**Request for Supplemental Information and Observations Model No. IR-100ST Revision 0 Docket Nos. 71-9385**

## REQUEST FOR SUPPLEMENTAL INFORMATION

RSI -Th-1 Provide the analysis of the impact from the bounding effects of the HAC fire and combusting batteries (e.g., concurrent or near concurrent events) to demonstrate that Important-to-Safety components, the content of the package, the shielding material, and the sealed source capsule, can retain their respective shielding capability and containment capability after the HAC drop, puncture, and thermal tests, considering the effects of reacting and combusting battery power cells. An evaluation should also include the number of packages on a conveyance and the material and process used to cover the package during transport.

The application describes a number of energy sources that could combust and raise temperatures beyond those analyzed with the 0.84 W decay heat described in section 3.1.2 of the application and the combusting polyurethane foam during the 30-minute 800 °C HAC fire noted in section 3.4.2. For example, section 2.7.4 of the application indicated that the maximum internal temperature of the four lithium power cells could be greater than 1,832°F (1,000°C). In addition, the resulting vented gases from combusting batteries could ignite during this condition.

However, the SAR's thermal evaluation did not consider these additional thermal inputs on the package (e.g., shielding material, lock assembly, outlet port assembly, pigtail assembly, stainless steel housing), and importantly, on the sealed source (i.e., unanalyzed condition). The combined impact of temperature associated with the 1,000 °C power cells, their ignition, and the 800 °C engulfing fire condition could raise:

1. temperatures higher than the shield material's melting point and
2. temperatures to be near the source capsule's limit for maintaining its integrity (e.g., allowable metal temperature, pressure within the capsule's pressure boundary).

For example, the higher temperatures from the power cells and their combustion during the HAC fire could potentially expose the sealed source to a temperature higher than 800°C for more than 10 minutes, which are sealed source fire conditions described in 10 CFR 71.75(b)(4). These are important considerations because, as noted in section 2.12.1.7.2.4 (SAR revision 4, June 2015), a dummy source is used during the HAC tests. Therefore, the condition of a sealed source after the tests is not evaluated. An analysis of the impact from the bounding effects of the HAC fire and combusting batteries (e.g., concurrent or near concurrent events) at transport conditions should be provided and assumptions should be accurate or conservative, rather than assuming conditions that "minimize" temperatures (see RSI-Th-2, below).

This information is needed to determine compliance with 10 CFR 71.35.

**Response:** During the 30-minute 1,475 ºF (800 ºC) HAC thermal test, the individual cells of the $LiFePO_4$ power cells would be expected to exceed the threshold temperature necessary to exceed thermal runaway. For lithium-ion power cells other than $LiFePO_4$ cells, the average temperature rise for the onset of thermal runaway was experimentally determined to be a maximum of 495 °F (257 °C) [Fire Hazard Analysis for Various Lithium Batteries, DOT/FAA/TC-16/17, March 2017]. Based on lithium-ion batteries (non-$LiFePO_4$ batteries), the maximum internal cell temperatures could be over 1,832 °F (1,000 °C) with the assumption that all four lithium power cells are 100% charged and have undergone a hypothetical thermal runaway. Note that this high temperature is within the power cell and not the temperature of the external steel casing encasing the cells. These conditions are localized to a small area in the PM Tag enclosure, which does not directly contact and is located below the welded stainless steel housing. These extreme high temperatures are from a potential short duration thermal runaway and would exceed the approximate melting temperature of 424 °F (218 °C) of the plastic material surrounding the power cells in the PM Tag enclosure [SABIC Polyetherimide Resin Technical Data Sheet, Form No. TDS-4195-en, 4/11/2018]. Even conservatively assuming the PM Tag enclosure or the sensor surround does not melt and still contains the power cells, the maximum internal cell temperature of 1,832 °F (1,000 °C) is significantly lower than the melting temperatures of either the stainless steel of the housing (2,800 °F [1,538 °C]) or the contained DU shield (2,071 °F [1,133 °C]). Another fact is that the duration of a potential thermal runaway event of lithium power cells is significantly shorter that the HAC 30-minute thermal event.

With the physical separation between the power cells and with the shorter duration, the IR-100ST package is not affected by a potential thermal runaway of the $LiFePO_4$ power cells.

