Developing a new transportation container for irradiation source

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Abstract. China Institute for Radiation Protection (CIRP) was commissioned the work of developing FCTC10 container. FCTC10 container is designed to transport $^{60}$Co special form radioactive sources used in irradiation industry. With a loading of $6.7 \times 10^{15}$ Bq, the package is a Type B(U). The dynamic finite element analyses were performed. The structural integrity of the transport package was evaluated considering the hypothetical accident condition conditions include 9 m free drop on rigid surface (drop I). Several candidate drop postures, including top over-the-corner drop, side drop and top drop, which are known to cause the most severe damages to the packages of cylindrical shape in most cases. It is shown that the posture of top over-the-corner for 9 m free drop is the most damaging posture, and the posture is chosen as the best experiment program in the following physical experiment of real package. And also the simulation results of deformation of a whole or a part of the package play a guiding role in the optimal design and experiment of container.

1. Background

With the rapid development of nuclear technology in industrial application, irradiation process is applied widely in various fields, such as medical disinfection and sterilization, food preservation, radiation chemical engineering, breeding, environment treatment, etc. Up to now, there are more than 200 large-scale γ irradiation facility with a total activity of more than $7.4 \times 10^{18}$ Bq. In the US, irradiation sterilization facilities with an activity of about $3.7 \times 10^{15}$ Bq were designed and constructed. In China, approximately 200 irradiation facilities were constructed, of which more than 100 facilities were designed to use sources of above $1.1 \times 10^{16}$ Bq, while more than 40 facilities use sources of above $3.7 \times 10^{16}$ Bq. Designed capacity of source loading is more than $3.7 \times 10^{15}$ Bq, and the actual loading is about $1.3 \times 10^{18}$ Bq [1, 2].

$^{60}$Co is a common used industrial irradiation source. At present, the activity of a $^{60}$Co source used in the large-scale irradiation facility is about $3.0 \times 10^{14}$ to $5.2 \times 10^{14}$ Bq, which is Category I source specified in GB11806, and the transport contender loading such a source is Type B package, accordingly. FCTC10 container with a loading of $6.7 \times 10^{15}$ Bq $^{60}$Co source is a Type B(U), Category III (yellow) package [3, 4].

2. Structure of FCTC10 container

As shown in Figure 1, the container consists of shielding container, hanging basket, protective cover and bracket. Shielding container comprises inner container, lead plug, heat insulation, shock absorber. From inside out, the container includes 10 mm inner stainless steel (06Cr19Ni10) shell, tungsten alloy bucket, protective cover, lead filling, and 16 mm outer stainless steel (06Cr19Ni10) shell. All 36 are
distributed on the container and welted with the container itself; the bolt M24 is used for connecting the stiffened plates and the heat insulation cover, the shock absorb set between the heat insulation cover and lead plug; the bolt M10 is used for connecting the positioning flange and platen, the bolt M24 used for connecting the lead plug and container; heat insulation is connected with 4 plates, and fixed with bolt M24; heat insulation cover is also connected with 4 plates, and fixed with bolt M24. The total mass of package is approximately 5,100kg. According to GB11806, it is a Type B(U), Category III (yellow) package. The design container itself is based on ASME Boiler & Pressure Vessel Code Sec. III Div.3.

![Figure 1. Structure of FCTC10 transport container.](image1)

3. The model of finite elements

3.1. Distribution of finite element grids
With the complex package structure and a large number of components and parts, the package has to be simplified properly. The dowel and drainpipes have little impact on the performance of structural mechanics so that the process of building the model will neglect them.

As shown in Figure 2, in order to guarantee the accuracy and efficiency of calculation, 8 node hexahedron elements with linear C3D8R and SD4 quadrilateral shell elements are used in the package. Due to the irregular shape of heat insulation cover shell, it is difficult to build regular grids. As a result, the cover shell is built outside the heat shielding for replacing the heat insulation cover shell so that the penetration phenomenon can be solved during the process of calculation. The total element number of the whole model is 164,531, the total node number 247,574. In order to avoid the initial permeation and increase the calculating accuracy the grids will be refined in the relative area.

![Figure 2. E model of finite elements for package.](image2)
3.2. Materials
Mechanical parameters of all materials for the model package are shown in Table 1.

Table 1. Composition of the container components.

| Material                 | Density /g cm⁻³ | Yield Stress/MPa | Elastic Modulus/GPa | Poisson’s Ratio | Tensile Stress/MPa |
|-------------------------|-----------------|------------------|--------------------|----------------|-------------------|
| 06Cr19Ni10              | 7.93            | 205              | 195                | 0.3            | 520               |
| 0Cr17Ni12Mo2            | 8               | 205              | 201                | 0.3            | 520               |
| 05cr17Ni4CuNb           | 7.78            | 1000             | 206                | 0.3            | 1070              |
| lead                    | 11.37           | 4.4              | 15.72              | 0.4            |                   |
| Tungsten alloy          | 11.75           | 517              | 360                | 0.285          | 724               |

3.3. Postures for 9 m drop
According to the container structure, as a kind of protection, the package bottom is the base plate made of steel plates. When the package bottom or the package base angle drops, the shock to the container won’t matter. Thus, here are only 3 postures of the container falling on the ground.

