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DESIGN MODIFICATIONS TO THE HS SAFKEG 3977 A PACKAGE TO ALLOW TRANSPORTATION OF MOLYBDENUM 99 CONTENTS

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ABSTRACT

The Croft Associates Safkeg-HS 3977A package, hereafter referred to as "*HS*", is a general-purpose container for the transport of non-fissile nuclides and limited quantities of fissile nuclides as specified under United States Nuclear Regulatory Commission (NRC) general licences, for non-exclusive and exclusive use. The package has been designed for transportation of a variety of solid, liquid or gaseous contents by road, rail, sea and air. The package was originally designed in 2008 and tested in 2010 to provide substantiation for the initial license application. The *HS* consists of a single resealable containment vessel, (design No. 3978) fabricated from stainless steel with encased depleted uranium shielding, carried within insulating cork packing in an outer stainless-steel keg, (design no. 3977).

This initial package design was successfully licenced by the NRC, confirming that the package met the requirements of 10 CFR 71 [i] and the IAEA Regulations for the Safe Transport of Radioactive Material [ii]

Further to this licence award, the *HS* package has been subject to a further design and licensing modification to allow for the optimised transportation of Molybdenum-99 contents in liquid form.

This paper summarises the design and licensing challenges introduced by the incorporation of Mo 99 contents in liquid form, describing how these were overcome, through a combination of a bespoke shielded insert design and modifications to the containment vessel (CV) which culminated in a further successful licence award upon the *HS* package.

INTRODUCTION

The *HS* package is a general-purpose container for the transport of non-fissile nuclides, under non-exclusive and exclusive use. In the package's latest configuration, the contents may be in solid, liquid and gaseous form, and transported by road, rail, sea and air. The contents of the package are wide ranging, with approximately 50 radionuclides approved for transport, including some nuclides in excess of 3000 A2 and therefore the package is classified as Category I as defined in NUREG 1609 [iii]

DEVELOPMENT OF THE ORIGINAL *HS* PACKAGE

The *HS* was originally conceived in 2008 to meet the need of US and international operators for a general-purpose Type B(U) container able to transport a wide array of radionuclides. The design development led to a full prototype and test programme commencing in 2010, which culminated in an initial issue of Certificate of Compliance (CoC) [iv] by the NRC in early 2014.

The general arrangement drawing of the originally configured *HS* is provided within Figure 1 below. This figure shows the major features of the original package design, in particular note the one-piece CV lid construction.