The special form radioactive capsules that the IR-100ST will transport are INC Model Number A and Model Number 791, and SPEC Model VSe. Both of the INC capsules are welded metallic stainless steel encapsulations while the SPEC capsule is a welded metallic vanadium. As noted in SAR Chapter 4.0, all three capsules have been certified to comply with the special form requirements of 10 CFR §71.75. Each capsule is positioned in the approximate center of the 38-$lb_m$ DU shield, surrounded by the polyurethane foam, which are within the welded stainless steel housing. Due to the thermal mass of the DU and the insulating effect of the foam in the housing, the special form capsule is not affected by a thermal runaway event from the lithium power cells.

The applicable sections of the SAR have been updated with this information.

RSI-Th-2 Provide the following:

a) details (including supporting documents) of the combustion time period and combustion thermal energy input (e.g., Btu/hr) to the package from the thermal runaway/combusting batteries used in the package,

b) the bases for the greater than 1,000 °C (1,832 °F) battery runaway temperature, and

c) the bases for the assumptions associated with the ignition of battery vent gases.

d) clarification that the DU shield will not undergo a pyrophoric reaction when exposed to the combined effect of the 30 minute 800°C HAC fire and potential thermal runaway/combusting batteries.

Section 2.7.4 of the application noted that the battery runaway temperature could be greater than 1,000°C and assumed the following:

1. the urethane sensor surround does not melt or burn during the 30-minute 800 °C fire,

2. flames from the batteries would not directly impinge on the stainless-steel housing and would be directed away from the package housing, and

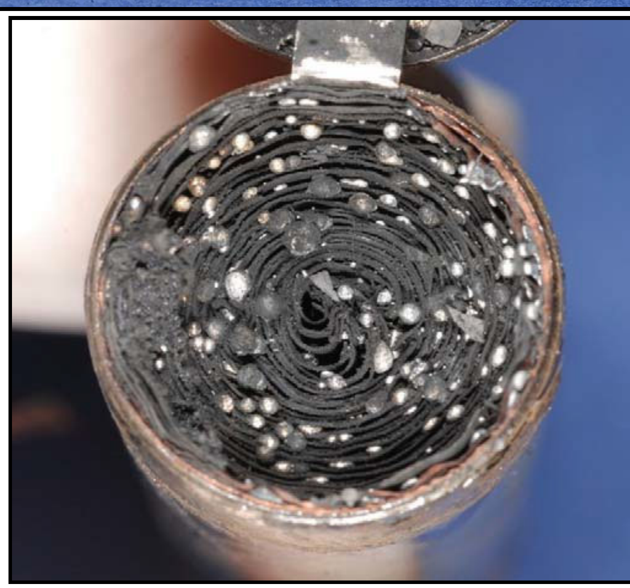
3. the assumptions of the evaluation would “minimize” temperature increases to the stainless-steel housing.

However, the bases for the above assumptions were not clearly described. For example, the application did not include the rationale for:

1. Assuming the urethane sensor surround does not melt or burn during a 30-minute 800°C fire (section 3.4.2 of the application noted that polyurethane foam was completely consumed during the HAC fire).
2. Assuming the flames from the batteries would not impinge on the stainless-steel housing.
3. The manner that high-temperature batteries (greater than 1,000°C) and flames from the batteries would interact with the package and content during a concurrent (or near concurrent) HAC fire.

**Response:** As noted in the previous response, the plastic materials utilized for the urethane sensor surround and the PM Tag enclosure would be consumed in the HAC 30-minute 1,475 °F (800 °C) thermal event. The assumption that these materials would not melt was to emphasize that the thermal effect of the potential lithium power cell thermal runaway event on the welded stainless steel housing and the DU gamma shield. This conservative assumption demonstrated that the highest reported lithium-ion battery cell temperatures are still well below the melting temperatures of either the stainless steel or the DU gamma shield. Note that should the four $LiFePO_4$ batteries experience a thermal runaway event, the resulting cell temperatures would be lower than these quoted higher cell temperatures for other lithium-ion batteries.

The pictures below illustrate the condition of an 18650 power cell following a thermal runaway event. As illustrated by these photographs, the cell separator was consumed and the aluminum within the cell melted. However, the cell's steel casing and the anode copper current collector were still intact. The resulted temperature from this event did not breach the steel casing.



