Condition Evaluated:

The condition this technical evaluation addresses is the current state and overall future serviceability of the roof of building 2336W (Waste Receiving and Processing, or WRAP). There are a series of issues with the WRAP roof that became evident immediately after construction. Currently it is challenging to demonstrate that the roof has sufficient structural capacity to resist code prescribed loads. In order to best describe this condition, the unique roof structure of WRAP will be described, and a history of the issues that have been encountered with the roof will be detailed. The WRAP roof has exceeded it's warranty life of 10 years. The purpose of this technical evaluation is to provide a description of the justification for roof repair or replacement so that the facility may stay in service for an additional period of 25 years.

WRAP Building Description and Original Construction:

The WRAP structure is a 38,000 square foot pre-manufactured metal building manufactured by American Buildings. It was constructed in 1994. Kaiser Engineers Hanford (KEH), the prime Hanford site contractor at that time, administered the construction of the building. United Engineers and Constructors was design agent for KEH. The overall framing system and lateral force resisting system of the structure is typical for metal buildings (steel moment resisting frames in one direction, rod bracing in the other direction). This structure has a unique feature for metal buildings, it has interior masonry walls. These masonry walls are supported laterally by the metal building. A typical bay is shown in Figure 1 on the next page.

The safety basis documents are the primary regulatory documents that establish the requirements for safe operation of the WRAP facility. The solid waste operations complex Master Documented Safety Analysis, (MDSA) HNF-14741 Revision 12a describes the WRAP roof in two ways. The WRAP roof is part of the HVAC system, and the roof is part of the overall WRAP structure. The WRAP roof is a component of the HVAC ventilation system in the sense that it is part of the physical barrier required to maintain air pressure and flow of the system. The WRAP roof is also a component of the overall WRAP structure. The MDSA credits the WRAP roof as safety significant. The MDSA requires that the WRAP facility safely withstand a Performance Category 2, (PC-2), seismic event. Like all metal buildings, the WRAP roof is not a structural diaphragm. The roof structural panels are not counted on to transfer force in their own plane. The only seismic function the roof panels perform is to transfer their own seismic reaction to the supporting roof structure.
FIG. 1 PARTIAL ROOF FRAMING PLAN
SCALE: 1/8" = 1'-0"
Roof Structure Description:

The roof structure consists of urethane foam filled metal panels. Per the manufacturer's product data, the urethane foam is minimum 90% closed cell. These panels are 2 1/2" thick, and consist of 24 gauge (.0276 in. thick), top and bottom sheets filled with urethane foam. They were manufactured by American Panel Industries. This type of panel in a roof application is unique. The manufacturing company is no longer in business. The panels are 44 5/8" wide. The length of the panels at the ridge is 30'-6 1/2". The length of the panels at the eave is 29-8". A section view of the roof structure at the eave is shown in figure 2. The length of the panels between the eave and ridge is 30'-0". The panels are supported by 9 1/2" deep cold formed "Z" purlins spaced at 5'-0". The panels are connected to the roof purlins with three "Bulb-Tite" rivets per panel placed through the Z-Purlins (placed from below, extending through the top flange of the Z-purlin into the lower panel sheathing layer, as depicted in figure 3). The purlins are supported by steel frames at 25'-0" spacing.

**FIG. 2 EAVE DETAIL**

SCALE: 1" = 1'-0'
FIG. 3 CONNECTION DETAIL

SCALE: 1" = 1'-0"

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<tr>
<th>SECTION</th>
<th>THICKNESS T in.</th>
<th>AREA (in.^2)</th>
<th>WEIGHT lb./FT.</th>
<th>lx (in.^4)</th>
<th>Sx (in.^3)</th>
<th>rx (in.)</th>
<th>ry (in.)</th>
<th>ALLOW SHEAR STRESS (fv) ksi</th>
<th>ALLOW BEAM STRESS (fb) ksi</th>
<th>MAX ALLOW SHEAR (KIPS)</th>
<th>MAX ALLOW MOMENT (FT. KIPS)</th>
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<td>8.39</td>
<td>11.75</td>
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NOTE: MINIMUM YIELD STRESS OF STEEL = 55 KSI

