Development of Tritium Storage and Transport Vessels - 8128

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ABSTRACT

The purpose of this study is to develop tritium storage and transport vessels for industrial applications. Prototype tritium storage and transport vessels were designed and manufactured. Uranium and zirconium/cobalt (ZrCo) metals were selected for the storage materials. The prototype transport container for the vessel was designed on the basis of Type B transportation package standards. The transport container was composed of a steel drum, inner packing materials, and a storage vessel. A second refinement cap was installed on the prototype vessel to protect the valves on the 100kCi vessel. The vessel is stored in a steel drum packed with a thermal barrier and a shock absorber. Structural, thermal, shielding, and confinement analyses have to be performed for this container based on Type B requirements.

INTRODUCTION

Tritium is a radioactive hydrogen isotope which is generated by cosmic rays naturally or by a neutron capturing artificially in nuclear power plants. The nucleus of the tritium atom is unstable and decays into a Helium-3 by emitting beta-particles. The half-life of tritium atom is 12.3 years. Several years ago, tritium was considered as harmful for human beings and treated as a radioactive waste. But as perception grew of its usefulness in industrial radioactive applications and in the nuclear fusion field, tritium is considered a resource today.

Four CANDU reactors are currently being operated in Korea and tritium is mainly produced through a neutron capture by the deuterium atom in heavy water (D_2O) which is used as the moderator and coolant in CANDU reactors. The presence of tritium in the heavy water systems becomes a major source of an operator’s exposure. Tritium concentration in the systems tends to increase to equilibrium values with the age of the reactor. It was necessary to remove tritium in the CANDU plants to reduce the environmental hazard for their workers. Therefore, the Wolsong Tritium Removal Facility (WTRF) was constructed at the Wolsong Nuclear Generating Station to recover the tritium from its heavy water and has started operation this year. Tritium is considered as a radioactive waste with respect to WTRF operation and the separated tritium is stored in a metal hydride form in the storage vault of the WTRF. However it is considered useful for various industrial applications. Therefore, it was concluded that a facility for the certification and distribution of tritium should be constructed to apply tritium from the WTRF to the industrial applications. As a result, it became essential to develop a temporary storage vessel and its transport container.

Several types of tritium storage vessels and their transport containers have been developed, such as the H1616 transport container in the United States, a HTV (Hydride Transport Vessel) container in CANADA, and the ZrCo based HTV in Japan. The tritium was stored in a metal hydride form. Titanium is favorable for the long term storage of tritium, and uranium has been used as the temporary storage metal [1]. Recently, ZrCo alloy was developed as an alternative for uranium because it is not a nuclear material.

The tritium storage vessel is a simple pressure-resistant vessel and the transport container consists of a storage vessel, thermal barrier, shock absorber, and a steel drum. The tritium transport container in this study was developed to move tritium extracted from WTRF to the facility for the certification and distribution of tritium and to supply tritium to the tritium industry.

NATIONAL REGULATORY REQUIREMENTS

General Standards

The transport container of radioactive material must meet a notice from MOST (Ministry of Science and Technology) which regulates transport and packaging of a radioactive material. On the basis of this notice, the technical specifications for a tritium transport container were established.

There are two important items to point out for general handling conditions. First, transport containers should be designed in an easy to handle configuration if the weight is over 50 kg. Second, a lifting device on the container should not exceed the yield strength of a packaging material and sustain three times the package weight. The Korea National regulations classify a tritium container having above 1080 Ci as Type B. A Type B container must show its safety in normal operational conditions and accidental conditions. There are also Type A standards for storage of tritium less than 1080 Ci. However, the technical requirements of Type A packages are not as severe as Type B requirements. The Type A requirements include in part water spray, free drop, stacking, and puncture tests.

Accidental Test Specifications

The technical requirements for Type B transport containers follow:

- 9 m free drop onto an unyielding surface
- 1 m free drop onto a rigid bar which has a diameter of 15 cm and a height is of 20 cm.
- 800 °C fire test for 30 minutes
- Immersion in a water pool at a depth of 15 m for 8 hours

Free drop, puncture, fire and immersion tests must be done successively on a test container. To pass the tests, the radiation level should not exceed 10 mSv at 1 m apart from the container surface and the release amount of radioactive material should not exceed 1,080 Ci of tritium for one week after the performance of the tests.

