Shipping Grossly Dewatered resins in the RT-100 Type B Transportation Cask – 16068

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ABSTRACT

Ion-exchange resins are used in the purification of coolant water in boiling water reactor nuclear power plants. The spent resins are a form of low-level or intermediate-level radioactive waste. These resins may have a relatively high specific activity level and are normally transported to a disposal facility within a secondary container placed in a Type B transportation cask.

During transportation, hydrogen gas may build up in the cask due to radiolysis of the hydrogenous material in the contents. In the licensing process, a Type B cask is carefully analyzed to ensure that the maximum amount of hydrogen gas generated does not exceed 5%. The calculation to determine the mole fraction of hydrogen gas generated is a function of many variables, including the properties of the contents and the volume ratios of the contents. Because water generates hydrogen gas when it undergoes radiolysis, the amount of water present in the waste is normally limited.

Typically, Type B transportation casks are allowed to carry dewatered resins, meaning less than 1% free-standing water by volume. To ensure compliance with this limitation, the dewatering process requires specialized equipment to pump the water from the secondary container.

In an effort to enhance the usability of the RT-100 Type B transportation cask, Robatel Technologies re-analyzed the hydrogen gas generation calculation for contents including “grossly dewatered” resins. Grossly dewatered resins are defined as resins containing less than 20% free-standing water by volume. This higher limit is made possible by a more thorough hydrogen gas generation calculation, which ensures that the flammability limit is not reached during shipment.

In July 2015, The USNRC issued Revision 1 of the Certificate of Compliance for the Robatel Technologies RT-100 Type B transportation cask. This revision allows the cask to be used for grossly dewatered resins. With the revised Certificate of Compliance, the RT-100 is the first of its kind whose authorized contents include greater than 1% free liquids by volume.

As a result of this change, the cask user can meet the 20% maximum free-standing water volume with a much simpler gravity-driven dewatering process. It is no longer necessary to have a complex dewatering system to ensure compliance with regulatory requirements.

INTRODUCTION

Management of spent ion-exchange resins is a critical aspect of nuclear power plant operations. These resins are used to extract contaminates from water circuits, including make-up water, condensate, spent fuel pool, and reactor coolant circuits. Some of these contaminates include sodium, silica, chloride, and sulfates. When the amount of contaminates exceed operating specifications, the resins must be regenerated or replaced. If the resins contain radioactive nuclides, they cannot be regenerated, and must be properly disposed. A number of methods are used for treatment and disposal of spent resins: solidification (cementation, bituminization, or plastic solidification), oxidative decomposition (dry or wet oxidation), super-compaction, or transfer and disposal in a high integrity container (HIC) [1].

The average total volume of spent ion-exchange resins generated annually by commercial nuclear power plants in the United States is about 2568 cubic meters (90,620 cubic feet) [2]. These resins are classified as Class A, B, or C depending on their radioactivity, where Class A is the least hazardous and Class C is the most hazardous. (Generators normally limit spent ion-exchange resins to Class A or B due to disposal limitations on Class C waste.) The resins are generally transported in a Type B transportation cask to a near-surface disposal facility. Currently there are four licensed and operating disposal facilities in the United States.

The US Nuclear Regulatory Commission (NRC) established a set of requirements for waste in 10 CFR Part 61.56 to facilitate handling at the disposal site, and for health and safety of personnel. One requirement is that *“solid waste containing liquid shall contain as little free standing and noncorrosive liquid as is reasonably achievable, but in no case shall the liquid exceed 1% of the volume.”* It is normal for generators to dewater resins prior to transportation in order to meet this requirement at the disposal site. Possibly for this reason, Type B transportation casks are normally licensed for contents including “dewatered resins”.

The typical dewatering process is described as follows; (1) A HIC or liner equipped with an underdrain manifold is filled with waste, (2) suction is applied to the manifold to remove water from the HIC or liner, (3) once a loss of suction is experienced, pump down is continued for a specified period of time, (4) the HIC or liner is allowed to rest for a prescribed period of time, (5) the underdrain manifold is siphoned for a prescribed period of time, (6) the volume of collected liquid is measured. If the volume is less than a prescribed quantity, it can be demonstrated that the HIC or liner contains less than 1% free-standing liquid [3]. An example of this type of dewatering device is shown in Figure 1.