The assumption that any gases released and ignited from a potential thermal runaway event of the $LiFePO_4$ batteries would not affect the stainless steel housing. The lithium power cells are located in the PM Tag enclosure, which is located below the stainless steel housing. The power cells are aligned parallel with the longitudinal axis of the IR-100ST. Again, assuming the urethane sensor surround does not melt or burn from the 30-minute 1,475 ºF (800 ºC) fire, any flames that may be generated from potential vented flammable gases (which are not "self-igniting") will be highly directional and could not be directed onto the welded stainless steel housing that is orientated 90-degrees from the top end of the $LiFePO_4$ power cells where a gas jet would originate.

It has been demonstrated in numerous burn tests that depleted uranium will not undergo a pyrophoric reaction unless there is sufficient oxygen available to oxidize the uranium. For the IR-100 CTU that was subjected to the 30-minute, 1,475 °F (800 °C) fire test, the bottom edge weld joint failure permitted oxygen to enter the stainless steel housing, which allowed the polyurethane foam to combust. However, any oxygen that did enter the cavity was not sufficient to initiate a pyrophoric reaction, as shown in Figure 3.4-2 of the SAR. Because none of the weld joints on the IR-100ST CTU packages failed, there is no pathway for excess oxygen to enter the stainless steel housing and oxidize the DU gamma shield. As noted above, the lithium power cells have no effect on the DU shield due to their bottom location and orientation.

The applicable sections of the SAR have been updated with this information.

## OBSERVATIONS

### Structural Evaluation

**Obs-St-1** Provide evaluations for hypothetical accident condition (HAC) drop and puncture tests considering a package orientation to maximize damage at or near the vent hole located on top of the package [shown on Drawing IR100ST-B, Sheet 3, Revision 0 and Safety Analysis Report (SAR) Figure 2-1], which may result in an excessive opening into the housing cavity for a subsequent fire event.

The SAR section 2.12.1.5 provides the technical basis to select a worst-case package orientation that could potentially compromise depleted uranium (DU) shield integrity and/or the special form source of the package under the free drop and puncture tests. To maximize the damage to the package and potentially separating the radioactive source, the applicant selected two orientations for the free drop and puncture tests: 1) CG-Over-Lock Assembly: This orientation targets the lock assembly that secures the special form source in the DU shield for both the NCT and the HAC; and 2) CG-Over-Lock Assembly Lower Edge: This orientation again targets the lock assembly by attacking the lower edge to potentially pry the assembly off of the body for both the NCT and HAC.

The SAR package drawing IR100ST-B and the Figure 2-1 depict a vent hole on top the package, which can be a weak point and may result in an excessive opening at this location under the free drop and puncture tests, and should be evaluated for a subsequent fire event. Under this scenario, the shielding integrity may be compromised due to an excessive opening into the housing cavity, and subsequent thermal degradation of the DU shield itself in the HAC fire event.

This information is needed to determine compliance with 10 CFR 71.73.

**Response:** The hole on the top of the stainless steel housing is for installation of the polyurethane foam that surrounds the DU shield. The handle of the sensor surround acts as a "defacto" impact limiter and protects that top area of the welded stainless steel housing from impacts from either the free drop or the subsequent 1-m puncture drop. Additionally, there is a nameplate that is pop-riveted over that area, which furthers protects the top surface of the housing. Note that the IR-100 package, which does not contain any exterior components that could act as an impact limiter, was free and puncture dropped that resulted a failure of the bottom edge weld joint. After exposure to the HAC thermal condition, the test package successfully passed the post-test shielding test, even with the bottom edge failed weld joint.

As explained in the SAR, the drop orientations were selected to attempt to dislocate the special form radioactive capsule from its shielded position in the DU gamma shield. Any movement of the source from the shield position would result in a failure of the package to meet its safety function under 10 CFR 71.

**OBS-St-2** Clarify and correct as necessary the weld details for the support saddle (Item 5) to the housing base (Item 6) shown on the SAR drawing IR100ST-B, Sheet 3, Revision 0.

