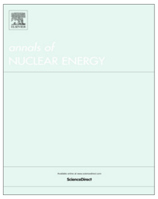
Annals of Nuclear Energy 105 (2017) 240–248

Contents lists available at ScienceDirect

Annals of Nuclear Energy

journal homepage: www.elsevier.com/locate/anucene



Performance of Gamma Chamber under blast loading

D.K. Sahoo [a,*], P. Dewan [a], P. Srivastava [a], A.K. Kohli [a], I.P.S. Sandhu [b], Rajesh Kumari [b], D.R. Saroha [b], Anirban Guha [c], Asim Tewari [c], R.K. Singh [d]

[a] Board of Radiation and Isotope Technology, BRIT-BARC Complex, Sector 20, Vashi, Navi Mumbai 400703, India
[b] Terminal Ballistics Research Laboratory, DRDO, Ministry of Defence, Sector 30, Chandigarh, India
[c] Department of Mechanical Engineering, Indian Institute of Technology, Powai, Mumbai 400076, India
[d] Bhabha Atomic Research Centre, Trombay, Mumbai 400085, India

ARTICLE INFO

Article history:
Received 30 March 2016
Received in revised form 24 February 2017
Accepted 6 March 2017
Available online 21 March 2017

Keywords:
Gamma Chamber
Containment
Blast loading
Structural integrity

ABSTRACT

Gamma Chambers carrying radioactive source are transported in public domain and in addition are also used in various research laboratories and industries and hence the associated security concerns are important. With increase in global terrorism, these devices can potentially be targeted. Hence, it is imperative to study the performance of Gamma Chambers under blast loading. Numerical simulations were carried out using finite element analysis and later verified by experimental tests. There is a good agreement between the simulated and experimental results. The results show that there is hardly any damage to the containment of the Gamma Chamber under blast loading of 10 kg TNT equivalent charge at 1 m stand-off distance from the surface of the Gamma Chamber. However, components in the lower part of the Gamma Chamber get deformed exposing lead when 10 kg TNT equivalent charge is detonated below the main body of the Gamma Chamber. Post blast microstructure study was carried out to know the mode of fracture. It is concluded that the Gamma Chamber maintains its structural and shielding integrity under the conditions simulated in this experiment.

1. Introduction

Board of Radiation and Isotope Technology (BRIT), India, is dedicated to application of radiation and radioisotope in industry, healthcare and agriculture. BRIT has designed various laboratory research irradiators such as Gamma Chamber – 5000 (GC 5000), GC 1200, GC 900 for various applications in food preservation, mutation breeding, radiobiology, radiochemistry, sterile insect technique, studies in biological and genetic effects of radiation, radiation sterilization etc. The Gamma Chambers are designed to meet various national and international standards such as American National Standards Institute (ANSI) – N433A-1997 ANSI, 1977 and International Atomic Energy Agency (IAEA) TS-R-1 Regulations for the Safe Transport of Radioactive Material, 1985; Regulations for the Safe Transport of Radioactive Material, 2009; Safe Transport of Radioactive Material, 2016. Fig. 1 shows the sectional view of a typical Gamma Chamber. These Gamma Chambers are self-shielded in which lead, encased in AISI SS304L steel or mild steel, is used as a shielding material to keep the radiation levels within limits. The cask holds the source cage in which Co^{60} radioactive sources are arranged in a circular manner for delivering the radiation dose. The drawer which is provided with a cylindrical sample chamber moves up and down inside the cask by a mechanical drive arrangement for loading and unloading of the samples.

BRIT has supplied many such Gamma Chambers to different research institutes and laboratories across the world. These are transported by road to various parts of the country. Since these Gamma Chambers are provided with normal security arrangements, these can potentially be targeted by persons with malafide intentions. If any blast happens near the container, there is risk of radioactive material getting uncovered and the persons near the Gamma Chamber can get exposed to radiation. Hence, it is prudent that these containers should be able to resist the dynamic loading caused by a blast to prevent radiation exposure to general public.

Different postulated blast scenarios that can create a potential threat to the integrity of the cask are visualized. The Gamma Chambers containing radioactive sources are transported by road to reach the consignee where it is installed for its use. During its travel it goes through public domain in plains, hill areas and tunnels etc. One of the possible threats that can be visualized is during transportation of Gamma Chamber from consigner to consignee. The person with malafide intentions can hide the explosive on the ground or near the walls of the tunnel which are approximately

---

* Corresponding author.
E-mail address: dksahoo@britatom.gov.in (D.K. Sahoo).

http://dx.doi.org/10.1016/j.anucene.2017.03.015
0306-4549/© 2017 Elsevier Ltd. All rights reserved.

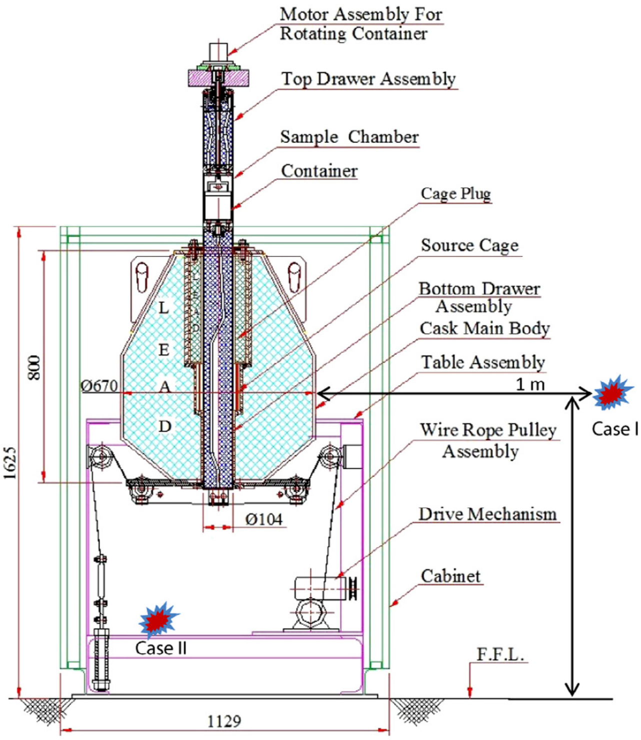


Fig. 1. Sectional View of Typical Gamma Chamber with major dimensions in millimeter.