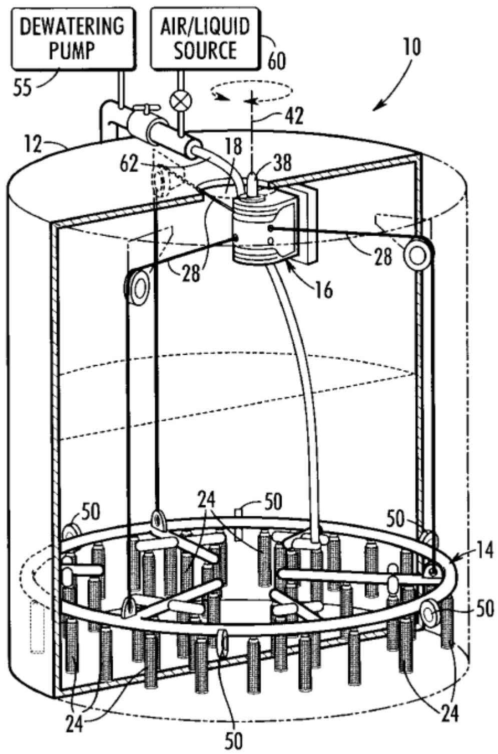

Figure 1. Example of a Dewatering Device [4]

This dewatering process has some drawbacks. Dewatering can take several days to complete. If the container is not shipped immediately, another dewatering attempt may be required. This may result in significant personnel dose. Additionally, the generator or shipper takes the responsibility to ensure the waste meets the requirements of 10 CFR Part 61.56. If the generator or shipper declares the HIC or liner as dewatered, and the moisture content is more than expected when it arrives at the disposal facility, then this situation may be in violation the Certificate of Compliance and could result in a financial penalty [5, 6, 7, 8].

An alternative approach may be possible, were the generator takes on less risk and reduces exposure to site personnel, while meeting transportation and disposal requirements. In this approach, the generator “grossly dewaters” the HIC or liner to ensure the waste is less than 20% free-standing water by volume. This may be achieved through a simple gravity-driven approach, rather than a complex dewatering system. Regardless of the type of system used, a second dewatering attempt after storage may not be necessary due to the higher free-standing liquid limit. The HIC or liner is then loaded in a Type B cask certified to carry grossly dewatered resins, such as the RT-100, and transported to a disposal facility, such as Waste Control Specialists (WCS), authorized to treat and process resins that have not been certified by the generator to meet the less than 1% free-standing liquid requirement [9].

In 2015, Robatel Technologies, working in collaboration with Exelon and WCS, revised the RT-100 Type B(U) cask safety analysis report to account for shipment of grossly dewatered resins. This effort required a review and revision of the containment analysis to ensure the hydrogen gas generated through the process of radiolysis during transportation did not exceed 5% by volume. The certificate of compliance was revised in 2015 to include grossly dewatered contents. This paper describes the containment analysis and the tools available to the cask user to ensure regulatory compliance.

HYDROGEN GAS GENERATION

Hydrogen gas can accumulate in closed containers due to radiolysis of hydrogenous material in the contents. Based on NRC guidance, the flammability limit of 0.05 volume fraction hydrogen in air should be avoided. This can be accomplished by following the guidance outlined in NUREG/CR-6673 [10]. The methodology to verify the flammability limit is not exceeded is summarized as follows:

1. Determination of the G-values for the contents.
2. Establish volume ratios for the contents to determine the fraction of decay heat energy absorbed by each content type.
3. Establish the free gas volume.
4. Calculate the maximum allowable decay heat as a function of waste volume.
5. Provide the cask user with two tools to verify a specific shipment:
    a. A simplified model, the Loading Curve, where some variables are fixed.
    b. An analytical model, where the user may input values for each variable.

General Description of the Model

A general description of the containment model used to define the cask contents was developed as a basis for the calculation. The certificate of compliance for the RT-100 limits the contents to:

Dispersible solids, in the form of both dewatered and grossly dewatered resins and filters, contained within secondary containers.

A simplified containment model is shown in Figure 2, with further details given in subsequent sections. The RT-100 transportation cask contains a polyethylene liner held in place with shoring. The secondary container includes a volume of waste, consisting of ionic resin, air, and water. Some water is present as moisture contained within the resin bead, along with a volume of “free water” settled at the bottom of the secondary container.