FIG. 4 Z PURLIN PROPERTIES

SCALE: 1" = 1'-0"
Roof Blistering and Repair:

Within a year after the initial construction of the building roof blisters appeared. As the temperature of the roof panels increased, gases created by the urethane foam trapped within the sealed panels expanded. Thus, large blisters appeared on the top surface of the panels. These blisters ranged in size from 1 in. to 16 in. in diameter and approximately 8 in. in height. The occurrence of blisters were spread randomly across the surface of the roof. The roof panels were under warranty from the manufacturer. A repair effort was completed. Small holes were drilled in the top metal sheet of the panel at the center of each blister. Workers then applied pressure to the blisters, collapsing them. Adhesive was injected into the vent holes. The holes were sealed with screws. Some screws were placed with a neoprene washer, others were not. For several years after 1995 there was blistering during the summer with an associated repair effort. See figure 5. Blistering is no longer occurring on the roof panels.

Along with the physical repair of the panels the prime contractor required that the panel manufacturer certify that the repaired panels were structurally sound. The capacity of the panels was originally based on testing rather than analysis. In 1995 a calculation was submitted and accepted that investigated the repaired panels. The calculation was performed by an Engineer named John A. Harstock. Harstock authored a book titled "Design of foam filled structures". The calculation documentation that has been discovered to date does not contain an engineering seal. The calculation assumed that the portion of the panel that received repair adhesive was ineffective in carrying imposed loads. The calculation demonstrated that a panel with reduced connectivity between the metal sheets and foam core can safely withstand code prescribed forces. There is no reason to believe that these calculations are incorrect or flawed. However, because there is no nationally accepted design code for these foam filled structural panels, there is no way to independently verify that the calculations are acceptable.
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<th>OCTOBER 9, 2019</th>
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<td>AFFECTED SYSTEM STRUCTURE OR COMPONENT</td>
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**Roof Leaking and Ongoing Maintenance:**

From the mid nineties until now the roof has leaked. In 1998 the panel manufacturer performed an inspection of the roof. The manufacturers representative stated that calking and several trim details were to blame for the leaking. From the late 1990s until now a roof repair contracting crew has intermittently been brought on site. The contractor’s efforts have been focused on testing and sealing of the screws that were placed as part of the blistering repair. If screws were unable to be tightened, they were replaced. In some cases sealant was placed over the screws. There is no evidence roof repairs beyond the maintenance of the screws has occurred.

**Evidence of Water Intrusion in Panels, Delamination Concern:**

In November of 1997 water was observed flowing upward from a repair screw location as a result of application of foot pressure on the top of the roof panel by an inspector. In April of 2018, as part of the ongoing screw maintenance effort, a screw that was suspect was removed from the roof. In this instance, water leaked out from the empty hole after the screw was removed. Recent efforts to maintain the roof have been postponed by this discovery as the project does not know the extent that other repaired panels have water intrusion. If the panels are delaminated to a greater extent then what has been previously analyzed, structural capacity cannot be relied upon. The previous blistering and repair of the panels is conceptually independent of the current frozen water driven delamination concern.

**Reference Documentation:**

1. ASTM E 72, Standard Test Methods of Conducting Strength Tests of Panels for Building Construction.
2. HNF-14741, Revision 12a, Solid Waste Operations Complex Master Documented Safety Analysis.

