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Transport of High Activity Isotopes in the BEA Research Reactor Package

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ABSTRACT

The BEA Research Reactor Package has been in use for nine years in the DOE complex as a workhorse for moving used research reactor fuels. Over its lifetime, the packaging's NRC approval has been amended to include a broad range of research reactor and materials test reactor (MTR) fuels. Because the packaging has very heavy shielding, it is also readily amenable for use with high-activity payloads such as cobalt-60. Because such isotopes with their high heat generation were not part of the original design specification, some design challenges were presented when the Isotope Program Office of Nuclear Physics, Office of Science, U.S. Department of Energy (DOE-SC IP) requested the addition of cobalt 60 to the approved payloads. The first problem addressed was the movement of the decay heat out of the package without generating excessive temperatures in the important-to-safety components of the package, such as the basket, the structural shells, and the shielding. The thermal limit of the payload itself was a particular challenge, since it was made of aluminum. Next, since an early payload target design had experienced a rupture failure in the past, it was necessary to design a target holder to preclude loss of control of the individual activated pellets in the event of target rupture. The use of the target holder ensures safe transport of the target. For added safety, the target was redesigned to eliminate the rupture failure. Finally, the concentration of the heat source meant that the cask surface temperature would exceed regulatory limits in the shade, and consequently a personnel barrier needed to be included. This paper will describe these challenges and the design approaches taken to meet them.

INTRODUCTION

The BEA Research Reactor (BRR) package is a Type B(U)F-96 package designed for transport of used research reactor or materials test reactor (MTR) fuels. Among the approved payloads are fuel elements from many university and government research laboratories, including PULSTAR and TRIGA elements. It has been in use since 2010. The inner cavity has nominal dimensions of 406 mm [16 inches] in diameter and 1,372 mm [54 inches] long. The nominal side thickness of lead is 203 mm [8 inches]. The lid is fastened using 12, 25 mm [one-inch] diameter alloy steel bolts and sealed with an elastomer containment seal. A drain port is located near the bottom of the cask body. The gross weight of the package is 14,512 kg [32,000 lb]. The cask is NRC certified for leak-tight containment. A cross section of the package is shown in Figure 1, including upper and lower, closed-cell, polyurethane foam impact limiters.

Because the BRR cask has a very heavy lead shield and may be immersed in water, it can be used for the transport of high-intensity gamma emitting payloads such as cobalt-60 production targets. Because such payloads were not part of the original design specification, adapting the package to the different characteristics of the payload presented some challenges, which are discussed in this paper.

COBALT-60 PRODUCTION TARGETS

Cobalt-60 is typically produced by exposing cobalt-59 to a high-intensity neutron flux such as is available from the Advanced Test Reactor (ATR) at the Idaho National Laboratory (INL). The cobalt-59 target material is made into a large number of small (approximately 1-mm diameter x 1-mm thick) pellets which are built into a target rod. The target rod is approximately 16 mm [5/8 inches] in diameter and 406 mm [16 inches] long. The mature cobalt-60 activity of the targets ranges up to 522 TBq [14,100 Ci], equivalent to 217 W of decay heat each. Since the maximum heat output of any currently licensed MTR fuel element is 158 W, and since the targets are much smaller than the fuel elements, it is clear that the heat rate and size of the cobalt-60 targets can pose a challenge for heat removal.

Several target designs have been adopted at different times. One particular design, which included a relatively thin outer aluminum shell, was subject to water intrusion through small weld flaws during irradiation in the reactor. During vacuum drying in the cask prior to shipment, the water could turn to steam and burst the shell, releasing a quantity of pellets into the interior of the cask. To preclude this from happening, two steps were taken: a careful redesign of the target to preclude water intrusion, and the design of a target holder, capable of draining water but retaining, if necessary, any small pellets released from the possible failure of an older target.

DECAY HEAT

To maximize transport efficiency, it was desired to place as many irradiated targets into the BRR package as possible, up to the previously licensed decay heat limit of 1,264 W. But because the cobalt-60 targets are significantly smaller and individually hotter than the used fuel elements, there were several challenges to the design related to heat:

- Because the targets needed to be placed in target holders, an added thermal barrier was present.
- Because the target material was aluminum alloy, the maximum target temperature during vacuum drying of the cask needed to remain below 482 °C [900 °F]. (This temperature limit was derived from short-term creep considerations.)
- Because the targets are very compact compared to MTR fuel elements and they emit more heat than the MTR fuel elements, getting the heat out of the target and into the cask structures required close attention to the thermal pathways.
- The variation in decay heat between old and new targets was wide. A proper thermal spacing of high activity targets in the basket would be inefficient for transport of cooler, lower activity targets. A single basket was a design goal.