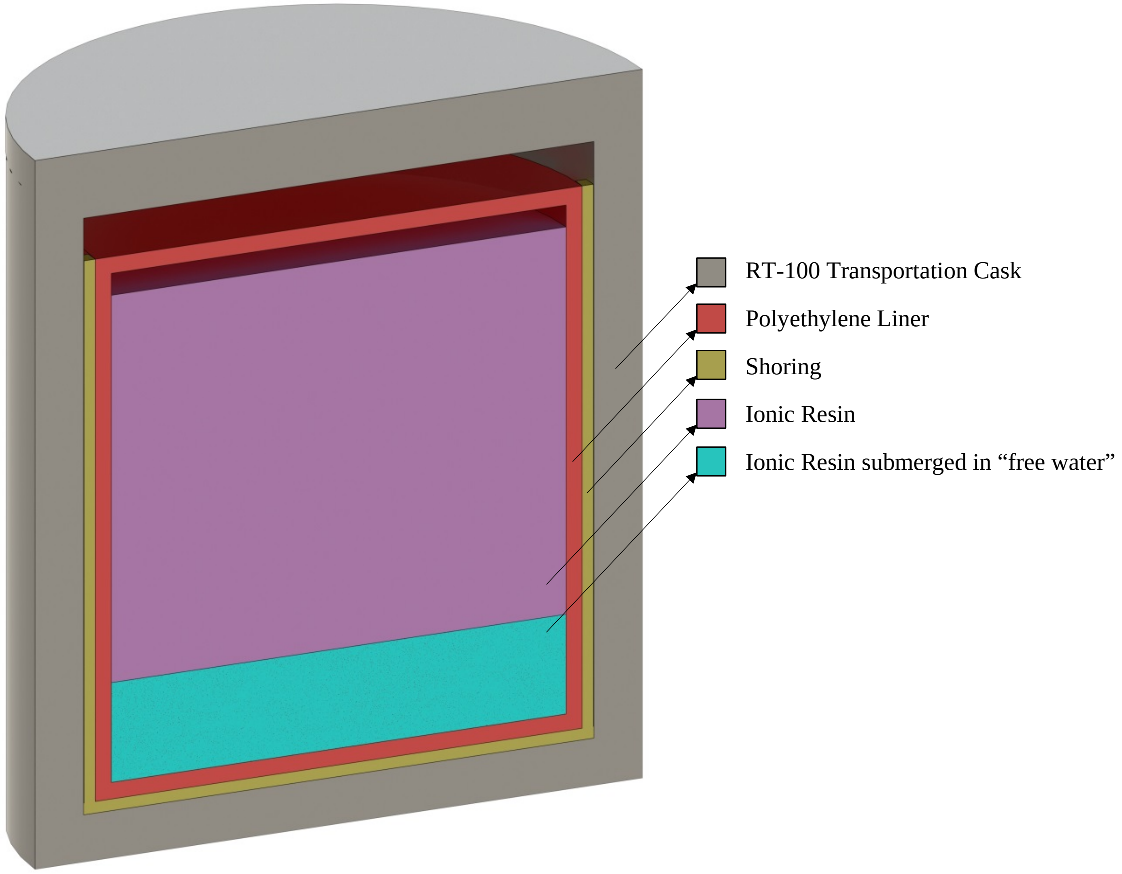

Figure 2. RT-100 Containment Model

Determination of G-Values

First the radiolytic hydrogen yield, or G-value, is established for each content type. Potential materials in the waste that can undergo radiolysis are polystyrene, nylon, polyamides, ion exchange resins, and any residual water. Secondary container and shoring materials include polyethylene, wood and polypropylene. Robatel Technologies created a bounding model by establishing some basic restrictions and eliminating materials with lower G-values. As a result, the model may be simplified to include only the following materials as shown in Table 1.

Table 1. Containment Model Contents

Content Type	Material
Waste	Ion Exchange Resins
Waste	Water
Shoring and Liner	Polyethylene

Establishing Volume Ratios

The volume ratios of the contents must be established to determine the fraction of decay heat energy absorbed by each material type. Two variables are established; the volume occupied by the waste (V_{waste}) and the volume occupied by the secondary container, shoring, and filters in the waste (V_C).

The volume occupied by the waste is assumed to consist of ion-exchange resin, water, and air. The ion-exchange resin is assumed to take the shape of uniform spheres, constituting 63.36% of the waste volume. The water is assumed to take up 25.75% of the waste volume, to account for grossly dewatered contents. The remaining waste volume is assumed to be air.

Establishing Free Gas Volume

The free gas volume (V) is simply the cask cavity volume minus the sum of the container, shoring, and filter volume (V_C), and the waste volume occupied by ion-exchange resin and water ($0.8911V_{waste}$).