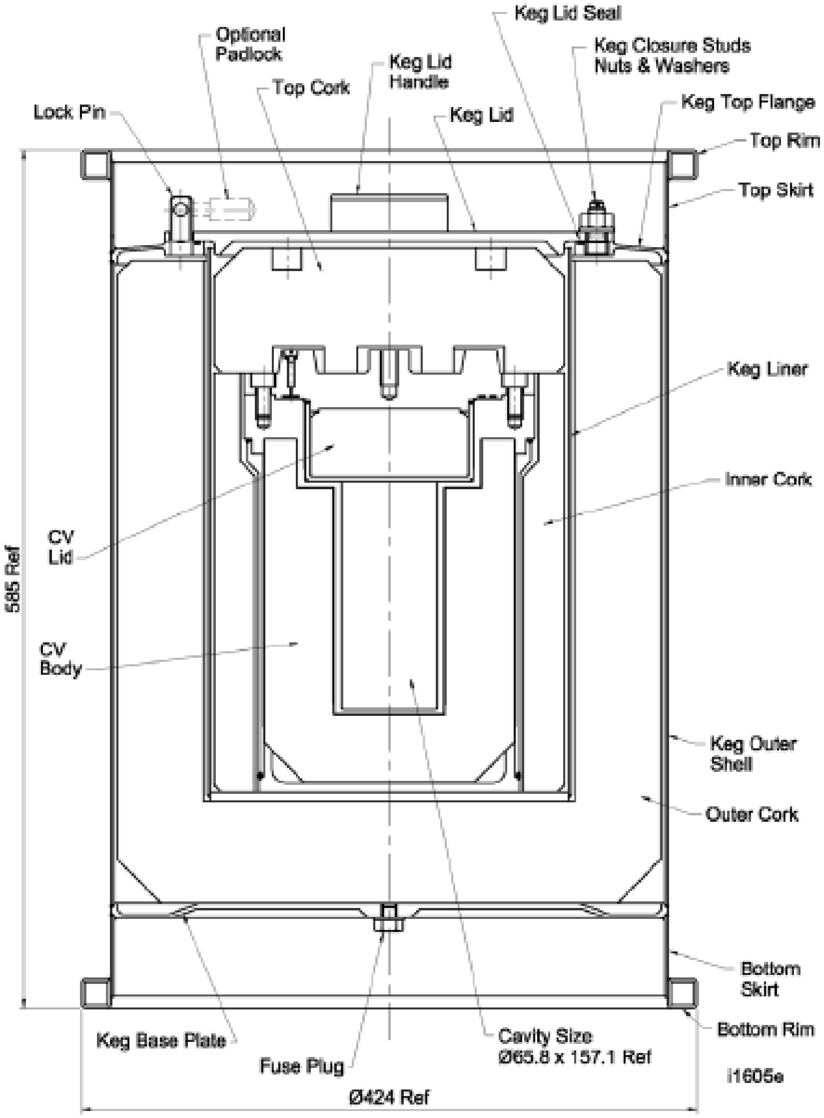

Figure 1. Design features of original *HS* package with standard CV lid

With reference to Figure 1 above, it can be observed that the HS package, as originally configured, consists of a single resealable CV, design no. 3978. This CV variant is composed of a body and a lid. The body is fabricated from three pieces of stainless steel: the CV flange/cavity wall, the CV outer wall and the CV base. The CV flange/cavity wall and the CV base are machined from solid. The CV flange/cavity wall is welded to the CV outer wall to form the cavity into which the body Depleted Uranium (DU) shielding is fitted. The base is then welded to the outer wall to completely seal the DU shielding securely in position within the CV body.

The original standard CV lid is fabricated from two pieces of stainless steel, the CV lid top and the CV lid shielding casing. Both pieces are machined from solid. The CV lid shielding casing has DU inserted prior to welding of the CV lid shielding casing to the CV lid top. This completely seals the DU shielding securely in position within the CV lid. Figure 2 below shows the standard originally configured CV in more detail.

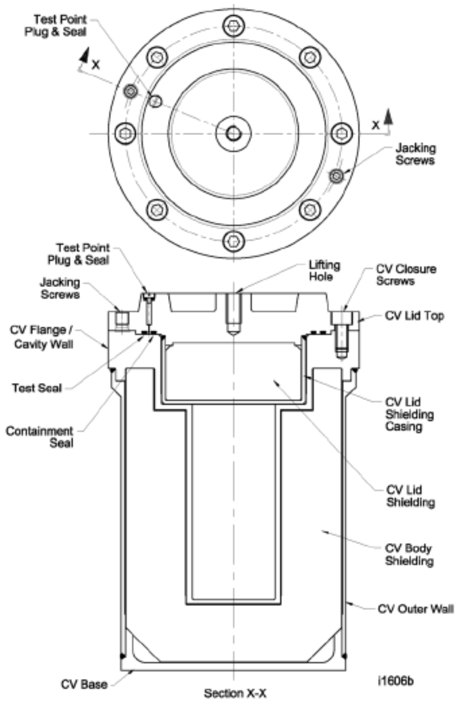

Figure 2. Standard *HS* CV design no. 3978 configuration

The standard *HS* CV, design no. 3978, has a cavity height of 157.1mm and a diameter of 65.8mm. This cavity will then accept a specific insert to suit the contents type and related product container, the insert options are described subsequently within this paper. The CV operates at atmospheric pressure, although the internal pressure may vary due to heating of the gases within the CV by decay heat of the contents, gas generation and atmospheric temperature and pressure changes.