- The concentration of heat into the cask near the top of the cavity, related to the target's shorter length compared to MTR fuel elements, caused an increase in temperature of the cask outer surface, necessitating inclusion of a personnel barrier.

FACILITY INFRASTRUCTURE LIMITATIONS

The cobalt-60 targets will originate, at least initially, at the ATR at INL. After removal from the reactor, the irradiated targets will be stored underwater in the ATR canal. For loading with targets, the BRR cask is lowered into the canal using the facility crane. However, because it is not possible to disconnect the crane and lift rigging from the cask, the rigging must remain in place during loading of the cask. This means that the crane cannot be used to assist in loading the cask. Consequently, anything placed into the cask while in the pool must have a weight not exceeding that which can be manually lifted, including the handling pole. This meant that the basket needed to be of one piece, placed into the cask prior to immersion, and be easily loaded from the top in the presence of obstruction from the lift rigging.

TARGET BASKET DESIGN

Because the BRR package is already NRC certified and in frequent use, it was necessary to meet the design challenges created by the cobalt-60 payload without any changes to the cask. The design features of the basket, of the target holder, and the addition of a personnel barrier, along with the existing features of the BRR package, were sufficient to meet the design needs.

The basket design for the cobalt-60 targets is shown in Figure 2. The design consists of a central tube which supports four disks. The target holders are placed in two concentric circular rows of holes in the upper two disks. (All targets, regardless of design, are required to be placed in target holders.) The third disk from the top provides bottom support for the target holders. The lower disk provides for lateral stability at the bottom of the basket. The diameter of the disks and the height of the basket fit the internal cavity of the BRR package.

There are two main types of target, and consequently, two types of payload:

- Type 1 payload is for any load that includes one or more high-activity targets (activity more than 148 TBq up to 522 TBq [4,000 Ci up to 14,100 Ci]).
- Type 2 payload is for target activities up to 148 TBq [4,000 Ci].

Type 2 targets had a decay heat value low enough that concentration of heat did not present a thermal challenge. Thus, to maximize the quantity that could be shipped in the BRR package, a basket with 20 cavities was designed, as shown in Figure 2. For a full payload of 20 targets with up to 148 TBq [4,000 Ci] each, the maximum heat load of the Type 2 payload was 1,234 W, equivalent to 2,960 TBq [80,000 Ci].

Type 1 targets had nearly four times the decay heat of Type 2 targets. Thus, a smaller quantity of up to 10 targets could be carried. To prevent excessive concentration of heat in adjacent locations, two measures were taken:

1. Restrict Type 1 targets to a single (inner) row. To ensure that this occurs, a "loading collar" was included, effectively blocking off the outer row of holes in the basket. The loading collar is shown bolted to the top disk of the basket for the Type 1 payload on the

left side of Figure 2. For Type 2 payloads, it is not needed, and is conveniently bolted to the lower disk for storage, as shown on the right side of Figure 2.

2. Require Type 1 targets to utilize zone loading. The 10 holes of the inner row were divided into five zones of two adjacent holes each. The safety analysis restricts the total activity for each zone to a total of 814 TBq [22,000 Ci], with a total limit in the cask of 3,034 TBq [82,000 Ci] (equivalent to the maximum allowable heat load of 1,264 W).

The basket has two other important features as shown in Figure 3. One is a relatively thick top disk. Primarily, this thickness of steel was used to reduce the gamma intensity directed at the top shield plug of the BRR cask. In addition, it aided heat transfer from the center of the basket to the outside. Second, the hollow tube at the center of the basket was filled with a loose fitting, essentially full length aluminum bar whose sole purpose was to transfer heat toward the cooler bottom of the cask. Aluminum was chosen for its low cost and relatively high conductivity.