Calculate Maximum Allowable Decay Heat

The maximum allowable decay heat (D_H) is calculated using eq. 4.8 from NUREG/CR-6673:

$$X_H = \frac{n_H}{n_0 + n_{net}} = \frac{\frac{D_H}{100}\frac{\alpha G_T t}{A_N}}{\frac{P_0 V}{R_g T_0} + \frac{D_H}{100}\frac{G_T t}{A_N}}$$

This equation is simplified following the method described in Section 4.4.2 through Section 4.4.5 of the RT-100 Safety Analysis Report [11], based on the previously established volume ratios for the three types of contents:

$$D_H = \frac{50 A_N X_H \frac{P_0 V}{R_g T_0}(0.2575V_{waste} + 0.6336V_{waste} + V_C)}{(0.6336V_{waste})G_{Ti}t[\alpha_i - X_H] + V_C G_{TC} t[\alpha_C - X_H] + (0.2575V_{waste})G_{TW}t[\alpha_W - X_H]}$$

SIMPLIFIED MODEL (LOADING CURVE)

A simplified model known as the loading curve can be created to assist the cask user. The loading curve is simply the maximum allowable decay heat (D_H) as a function of the waste volume (V_{waste}). First the mole fraction of hydrogen (X_H) is set at 5%. Next we fix the shipment time (t) at 10 days, and set the initial pressure (P_0) and temperature (T_0) at 1 atm and 38 °C (100 °F). We then fix the volume occupied by the liner and shoring (V_C) by limiting the liner types. The other variables are either constants (A_N and R_g) or previously determined (G_T and α). The result is the curve shown in Figure 3.

Following the procedure described in the RT-100 Cask Book, the user inputs each isotope to be loaded into the cask into a loading table. In addition to evaluating the shielding and containment criteria, the loading table calculates a heat load for each shipment. This heat load is automatically plotted on the loading curve as shown in the example in Figure 3. This curve can be used as long as the shipment meets certain criteria specified in the RT-100 Loading Procedure and Safety Analysis Report [11]. The loading curve provides the cask user with a simple method to evaluate the hydrogen gas generation for a given waste shipment.