DESIGN FACTORS

This paper describes the development of a tritium storage and transport container. Simple operational schemes include fixing tritium in a hydriding metal, storing it in a storage vessel, and transporting the containment vessel in a transport container. Before designing a transport container, several constraints for the package were defined:

- A transport container having a tritium storage vessel must be moved to a destination within one year before the pressure develops due to a helium-3 generation. If it is not possible, the pressure level of the storage vessel must be controlled to below 1 atm before movement and the transporting period is limited to one month.
- A tritium stored vessel must be designed for 10 years, and it is recommended that the pressure release is performed on the storage vessel once a year.

Capacity of tritium storage vessels

The radioactive capacity of tritium storage vessels is specified in amounts of 100,000 Ci, 10,000 Ci, 5,000 Ci, and 1,000 Ci. Table I shows the amounts of tritium and the equivalent amounts of metals for storage of tritium. As a storage metal, uranium and ZrCo alloy are considered. The effect of the storage metal on a vessel design is its volume and the equilibrium pressure for tritium gas. The expected storage metal volume is much less than the overall volume of a storage vessel. Two storage metals can store tritium to three times of its theoretical atomic level. However the capacity is limited to a $UT_{2.5}$ and $ZrCoT_{2.0}$ by considering the safety and the effectiveness of absorption and desorption operations which is based on the range of the plateau region of P-C-T curves.

Table I. Radioactivities of tritium and the amount of storage metal needed.

Radioactivity (Ci)	100,000	10,000	5,000	1,000
Tritium (g)	10.20	1.02	0.51	0.102
Tritium (at-mol)	3.40	0.34	0.17	0.034
Uranium (g)	299.8	30.0	15.0	3.0
Uranium (mol)	1.26	0.13	0.06	0.013
ZrCo (g)	255.4	25.5	12.8	2.6
ZrCo (mol)	1.70	0.17	0.09	0.02

Thermal Condition

Tritium is a beta decay material and generates heat. The average energy of beta rays is 5.69 keV.

$$^{3}H \rightarrow {}^{3}He + \beta \quad \text{(Eq. 1)}$$

The thermal energy of 100,000 Ci of tritium is 3.4 W; this value gradually reduces with time as calculated in the following equations.

$$H_d(t) = 1 \times 10^5 \times 3.7\times10^{10} s^{-1} \times 5.69 \text{ keV } s^{-1} \times e^{(-\lambda t)}$$
$$= 2.1 \times 10^{16} e^{(-\lambda t)} \text{ keV } s^{-1}$$
$$= 3.4 e^{(-\lambda t)} \text{ W} \quad \text{(Eq. 2)}$$

Here, a collapse constant $\lambda = \ln 2/t_{1/2} = 1.78 \times 10^{-9}$ sec^{-1}. Therefore the thermal generation is taken into consideration in the container design in order to maintain the vessel below a defined design temperature.

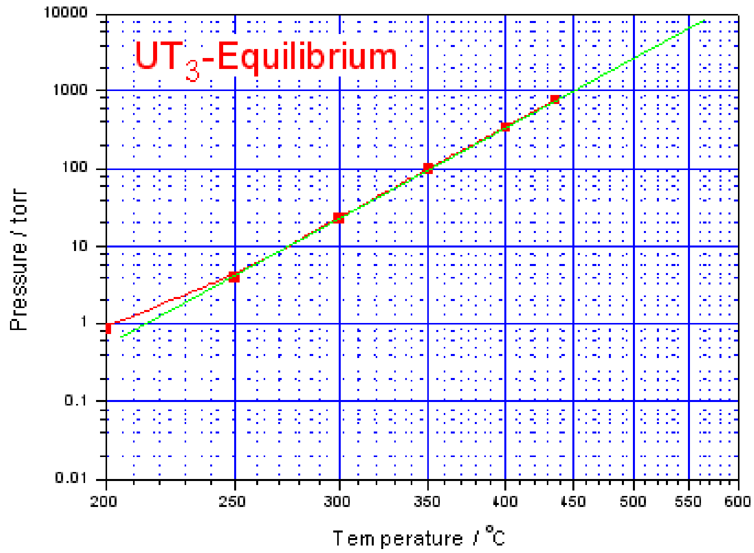

Fig. 1. Pressure equilibrium curve of uranium metal and tritium.

Pressure Condition

In a vessel design, the pressure condition is a key factor because it directly affects the mechanical safety. Pressure development in a tritium storage vessel is caused by thermal release of absorbed atoms from a storage metal and helium generation due to decay.