To demonstrate the effectiveness of these heat transfer design measures, a thermal analysis using gamma heat deposition was utilized. The gamma radiation absorbed by the target itself, the target holder, the basket structure, and the aluminum bar was calculated by the shielding analysis software and transferred to the thermal analysis software, where it was applied as a volumetric heat generation in the materials. The remaining decay heat was applied as a heat flux over various portions of the inner cavity walls, proportional to the gamma flux in those areas. The analysis shows about 1/5 of the total heat load going down the aluminum bar. Conservatively, convection is neglected. Heat is transferred only by conduction (including through still air) and radiation between components. The resulting temperatures of important-to-safety components, such as the elastomer containment seal, the structural shells, the lead shielding, and the aluminum target itself, remained below acceptable limits.

PERSONNEL BARRIER

Partially related to the facility limitations discussed above, the payload, which must be manually loaded, needed to be placed at the top of the basket, which placed it essentially at the top of the payload cavity. With an active heat-producing length of only about 356 mm [14 inches], this meant that all of the heat was concentrated in the top 25% of the payload cavity. As noted above, the temperatures of the cask components remained acceptable. However, the maximum surface temperature in the shade is limited by 10 CFR 71.43(g) [1] and SSR-6 §655 [2] to 85 °C [185 °F]. The design of the BRR package includes impact limiter attachments, similar in shape to fins, that are attached to the package outer shell near the top and bottom of the cask body. The temperature at the root of these structures was very close to 85 °C [185 °F] with the prior fuel element payloads, which had an axially longer heat distribution. In spite of the action of the basket's aluminum bar, and of the conductivity of the massive lead shielding, the temperature of the impact limiter attachments exceeded the regulatory limit. Thus, a personnel barrier was designed, whose use applies to all shipments of cobalt-60, regardless of actual activity. A figure of the BRR package showing the personnel barrier (with one of four segments removed for clarity) is shown in Figure 4.

TARGET HOLDERS

As noted above, experience had shown the possibility of a cobalt-60 target failure in which some irradiated pellets could come out of a target. To preclude this event from happening again, all targets are transported in target holders. (As defense-in-depth, the target was also redesigned to preclude water intrusion.) Design of a new target holder was also part of this effort.

Based on previous designs, the target holder closure (body and cap) utilizes a spring-loaded, quarter-turn concept. The target holder must be self-draining, but the drain holes must not allow passage of any tiny cobalt pellets, should any be released by the target. It must be easy to use with remote handling tools under deep water. It does not need to retain pressure, so it may have thin cross sections. It must be easily remotely grappled from its top end. Each target holder contains one target.

A view of the target holder is shown in Figure 5. The cap and a short section of the body are made with a hexagonal shape to enhance the ability to grasp it with remote tools under water. A separate tool was also developed for use in the ATR canal to hold the body while manipulating the cap, making the use of the holder even easier. The cap also has a relatively long overlap with the mating part of the body, such that when the target holder is installed in the BRR cask, the cap would not have enough room to come off the top of the body during transport. The drain holes are checked with a 0.5-mm [0.02-inch] diameter wire, or tested with water, prior to each use.

SUMMARY

A project was undertaken to add a cobalt-60 payload to the BRR package. Challenges were presented including decay heat, concentration of the heat in a small volume, and facility loading restrictions. The cobalt-60 payload was approved by NRC and first use is scheduled for August, 2019. The project resulted in the development of a new basket, target holders, and a personnel barrier for use with the BRR package.

REFERENCES

1. Title 10, Code of Federal Regulations, Part 71 (10 CFR 71), *Packaging and Transportation of Radioactive Material*.
2. International Atomic Energy Agency, *Regulations for the Safe Transport of Radioactive Material*, SSR-6.