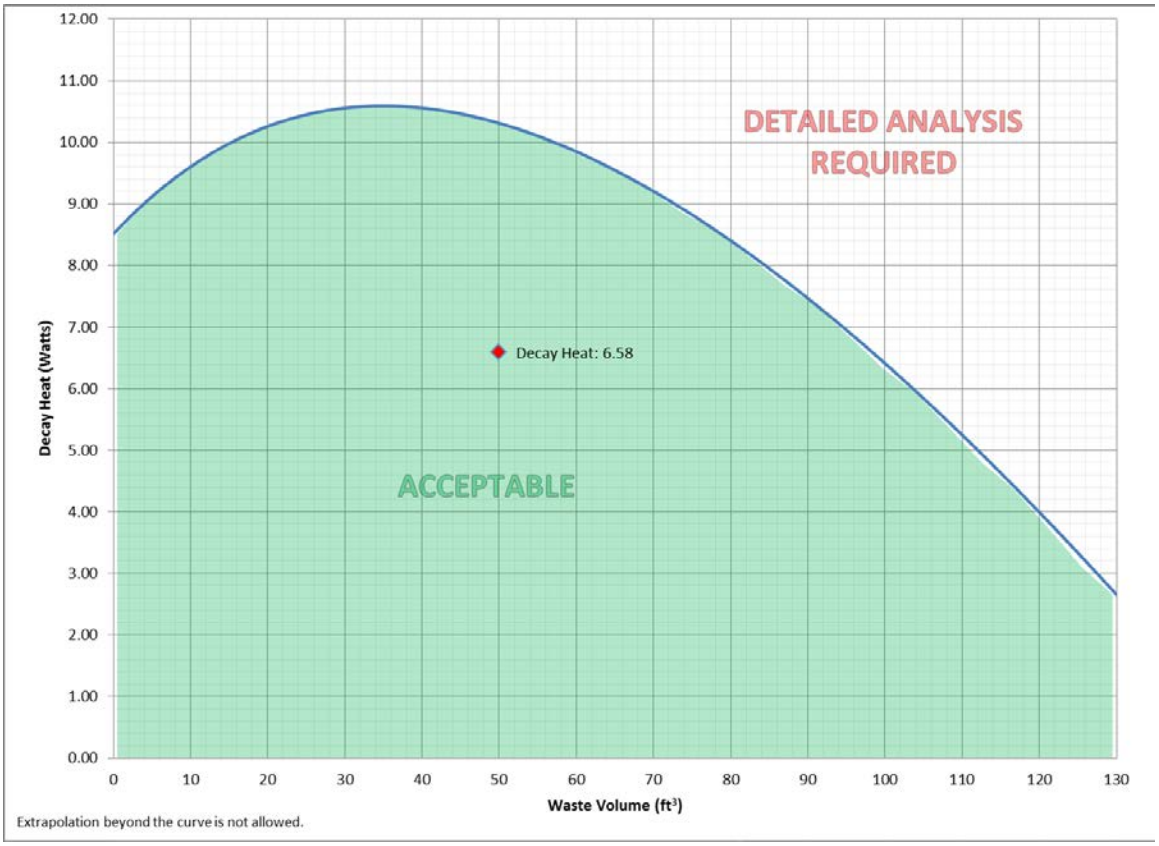

Figure 3. Package Loading Curve for Hydrogen Generation

ANALYTICAL MODEL (DETAILED ANALYSIS)

In certain cases the loading curve cannot be used; for example, if the loading conditions exceed the specified temperature or pressure, if a non-specified liner type is used, if the user includes polypropylene or polyethylene filters in the waste, or if the shipment is expected to take more than 10 days. In these cases, a more detailed analysis is required to confirm the hydrogen gas content does not exceed 5% during shipment. The user is given two options: calculate the maximum allowable shipment time for a measured decay heat, or calculate the maximum allowable decay heat for a fixed shipment time.

To assist the cask user, a table is provided to simplify the calculation. The user inputs basic information such as the loading conditions, the waste volume, and the secondary container or liner type. The table provides the user with the maximum allowable decay heat or the maximum allowable shipment time for a given waste shipment. An example analysis is shown in Figure 4.

Hydrogen Gas Generation — Analytical Model used for Detailed Analysis

1 Enter the air temperature and atmospheric pressure at the time of loading.

• Pressure	29.92	in Hg
• Temperature	89	°F

2 Enter the volume occupied by the secondary container, shoring, and polyethylene or polypropylene filters in the waste.

• select secondary container		– or –	enter volume occupied by the secondary container	
Radlok 500				ft^3
• Shoring Volume	3.7	ft^3		
• PE/PP Filter Volume		ft^3		

3 Enter the volume occupied by the ionic resin and stainless steel filters in the waste.

• Ionic Resin Bulk Volume*	133	ft^3
• Steel Filter Volume	2	ft^3

4 Enter the G-Values and Alpha Fractions for the waste.

• select Gamma/Alpha Decay Heat Distribution†

0.8 / 0.2

– or –

• enter the values based on waste characterization‡

G_{Ti}		maximum of ionic resin or stainless steel filters in the waste
G_{TC}		maximum of container, shoring, or PE/PP filters in the waste
G_{TW}		water in waste
α_i		maximum of ionic resin or stainless steel filters in the waste
α_C		maximum of container, shoring, or PE/PP filters in the waste
α_W		water in waste

5 Enter one of the following known values.

• Decay Heat of Cask Contents		Watts
– or –		
• Cask Shipment Time	10	Days

6 Calculate results.

• Maximum Allowable Decay Heat	5.12	Watts
– or –		
• Maximum Allowable Shipping Time	0.00	Days

Figure 4. Example Detailed Analysis for Hydrogen Generation

CONCLUSIONS

Currently, generators typically have internal procedures requiring a liner to be dewatered if it has set in storage for more than six months since the last dewatering evolution. The reason for this rule is that the liner must be certified as containing less than 1% free-standing liquid prior to shipment. Previously, there were no type B casks on the market authorized to ship contents containing greater than 1% free-standing liquid by volume.

As a result of the modifications to containment analysis in the RT-100 Safety Analysis Report, the cask user is now authorized to ship “grossly dewatered resins”. These shipments may consist of up to 20% free standing water by volume. The generator could meet this requirement using a simple gravity-driven approach, rather than with a more complex dewatering device. The result is that the generator may not need to keep and maintain dewatering equipment, time is saved during preparation of resins for shipment, and personnel are exposed to less radiation dosage because multiple dewatering cycles are no longer required.

In addition, because of the large safety margin of 20% free-standing water, the generator and shipper reduce their risk of violating the requirements of the Certificate of Compliance. Dewatering of the resins can take place after transportation at a disposal facility such as Waste Control Specialists authorized to treat and process resins that have not been certified by the generator to meet the less than 1% free-standing liquid requirement. This adds more flexibility to support Exelon and other cask users’ needs during periods when waste needs to ship out in a timely fashion.

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