
</tbody>
</table>

6. CONCLUSION
In this paper, some drop analysis has been done to the container according to “Regulation for the safe transport of radioactive material”.

According to the results, the maximum plastic strain is 0.507, which is less than the material plastic strain limitation; the maximum stress is 494 MPa, which is less than the material strength limitation. So, the container is safe enough. But, some external components (such as the fireproofing cover and the fireproofing lid) of the container would be destroyed. The maximum tensile stress of bolts is 424.87 MPa, which is less than the bolts material strength limitation; the bolts will be safe enough.

REFERENCE
[1] Regulation for the safe transport of radioactive material (GB11806 OF CHINA), 1989
[3] Leonard, E.Schwer, And A Validation Case Study: Steel Billet Drop Tests and Simulations as Reported in NUREG/Cr-6608, 1999
Fig. 5. The maximum plastic strain of 1.2m falling (case 3)

Fig. 6. The maximum plastic strain of 1.2m falling (case 4)

Fig. 7. The maximum plastic strain of 1.2m falling (case 5)

Fig. 8. The normal acceleration between the shield cover and the container of 1.2m falling (case 4)

Fig. 9. The maximum plastic strain of 9m falling (case 1)

Fig. 10. The maximum plastic strain of 9m falling (case 2)

Fig. 11. The maximum plastic strain of 9m falling (case 3)

Fig. 12. The maximum plastic strain of 9m falling (case 4)
Fig. 13. The maximum plastic strain of 9m falling (case 5)

Fig. 14. The normal acceleration between the shield cover and the container of 9m falling (case 1)

Fig. 15. The normal acceleration between the shield cover and the container of 9m falling (case 2)

Fig. 16. The normal acceleration between the shield cover and the container of 9m falling (case 3)

Fig. 17. The normal acceleration between the shield cover and the container of 9m falling (case 4)

Fig. 18. The normal acceleration between the shield cover and the container of 9m falling (case 5)