- Thermal equilibrium: The retention of tritium in a metal is controlled by the equilibrium pressure. The equilibrium pressure increases with temperature. The highest temperature at which the vessel could operate is around 400~500 °C when desorption process is being operated. Other thermal factors such as decay heat or a fire test could be taken into consideration, but its effect on the increase of vessel temperature is less than the equilibrium pressure. Fig. 1 shows the equilibrium pressure with a temperature for UT_3 [2]. The equilibrium pressures at 450 and 500 °C are 1.32 atm and 3.42 atm respectively. Therefore it is concluded that the pressure condition due to a thermal energy is not severe.

- Radioactive decay: a gaseous He-3 is generated when tritium in a storage metal decays. The formed He-3 does not release instantly from the metal, but it generally starts to release after about one year. The generation rates meet the release rate after three years according to previous reports [3-4]. This behavior is similar in uranium and ZrCo alloys. Release of He-3 from the storage metal causes a pressure to develop in the storage vessel (Table II). Table II shows tritium and He-3 quantity and pressure versus time, is based on the assumption that the generated He-3 is released entirely right after its birth. According to the Table II, the pressure at 10 years in a storage vessel unvented is around 29.9 atm. Therefore, accounting for radioactive decay is very important in designing a pressure vessel.

Table II. Pressure development due to radioactive decay in a storage vessel (Vol. 1.5 L at 100 °C) containing 100,000 Ci tritium.

Year	T(mol)	^{3}He(mol)	Pre.(atm)
0	3.4	0	0
1	3.213991	0.186009	3.80
2	3.038158	0.361842	7.38
3	2.871945	0.528055	10.78
4	2.714825	0.685175	13.98
5	2.566301	0.833699	17.01
6	2.425903	0.974097	19.88
7	2.293185	1.106815	22.59
8	2.167729	1.232271	25.15
9	2.049135	1.350865	27.57
10	1.93703	1.46297	29.85

Radiation shielding

The maximum energy of beta-ray from tritium decay is about 18.54 keV. The maximum travel distance is about 6 mm in air and 7 μm in water. A metal barrier can easily block the beta ray and so the radiation shielding is not as critical in designing a vessel.

DESIGN CONCEPTS

Storage Vessel

The basic design concepts for a tritium storage vessel are determined and are summarized as follow:

- Design pressure is determined by the tritium decay.
- Storage vessel must resist the pressure due to the He-3 release for 10 years without any discharge.
- All parts in vessel must be joined by welding so as to sustain its air tightness.
- There are two valves for the vessel which serves as an inlet and an outlet.
- Metal filters are attached at the end of the inner tubes to prevent the escape of metal powder.
- The valves used have a good thermal resistance and air tightness.
- The valve location is sufficiently away from the vessel surface to reduce thermal transfer which affects the desorption process.
- A compact valve is recommended to reduce the vessel size.
- A VCR fitting is needed for the valves to connect other devices like a manifold.
- There are valve supporting bars on the vessel.
- The vessel material is a stainless steel.

Secondary container

The following requirements apply to the design concepts for secondary container.

- This is for the protection of a storage vessel from an outer accidental impact.
- This can serve as a sealing in case of valve leakage on the storage vessel.
- The secondary container is easy to separate from the storage vessel, thus a flange joint is recommended.
- A metal gasket or O-ring is recommended as a sealing material.
- The shape of the secondary container is easy to change.
- The parts that project from the container surface should be minimized.

Transport container

The following concepts apply to the design of the transport container.

- This container should be capable of releasing internally generated thermal energy and thermal blocking externally generated thermal energy simultaneously. The decay heat must be removed and the heat outside due to an accidental fire must be blocked.
- There are shock absorbing materials in the container.

- There is a need for a lifting device on the surface.
- This container must be water proof.
- The shape is adequate for loading on a transport vehicle.

As mentioned above, necessary factors for design of a tritium storage vessel and transport container are described. A more detailed discussion over the factors will be mentioned in design sections.

DESIGN SPECIFICATIONS

Storage Vessel Description

A proto-type storage vessel was designed on the basis of the design concepts (Fig. 2). It is a pressure vessel with two valves. There is a valve support which ties the two valves on the vessel. The bottom ends of a valve line in a vessel are welded with metal filters and the valves have 1/4" female VCR fittings. The valves and support are covered tightly with a protective cap. The protective cap is connected to the vessel body using a flange. It can be said that the cap acts like a secondary container. The leak tightness of the flange is accomplished by the use of a metal O-ring. All of the component parts are welded except for the flange joint.