1) Top over-the-corner drop: Regarding the intermediate point of the base plate of the heat insulation as the shock point, the line between the shock point and the barycenter of the package is perpendicular to the target surface and the included angle between the axis of package and the target surface is 57.5°.

2) Side drop: The outer surface of heat insulation touches the target surface, and the line between the contact point and the barycenter is perpendicular to the target surface.

3) Top drop: the top of the heat insulation parallels the target surface and the shock point is the top of the heat insulation.

Figure 3. The stress and deformation of top over-the-corner drop.

4. Simulation results and analysis

4.1. Stresses and deformation

4.1.1. Top over-the-corner drop. As illustrated in Figure 3, the largest number of TRESCA stress intention is 1.6GPa, which is at the Bolt M10, and the nearest 6 Bolt M10s are in yield stress and ruined. The largest number of Equivalent plasticity of outer container and lead plug shell is 0.175. The
whole impact area of package causes serious plastic deformation. 9 plates are badly deformed around the shock point, the heat insulation cover shell around the shock point warping with a range of 90 degrees, the height of deformation along the axis 55mm, the shoulder of heat insulation, which met with target surface, warping seriously.

4.1.2. Side drop. As shown in Figure 4, after the heat insulation touches the target surface, the largest number of package TRESCA stress intention is 1.262 GPa, which is at the shocked bolt connecting the plates and the heat insulation. The largest number of Equivalent plasticity of outer container and lead plug shell becomes 0.24. The impact area of package causes plastic deformation, 6 plates in the area deformed seriously, the impact area of heat insulation being pressed and concave, the amount of deformation 54mm, the range of deformation along the circumferential angle 70 degrees, the contact area of heat insulation and plates also deformed seriously.

Figure 4. The stress and deformation of side drop.

Figure 5. The stress and deformation of top drop.
4.1.3. Top drop. As shown in Figure 5, after the top of heat insulation cover touches the target surface, the largest number of package TRESCA stress intention is 1.368GPa, which is at the shocked bolt connecting the plate and the heat insulation cover. The largest number of bolt M24 TRESCA stress is 1.02GPa, which is at the nut and the bolt here is still in force. The largest number of Equivalent plasticity of outer container and lead plug shell becomes 0.218, which is at the lead plug that touches the heat insulation cover. The heat insulation cover is pressed and flat, the shock absorber and hanging basket deformed badly. The plate is deformed seriously due to the direct touch with the target surface.

In a word, when the package falls on rigid surface for 9m in 3 postures, the plate, heat insulation cover and shock absorber are deformed seriously and they absorb a majority of energy to reduce the shock from the outside environment to the package container itself.

4.2. Results analysis
We obtain the evaluating result of package safety according to the ASME Boiler & Pressure Vessel Code Sec. III Div.3. Table 2 collects the Primary membrane($P_m$) stress and Primary stresses($P_m+P_b$) of the inner shell, Average axial stress($\sigma_m$) and Average shear stress($\tau_m$) of the bolt M24. According to the figure, the package meets the requirements of the design criteria, and the safety of package design is verified [5, 6].

| Postures          | The stresses of the inner shell /MPa | Plastic strain | The stresses of the bolt M24/MPa |
|-------------------|------------------------------------|----------------|---------------------------------|
|                   | Stress criteria                    |                |                                 |
|                   | Primary membrane($P_m$)            | 328            | Average axial stress($\sigma_m$) |
|                   | Primary membrane+bending($P_m+P_b$)| 493            | Average shear stress($\tau_m$)  |
| top over-the-corner drop | $P_m$                          | 151            | $\sigma_m$                      |
|                   | $P_m+P_b$                         | 154.9          | $\tau_m$                       |
| Side top          | $P_m$                            | 96.8           | $\sigma_m$                      |
|                   | $P_m+P_b$                         | 97.6           | $\tau_m$                       |
| Top drop          | $P_m$                            | 71.1           | $\sigma_m$                      |
|                   | $P_m+P_b$                         | 71.1           | $\tau_m$                       |

5. Conclusions
FCTC10 container is designed to transport $^{60}$Co special form radioactive sources used in irradiation industry. With a loading of $6.7 \times 10^{15}$ Bq, the package is a Type B(U). The dynamic finite element analyses were performed. The structural integrity of the transport package was evaluated considering the hypothetical accident condition conditions include 9 m free drop on rigid surface (drop I). The numerical simulation that package fall on the ground for 9m in 3 postures under the accidental conditions shows that the posture of top drop causes the most serious damage, and this indicates that the posture of top over-the-corner drop is chosen as the best experiment program in the following physical experiment of real package.

1) adopting the finite elements calculation for the impact situation of the transportation container for irradiation source under the accidental conditions to provide important gauge for the safety evaluation of package

2) the deformation and the stress of the bolt M24 which fixes the lead plug and the container does not exceed the allowable value, and so does the deformation and the stress of the container itself. It ensures the containment and safety of the package.
3) the simulation results of deformation of a whole or a part of the package play a guiding role in the optimal design and experiment of container for irradiation source.

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