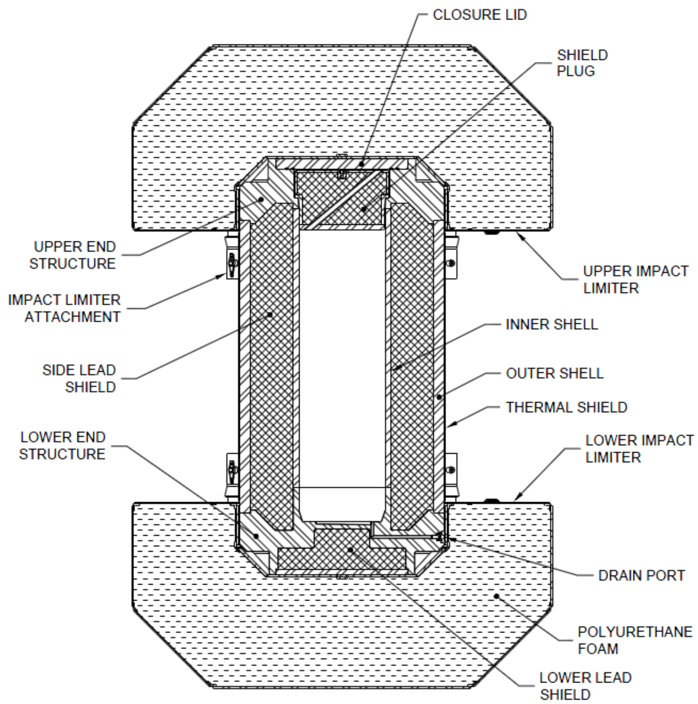

Figure 1 – BEA Research Reactor Package Cross Section

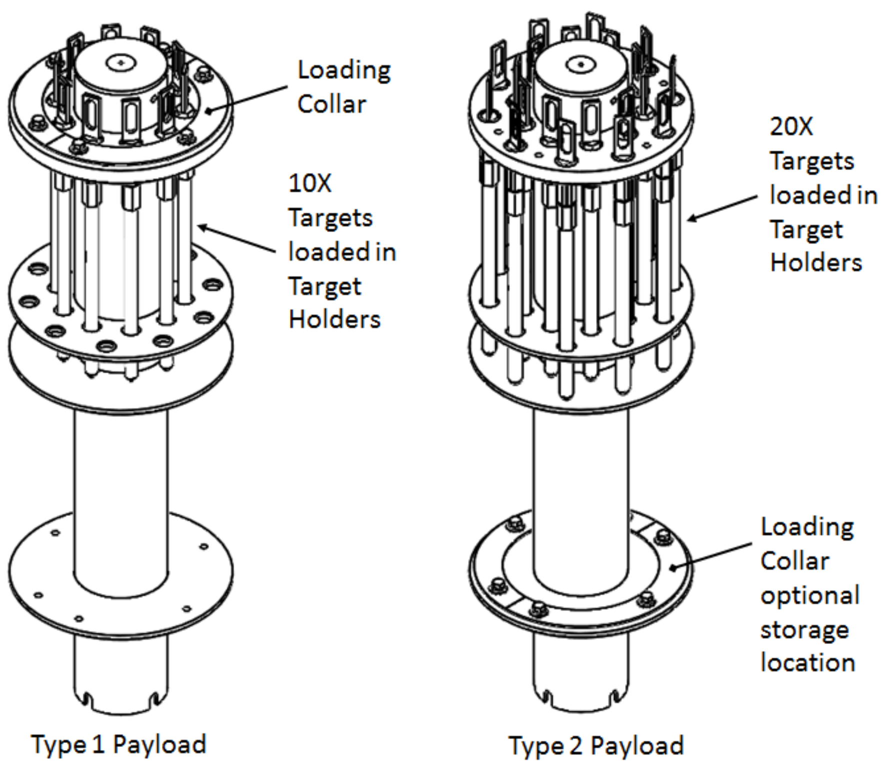

Figure 2 – Cobalt-60 Basket Design

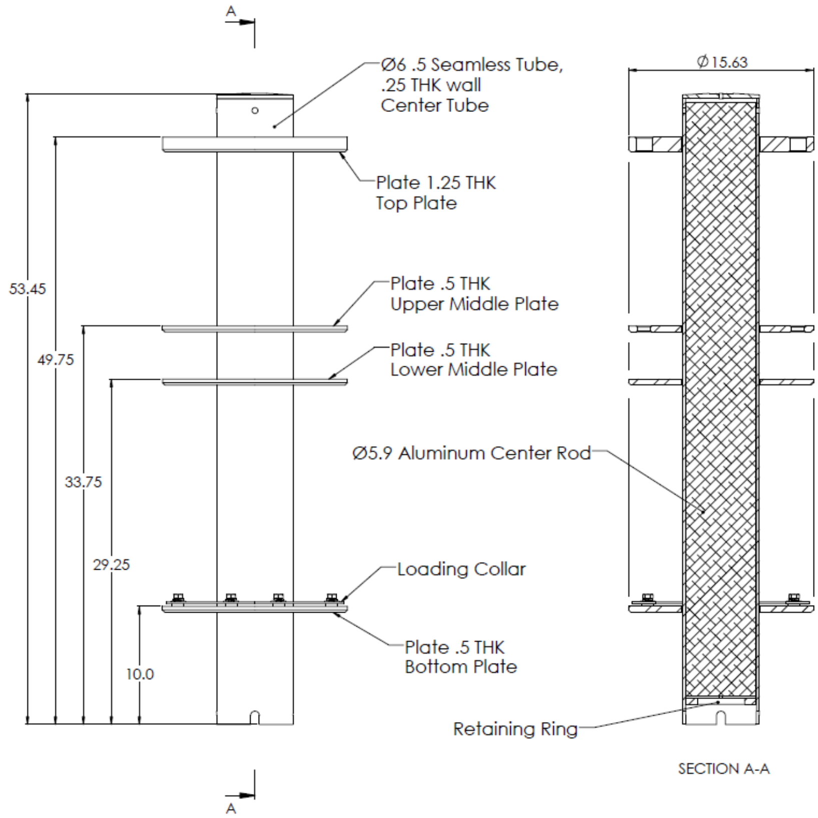