The lid is fitted with two concentric elastomeric O-ring seals, an outer test seal and an inner containment seal which define the containment boundary for the package. These two concentric seals form an interspace, access to the interspace between the two O-rings is provided via a dedicated test point for operational and maintenance leak testing. Leak testing is required for the CV to ensure that it meets the regulatory release limits specified in 10 CFR 71.51[i]

The CV is carried within insulating cork packing in an outer stainless-steel keg design no. 3977, referred to as the keg.

The keg design no. 3977 has a stainless-steel outer shell and an inner concentric stainless-steel liner, the void between these items being filled with insulating cork. The keg is sealed from external ingress as it has an O-ring weather seal in its closure. At the base of the keg is a fuse plug, incorporating low melting point alloy which will melt under HAC fire conditions, allowing gases to vent and the pressures in the keg to relieve without risk of further keg damage.

The keg is closed by a flat stainless-steel lid which is bolted down with 8 stainless-steel studs and nuts against the afore-mentioned O-ring weather seal. The studs are fitted with seal holes for the fitting of a tamper indicating device in accordance with 10 CFR 71.43(b) [v]. The lid may also be further secured, to prevent unauthorized removal, by a padlock attached to a lock pin welded to the keg closure flange.

For a general-purpose Type B(U) package able to take an array of radionuclides with significant activity levels, the *HS* package is designed to be compact with a resulting relatively low weight. This has significant advantages with respect to operational handling and transport shipment. The maximum weight of the package excluding the contents is 154 kg (339 lbs). The maximum contents weight is 9.29 kg (21 lbs), resulting in a maximum gross weight of 163 kg (360 lbs).

An inner cork liner is fitted between the keg liner and the CV. The inner cork liner consists of a body and a top cork. There is no cork directly underneath the CV as it sits on the keg liner. The top and side corks vary in thickness to suit the CV lid and keg geometry. An outer cork is enclosed between the keg outer shell and the keg liner. The keg liner is constructed from thin stainless-steel material, performing the functions of separating the inner and outer cork as well as protecting the outer cork during loading. The outer cork, top cork and inner cork provide insulation and energy absorption - thus providing protection to the CV during Normal Conditions of Transport (NCT) and Hypothetical Accident Conditions (HAC).

Figure 3 below shows the containment boundary of the *HS* package for the original standard CV configuration. As shown, the containment boundary consists of the CV flange/cavity wall, the CV lid top and the inner O-ring containment seal of the CV. As previously described, the containment seal is tested on manufacture, during periodic maintenance and in operation, to ensure it remains within regulatory limits regarding leak rate under both NCT and HAC.

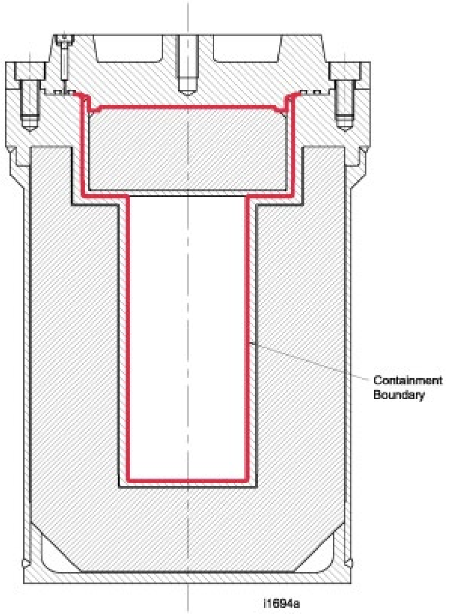

Figure 3. Standard *HS* CV design no. 3778 containment boundary

The CV cavity is designed to accept an insert to suit the specified contents and associated product container. The CV cavity size remains constant (diameter 65.8mm x 157.1mm height) for each of the specified inserts. Therefore, the variation within the insert range of wall thickness, shielding material and related insert cavity size is most important in terms of defining the contents and their related activity. Each insert has a separate applicable contents list stated within the Certificate of Compliance. The design was intentionally configured around an insert concept to allow for maximum flexibility with regards to shielding and containment of an array of potential contents. The variation of an insert is a relatively simple design modification, which can be undertaken to suit any new contents types, this simplicity ensures that any licence revision is simpler and more-timely in terms of delivery. Modifying packages in this way, enables most of the supporting evidence for the licence to remain fully applicable, with the variation kept to the insert shielding and issues of contents confinement.