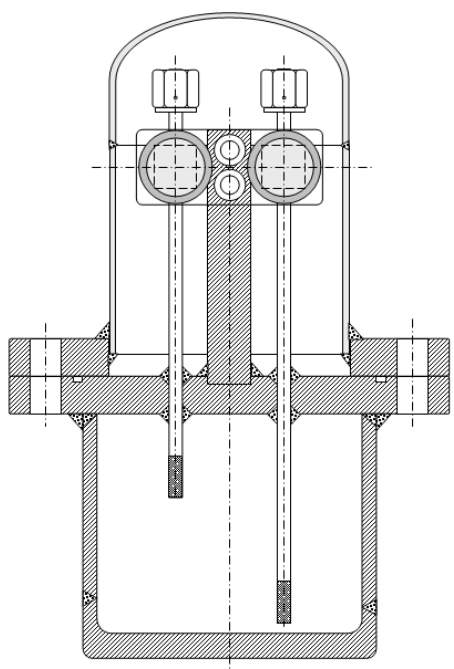

Fig. 2. Schematic diagram of tritium storage vessel.

Vessel body

The storage vessel is cylindrical in shape. The upper surface of the cylinder must be large enough to accommodate two valves. The necessary area is determined roughly by the size of two Swagelok SS-4H bellows valves. Other factors are also considered such like handling for transportation, placement for a sealing gasket, and a convenient location for heating elements. The final cylinder size is summarized in Table III.

The specified cylinder is designed for an inner pressure of 40 atm. The free volume in the vessel is 1241 ml except for the uranium volume of 80ml. Based on those parameters, the pressure developed within the vessel after 10 years is estimated to be 36 atm. Thus it is concluded that the proposed stainless steel cylinder design is sufficient for storing a 100,000 Ci of tritium. The blocking plate is attached by a welding on the bottom side of the cylinder opening. The thickness of the plate is 12 mm.

Table III. Specifications of a basic cylinder for the vessel body.

No.	O.D. (mm)	Height (mm)	I.D.(mm)	Vol. (ml)
Schedule 40	139.8	105	126.6	1321

Flange

The upper side of the cylinder opening is connected by a flange which is also used for the connection of the secondary container. The secondary container does not cover all portions of the storage vessel but the upper part mainly to enclose the valves. The thickness of a flange is 18 mm and the O.D. is 210 mm. There are 12 each M12 bolts to connect the secondary container.

Secondary container

The secondary container is cap shaped with a flange, and the O.D. is the same as a storage vessel, but the thickness is 3.4 mm, and the height is about 180 mm. The bottom part is composed of a flange to attach to the storage vessel flange. Its design pressure is 10 atm. For the leak-tightness of the secondary container, metal seal-ring is used on the flange.

Sealing

A metal O-ring (Garlock helicoflex) is used to seal the flange between a storage vessel and the secondary container. It is a silver coated with a tubing O.D. of 0.125 inch and a ring O.D of 5.860 inch.

Valves

The selected valve is the Swagelok Bellows-Sealed valve SS-4H. The maximum pressure is 68.9 bar and the maximum allowable operating temperature is 315 °C.

VESSEL ARTICLE

A proto-type storage vessel is manufactured with 316stainless steel wall material (Fig. 3). The storage volume is about 1320 ml and the design pressure is 40 atm. For the secondary container, the protective cap has a design pressure of 10 atm. The metal filters are 7 μm stainless steel filters. The amount of storage material contained is 255.4 g of ZrCo alloy for storage of 100,000Ci of tritium.

Fig. 3. Tritium storage vessel (right) with secondary container (left).

CONCLUSION

This paper describes the development of a tritium storage vessel and its transport container. The purpose of this container is to move the tritium from Wolsong TRF to the facility of certification and distribution. A prototype vessel was designed with a capacity of 100kCi and the container was designed to the Type B transportation package standards. Prior to designing, the design concepts were reviewed for the storage vessel, the secondary container, and the transport container. The detailed design specification was determined by factors such as the amount of tritium and the storage material, the thermal condition by the decay heat, desorption condition, the maximum possible pressure limit, and etc. Through various considerations, a cap protected storage vessel with two valves and its support was suggested. Activities are underway to finalize the specifications for a transport container. The size and materials to be used will be confirmed through a thermal and impact simulations.

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