The SAR drawing IR100ST-B, Section B-B depicts the weld details for attachment of the support saddle (Item 5) to the housing base (Item 6) with a note in the weld symbol tail “TYP, Item 3 to Item 4”. As shown on the bill of material for this drawing, Item 3 is the outlet port assembly and Item 4 is the copper sheet. As a result, it appears that the tail note for this weld symbol needs to be clarified and corrected as necessary since the arrow of a weld indicator line points at the joint between Item 5 and Item 6. Also, the fillet weld size and length are only shown below the weld reference line, which indicates the weld is to be provided only on one side (near side) of the support saddle. If this weld is also required to be placed on the other side (far side) of the support saddle, the fillet weld size and length also need to be shown above the weld reference line.

This information is needed to determine compliance with 10 CFR 71.73 and 10 CFR 71.107(a).

**Response:** Revision 1 of INC SAR Drawing IR100ST-B corrected the weld callout and sectional view on Sheet 3, Section B–B, that defines the 1/8-inch fillet welds for the two stainless steel DU supports (Item No. 5) to the inner wall of the stainless steel housing (Item No. 6). The corrected SAR drawing have been incorporated into the revised SAR.

**Thermal Evaluation**

**OBS-Th-1** Demonstrate that the batteries, which are new components to the package, do not affect package temperatures as reported in section 3.3.1 of the application and are bounding during normal transport conditions (NCT). The response also should consider the effect of the number of packages on a conveyance and the material and process used to cover the package during transport.

Although section 3.3.1 of the application indicated that the maximum package temperature during NCT is 155 °F, section 1.2.1 indicated that batteries can reach temperatures over 250°F. However, the application’s thermal analysis for determining package temperatures did not consider the following decay heat,

a) battery thermal input (approximately 10 Btu/hr.), or

b) potential high battery temperatures (i.e., at temperatures slightly below the maximum normal battery operational temperature setpoint).

Although the new thermal inputs may appear to be negligible, the source’s size, the proximity and location of the battery (with a temperature greater than 250 °F) to the sealed source, insolation thermal inputs, the manner and number of packages during transport, and the aggregate effects could have an impact on important component temperatures greater than those analyzed (e.g., battery operation limits).

This information is needed to determine compliance with 10 CFR 71.35 and 71.43(g).

**Response:** To determine the effect of the $LiFePO_4$ power cells on the NCT maximum temperature, ANSYS® model was updated to include the PM Tag enclosure in the lower part of the sensor surround. The PM Tag enclosure was conservatively modeled at a steady-state temperature of 140 °F (60 °C). This temperature corresponds to the maximum operating temperature that the power cell manufacturer specifies for charging or discharging the power cells. This assumed temperature results in a significantly greater heatload generated by the actual 2.5 W (8.54 Btu/hr) during charging of the power cells. With this thermal input for the $LiFePO_4$ power cells, the worst-case surface temperature for the IR-100ST is 156 °F (69 °C) that remains on the top, horizontal metallic surface, with the average surface temperature being 135 °F (57 °C). These revised temperatures compare to the original temperatures of 155 °F (68 °C) and 131 °F (55 °C), respectively, that excluded the thermal effect of the power cells.

A potential thermal runaway of the $LiFePO_4$ power cells would result in temperatures that would melt the plastic PM Tag enclosure and the bottom of the sensor surround. This melting of the enclosure would then result in the power cells falling away from the welded stainless steel housing and/or the steel housing falling over on its side. In either situation, the power cells have no effect on the stainless steel or the shielding of the special form capsule in the heavy DU shield.

Unlike the radioactive special form capsules, the dummy special form capsule utilized in the test units did not contain any materials that would have reduced the internal void volume in the capsule. This capsule configuration is a worst-case condition for a potential rupture of the welded metallic capsule during the 30-minute 1,475 °F (800 °C) fire event. No rupture of the dummy capsule occurred in the IR-100 package that was exposed to the HAC thermal event.

To prevent the effects of a potential thermal runaway, these power cells incorporate the following protective design features:

- Vent seals that activate at an internal high pressure of 261 to 348 psi (1.8 to 2.4 MPa)
- A current interrupt device (CID) that activates on excessive pressure due an overcharge condition
- A shutdown separator that activates when cells reach a temperature of 266 °F (130 °C), which could melt the cell's poly-separators

Note that a thermal runaway event is considered an off-normal event and is not considered a NCT event per 10 CFR §71.71.

The IR-100ST package is transported as a single package shipment**.** Therefore, the effect from the shipment of multiple packages does not apply.

The applicable sections of the SAR have been updated with this information.