In its original configuration, with the standard design no. 3778 CV, the *HS* had two insert options as described below:-

- Insert design no. 3982:-

This first insert, also referred to as the HS-12x95Tu, is a tungsten insert with inner cavity size of 12mm diameter by 95mm in height. The approximate mass of the insert is 9.2 kg. This insert is only utilised with the original standard CV. See Figure 4 below. This insert presents the greatest additional shielding, and by association the smallest cavity within the *HS* insert range.

Figure 4. *HS* CV insert design no. 3982

- Insert design no. 3985:-

This second insert, also referred to as the HS-31x114-Tu, is a tungsten insert with a inner cavity size of 31mm diameter by 114mm in height, The approximate mass of the insert is 7.9 kg. This insert is only utilised with the original standard CV lid arrangement. See Figure 5 below. This insert has a larger cavity, and by association less beneficial shielding than the insert design no. 3982.

Figure 5. *HS* CV insert design no. 3985

It is important to note that to provide confinement of the radioactive contents, for the above insert variations, the contents are enclosed within a client specific product container. This may be a quartz vial, aluminium capsule or stainless-steel bottle. Furthermore, the product container may itself be overpacked for handling and minimisation of contamination, typically with a plastic or metal can, or potentially with wrapping material.

With reference to the original NRC CoC [iv] it can be seen that the content options are specific to each insert type. In the original configuration of the *HS*, when fitted with insert design no. 3982, a wide array of solid radionuclides as normal or special form material were licensed for shipment. A total of 49 different radionuclides were originally licenced, fully defined along with maximum activity limits within Table 1 of the CoC. As an illustration of the activity limits, with respect to Mo-99, this configuration of package and insert was licensed for up to 5.27 E +01 TBq (1424 Ci) of content in solid form.

Similarly, if fitted with the design no. 3985 insert, the same array of solid radionuclides were originally licenced to the limits defined within Table 2 of the CoC. The limits are reduced from the Table 1 limits for the 3982 insert as the 3985 insert has a larger cavity, which results in less tungsten shielding material. As a comparative illustration of the reduced activity limits, with respect to Mo-99 this configuration of package was licenced for solid form only, in this instance to a reduced activity limit of 9.56E+00 TBq (258 Ci). Furthermore, this design no. 3985 insert was also licenced to take Kr-79 and Xe-133 gases within a suitable product container such as a fused quartz vial or aluminium capsule. The limits for these gases are reflected in the CoC Table 3.

MARKET DEVELOPMENTS

The *HS* package was successfully introduced in 2014 in a configuration suitable for a wide array of radionuclides in solid and gaseous form. It quickly became apparent from client feedback and further market engagement that the package was ideally suited to the transportation of further radionuclides utilised within the rapidly expanding medical diagnostics sector. In particular, client engagement led to a desire to introduce a capacity for the *HS* to transport I-131 and Mo-99, both in liquid solution form.

As the *HS* package in its original configuration was already licensed for both these nuclides in solid form, a close approximation of the activity limits could be established and was seen to be attractive to producers of these radionuclides.

The necessity for liquid form is a resultant of the production process. Taking Mo-99 as an example, the most common form of Mo-99 production utilised by current producers is through the fission of U235 targets, which produce Mo-99 along with other medically important isotopes such as I-131 and Xe-133. The U235 targets utilised in this process are typically encapsulated within aluminium or stainless-steel to protect the chemically reactive uranium metal or alloy and to contain the fission products produced during irradiation. Mo-99 is produced within the uranium bearing targets by irradiation with thermal neutrons.

The irradiated targets are then chemically processed in hot cells through either an alkaline or acid dissolution process. This dissolution results in a Mo-99 product held in a solution, the solution being dependent upon the exact dissolution process utilised. The transport of the Mo-99 in this solution form is of most interest to producers, and therefore a solution was required to allow the *HS* to ship Mo-99 in this liquid solution form.