Figure 3 – Basket Design Details (dimensions in inches)

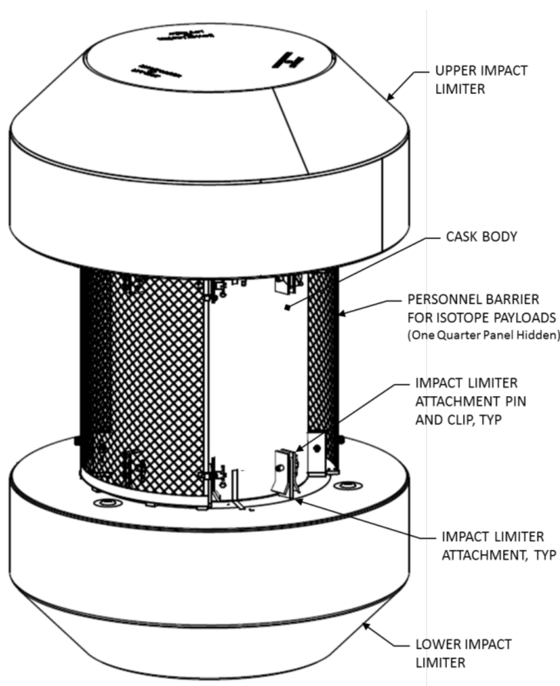

Figure 4 – BRR Package with Personnel Barrier

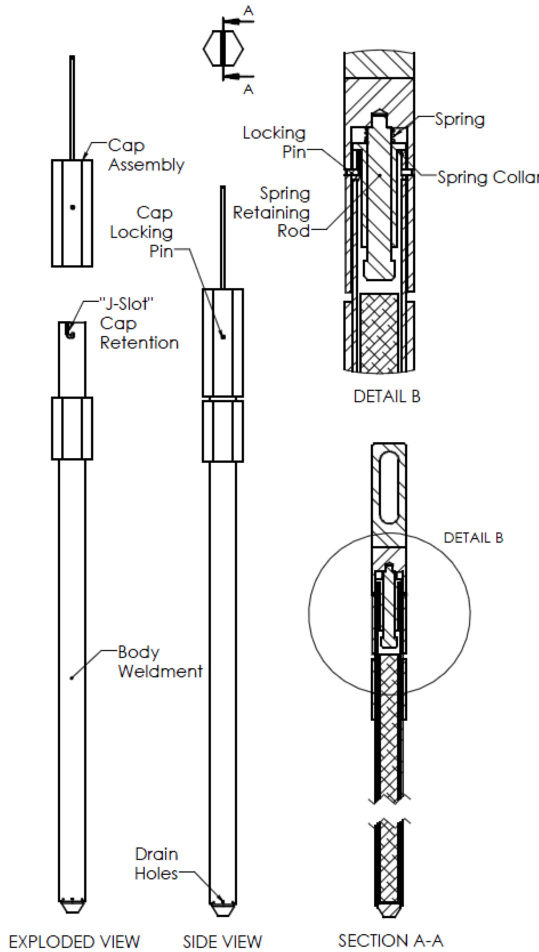

Figure 5 – Target Holder for Cobalt-60 Targets