1 m from the truck bed. Another possible threat is during its installed condition at the consignee's site. The most likely place is to hide it below the cask's main body where space is available. Hence, two cases were studied as shown in Fig. 1.

Case I: Transportation condition where the charge is assumed to be kept at a stand-off distance of 1 m and for the worst scenario the height is fixed in such a way that the blast is in front of the source cage

Case II: Installed condition where the charge is assumed to be kept under the cask's main body.

It has been noticed that in most of the blasts which occur in public domain 5 to 10 kg of TNT equivalent charge has been used. A person can carry this much amount of charge with ease and also this amount of charge can lead to substantial damage. Hence, 10 kg of TNT equivalent charge is chosen for the analysis under postulated blast loading. The paper presents simulations of these conditions using Finite Element Analysis (FEA) and experimental tests to verify the results.

2. Numerical simulation

2.1. Finite element modelling

The finite element model of the Gamma Chamber was made using Abaqus® (Theory Manual by Dassault Systems., 2011) and is shown in Fig. 2. The entire structure of the Gamma Chamber is discretized using 2D shell and tetrahedral brick elements. All the plate structures such as outer shell, inner shell and channels which are less than 12 mm thickness are modeled as shell element using 4 noded S4R elements with 5 integration points along the thickness. Thick plates of steel and lead are modeled using C3D8R, an 8-noded linear brick element with reduced integration. All bolted joints are modeled using solid elements.

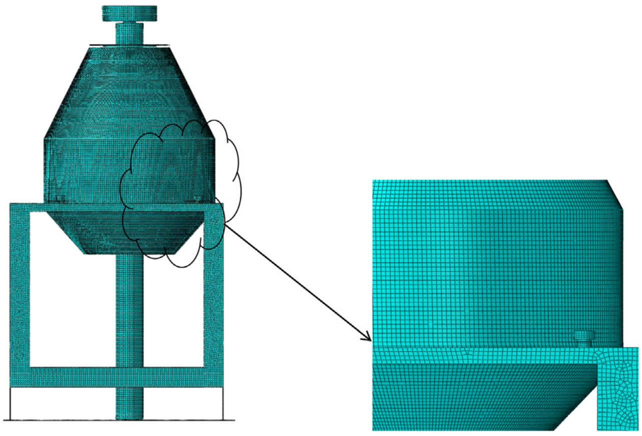


Fig. 2. Finite element model of Gamma Chamber.

Explicit finite element method is used for the analysis. The governing equations of the motion of the body are solved using explicit central difference integration method. Explicit methods are conditionally stable. Smaller element size will reduce the time step and increase the computer processing time with better numerical accuracy. Considering the large size of the model, finer mesh is considered at critical locations such as bottom part of duplex plug and outer shell and coarse mesh is used to mesh the lead present in the cask's main body. A total of 173138 elements and 185829 nodes are used in the mesh. An initial time step of 2×10^{-7} is used for the analysis.

2.2. Material model

Shock waves generated by the explosion of high explosive charge causes high rate of loading. The strain rates expected are very high of the order $10^4\ \mathrm{s}^{-1}$–$10^6\ \mathrm{s}^{-1}$ affecting material properties. Johnson Cook material model (Johnson et al., 1983) which is widely used for dynamic loading is employed in the analysis for steel. The equation is given by

$$\sigma = [A + B\varepsilon^n][1 + C\ln\dot{\varepsilon}^*][1 - T^{*m}] \tag{1}$$

where, $\boldsymbol{\sigma}$ = equivalent Von-Mises yield stress; $\boldsymbol{e}$ = equivalent plastic strain; $\dot{\varepsilon}^*$ = dimensionless plastic strain rate$(\dot{\varepsilon}/\dot{\varepsilon}_0)$ for $\dot{\varepsilon}_0 = 1s^{-1}$; *A, B, n, C and m* = material constant.

$$T^{*m} = \frac{T - T_{room}}{T - T_{ref}} \tag{2}$$

The first part of the equation represents the effect of strain hardening. The second part represents the effect of strain rate and the third part represents the effect of temperature. Tables 1 and 2 give the material properties of mild steel and lead used for the analysis respectively. It was also assumed that the materials fail when the effective plastic strain reaches the tensile failure strain in a quasi-static tension test. The failure strain for mild steel plates ($\boldsymbol{e_f}$ = 20%) and for lead ($\boldsymbol{e_f}$ = 40%) was considered. At these effective plastic strain levels of 20% and 40% for mild steel and lead respectively, the material loses all its strength and the element is deleted automatically from the analysis. This element is thereafter not considered in the calculation.

2.3. Blast load

A blast wave can be described by peak pressure, positive duration of the pressure phase, negative duration of the pressure and decay constant. Some of the blast load profiles used by researchers