HS DESIGN MODIFICATIONS

Following the market and client engagement described above, which established the need for the *HS* to accommodate additional liquid contents, design modifications were commenced. As part of the design process for considering the necessary modifications, wider features of the *HS* design were evaluated for optimisation. This included consideration upon the operability of the package, its handling in site operations and transport, and finally its ease of manufacture and repair.

It was the consideration of these wider features, and in particular how to improve operability within hot cells, which led to the introduction of an alternative CV design. This alternative CV arrangement, design no. 3978, was designed with a split CV lid, as shown in Figure 6 below.

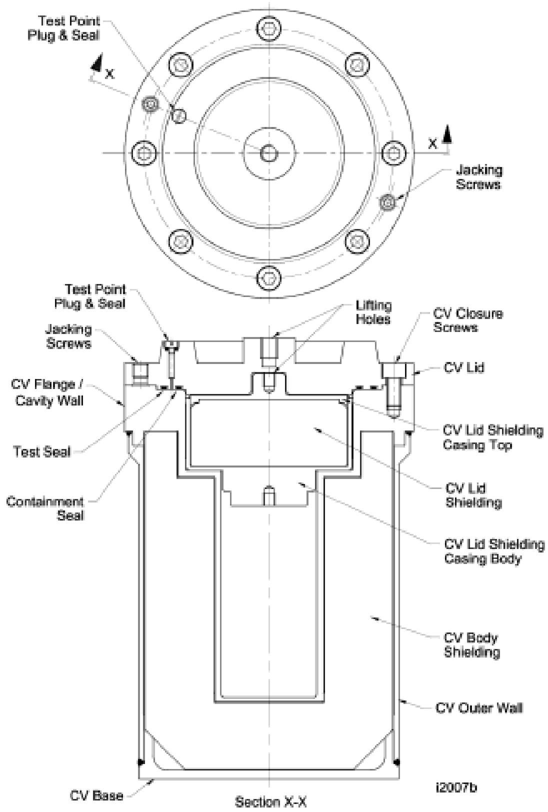

Figure 6. Split lid *HS* CV design no. 3978

The split CV lid is similar to the previously described standard CV lid with the stainless-steel being machined from solid and with the DU clad in stainless-steel, however, it varies in design from the standard CV lid in the following points:

- The CV lid top is not welded to the CV lid shielding. The CV lid shielding sits within the CV body in the same position as the standard CV lid.
- The CV lid shielding plug casing extends to form a stainless-steel plug in the CV body cavity. This plug ensures the correct location of the insert during transport.
- Two threaded holes are machined into the CV lid shielding plug. The bottom threaded hole allows the insert to be attached to the CV lid shielding plug and, once the CV lid top has been removed, a lifting attachment can be fitted to the top threaded hole of the CV shielding lid plug to enable it and the attached insert to be lifted out of the package.
- In this CV configuration, the cavity height is 132mm with a diameter of 65.8mm.

It can therefore be seen that the alternative split lid CV design offers the potential for improved operability by separating the shielding function of the lid from its containment function. This allows increased flexibility with regards to reducing the assembly activities in cell, as it is possible to remove the lid outside of a dedicated cell as the shielding plug remains in situ. A further advantage of the split CV lid configuration is that it requires a smaller in cell working height envelope.

The split lid design also improves the manufacturability of the lid when compared to the original lid design. With the original lid the O-ring seal ring grooves have to be precision machined with difficult access due to the presence of the integral DU shielding, whereas with the split lid the seal grooves are much more accessible, simplifying the machining accordingly.

The split lid design also enhances maintainability, as the item most often damaged and requiring replacement or repair is the seal groove feature. With the split lid design the lid can be repaired, or even replaced more economically than with the original design, as the DU component is separated, making the lid a simpler component to repair or replace as necessary.

As per the originally configured CV, the split lid CV cavity is also designed to accept an insert to suit the specified contents and associated product container. In addition to the original inserts, design nos. 3982 and 3985, two additional inserts have been added as part of the latest design modifications as described below:-

- Insert design no. 3987:-

This third insert design, also referred to as HS-55x128-SS, is a stainless-steel insert with inner cavity size of 55mm diameter by 128mm in height, the stainless-steel cavity is further lined with a titanium liner. The approximate mass of this insert is 1.8 kg with a liner installed. See Figure 7 below

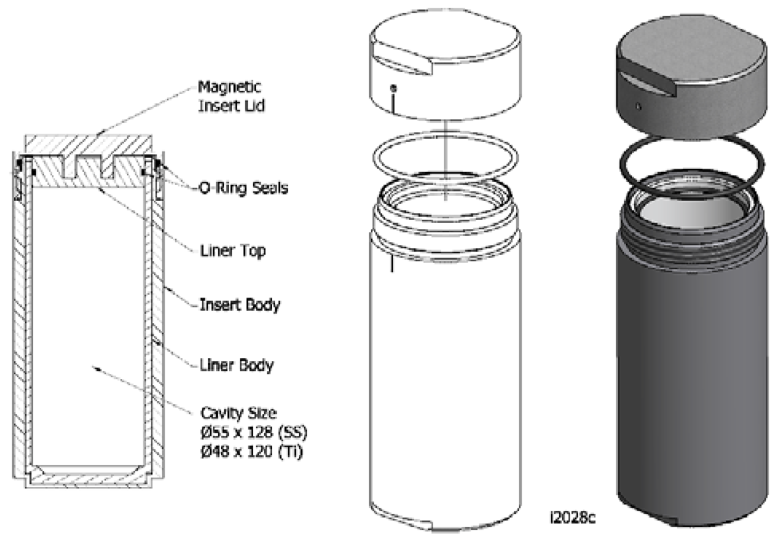

Figure 7. ***HS*** **CV insert design no. 3987**

- Insert design no. 4081:-

This fourth insert design, also referred to as HS-50x85-SS, is only utilised with the split CV lid arrangement. This insert is a stainless-steel insert with an inner cavity size of 50mm diameter by 85mm in height. Design no. 4081 is utilised in conjunction with a snap ring, which attaches the shielding insert to the shielding plug associated with the split CV lid design and is further coupled with a tungsten liner to provide additional shielding from the Mo-99 contents associated with this liner. See Figure 8 below.

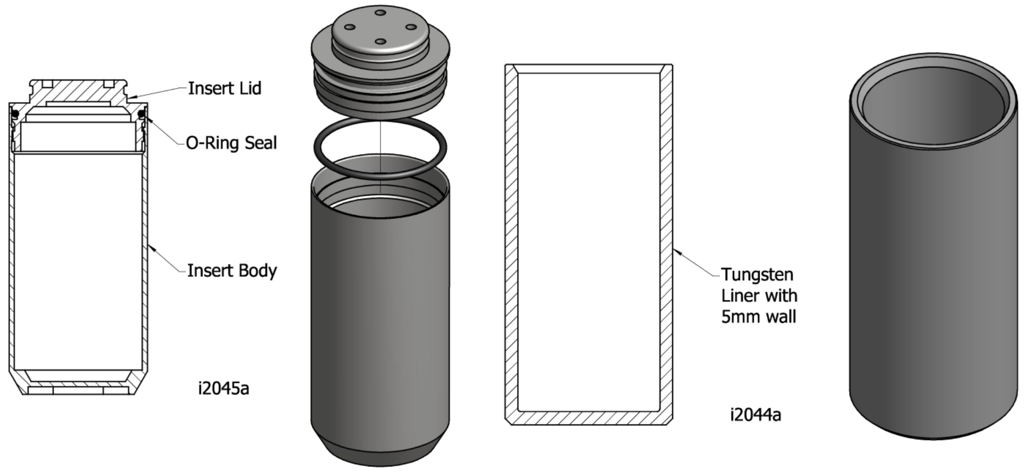

Figure 8. ***HS*** **CV insert design no. 4081**

With respect to insert design no. 4081, further confinement of the liquid Mo-99 contents is provided by the product container shown in Figure 9 below.

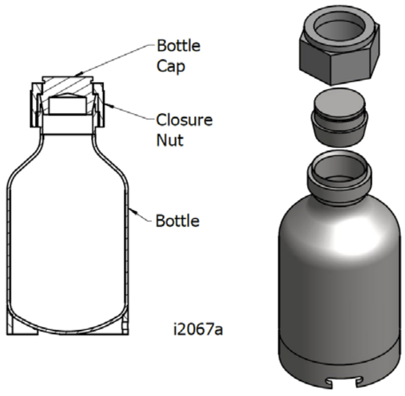

Figure 9. HS CV insert design no. 4081 – product container for Mo-99

As per the original configuration, the contents options are specific to each of the two additional insert types. With reference to the latest NRC CoC [vi], it can be seen that the new insert design no. 3987, coupled with the originally configured CV design no. 3778, is optimised for the shipment of I-131. This specific insert was provided to meet a client's operational requirement to ship I-131 liquids as either alkali or acidic salt solutions, within a quartz vial or aluminium capsule wrapped in LDPE or material of equivalent radiation resistance. The stainless-steel construction with an internal titanium liner mitigates against the potential for chemical or galvanic reactions. The activity limits for the contents related to this combination of CV and insert are limited to liquid I-131 only, as defined within Table 5 of the CoC [vi], with an activity limit of 7.4E +00 TBq (200 Ci).

Similarly, with reference to the latest NRC CoC [vi], the new insert design no. 4081, when coupled with the alternative split lid CV design no. 3985, is optimised for the shipment of Mo-99. This specific insert was also developed to suit a client's operations, and enables the insert to couple with a snap ring which interfaces with the stainless-steel product container shown previously within Figure 9. This insert configuration is exclusively provided for the transportation of liquid Mo-99 contents in the form of natrium molydenate in a matrix solution of NaNO3. The limits for these contents are reflected within the latest NRC CoC Table 4 [vi], which states an activity limit of 3.7E +01 TBq (1000 Ci) specifically for the liquid Mo-99 contents.

CONCLUSION

The Croft Associates *HS* was introduced into operations within 2015, in its original configuration of a single part CV lid, coupled with a choice of two tungsten inserts to suit a wide array of solid radionuclides.

As discussed within this paper, subsequent market developments and client engagement identified a need to enhance the *HS* such that liquid contents could be transported, specifically solutions of I-131 and Mo-99.

Therefore, a set of design developments were initiated, as detailed within this paper, resulting in the introduction of an alternative CV arrangement with a split, two-part lid separating the shielding from the CV containment. Additionally, a further two inserts were introduced, each one specific to the requirements of either I-131 or Mo-99.

With respect to Mo-99, the latest configuration of the *HS* package is now licensed by the US NRC to transport up to an activity limit of 3.7E +01 TBq (1000 Ci) in a liquid solution. The *HS* has US DOT and European validations which enable the package to be shipped both internally within the US, and to and from Europe.

The present availability of this liquid M0-99 capacity is pertinent considering the rapidly developing domestic and international market for medical diagnostics.

The developed *HS* design presents a compact, relatively low weight solution for the transport of radionuclides such as Mo-99 within this developing market. Furthermore, the latest iteration has been optimised for operational handling, and repairability, offering further tangible benefits to potential end users.

REFERENCES

[i] United States Nuclear Regulatory Commission, *10CFR 71.51Packaging and Transportation of Radioactive Material – Additional Requirements for Type B packages.*

[ii] IAEA, *SSR-6, Regulations for the Safe Transport of Radioactive Material*, 2012 Edition

[iii] United States Nuclear Regulatory Commission, *NUREG 1609 Standard Review Plan for Transportation Packages for Radioactive Material,* MARCH 31st, 1999.

[iv] United States Nuclear Regulatory Commission, *Certificate of Compliance for Radioactive Material Packages – Certificate Number 9338 – Revision Number 0,* MARCH 31st 2014.

[v] United States Nuclear Regulatory Commission, *10CFR 71.43 General Standards for All Packages.*

[vi] United States Nuclear Regulatory Commission, *Certificate of Compliance for Radioactive Material Packages – Certificate Number 9338 – Revision Number 3,* MARCH 28th 2018.