**Design Requirements:**

The panels were originally designed to withstand typical loads as described by 1991 Uniform Building Code, (UBC). The seismic zone was 2B. The basic wind speed was 70 mph, exposure C, (I=1.07). The design roof live load was 20 psf. The roof snow load was 20 psf. The capacity of the panels was based on tests conforming to ASTM E 72, Standard Test Methods of Conducting Strength Tests of Panels for Building Construction. The design loads applied to the panels are well within the capacity of the panels.
Performance and Regulatory Requirements:

If the panels deflect within acceptable limits with the applied service loads the panels perform acceptably from a structural code standpoint. The regulatory requirements for the panels are the structural code (the 1991 UBC).

Effect of Condition:

The effect of the leaking roof is that there has been leaking on the floor. The effect of the water within the panels may have resulted in some delamination.

Evaluation and Conclusion:

The WRAP roof is operable and conforms to the safety basis. However, the possible presence of water within the panels is a structural concern. These panels are a structural composite consisting of the top metal panel, the foam core, and the bottom metal panel working together. The metal panels themselves are very thin (24 gauge, or .0239 in. thick). If any one (or all three), of these elements were to be loaded separately, they could not resist the required load. The urethane foam between the panels acts as a link between the upper and lower metal panels. For the case of load being applied vertically downward, the top metal panel is in compression and the bottom metal panel is in tension. The urethane foam transfers shear between the top and bottom panels. If the shear transfer between the panels does not occur, the composite action, and thus strength, is greatly reduced.

The primary concern moving forward is separation, (or delamination), between the foam and the metal panels as a result of water intrusion and adhesive degradation. If ice has formed inside the panels, it is theorized that the ice has pushed outward against the top and bottom panels resulting in at least partial delamination. The following graphic, Figure 6, demonstrates the structural mechanics of the partially delaminated panel.

Translating this concern about the panels into a set rigorous conclusion of the panels either completely conforming to code requirements or entirely failing is not straightforward. Per code, the panels are required to resist seismic load, roof live load, wind loads, and snow loads. The ability of the panel to resist each load type will be discussed on the subsequent pages.
### CHPRC TECHNICAL EVALUATION

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**FIG. 6 DELAMINATION FROM FREEZING**

Scale: $\frac{3/4}{\text{in.}} = 1\text{-ft}$
Seismic Load:

With a typical building the roof panels are connected together and then these panels are connected to supporting members in a specified manner. The result is that the panels act together with each other as well as the supporting structure to form what is referred to as a diaphragm. With a diaphragm, force is transferred within the plane of the roof as well as transferred in and out of the plane of the roof. Thus, the building is tied together with the roof diaphragm. For buildings with roof diaphragms, the diaphragm forms the critical lateral force resisting element to support the structure during an earthquake.

The WRAP building is a pre-manufactured metal building. Thus, it has no roof diaphragm. Although the panels are connected to supporting members, (the purlins), there is no direct connection between the roof panels and the building's lateral force resisting elements, (the moment resisting frames or the rod braced frames). Therefore, the panels need only transfer force into and out of the plane of the panel. Because the seismic reaction is only a portion of the self weight of the panel, the seismic force that the panels must transfer is much smaller than the roof live, wind or snow load.

Snow loads:

The code required snow load for the WRAP roof is 20 PSF. Based on tests, the panels have the capacity to resist 58 PSF of snow load. About 15 in. of snow in depth equates to 20 PSF. Over the 25 year service life of WRAP, the roof has received this load on several occasions. No unacceptable deflection of the roof panels have been observed. The extent, if any, of delamination within the panels is entirely unknown. However, it can be reasoned that it is far more likely that if delamination were to exist within a panel that only a portion of the panel would be effected. Because of the reserve capacity within the panel, A panel could be partially delaminated and still not show any perceptible deflection and be able to resist the imposed snow load safely. In order for the panel to fail in a sudden dangerous manor under snow load the panel would have to have significant delamination throughout the panel width.

Wind Loads:

The code required wind load that is applied to the panels is about 40 PSF. The wind load is a uniform load. Unlike snow loads, the wind load is applied both toward and away from the panel surface. Conceptually, the issues of how the panel resists wind loads are similar to snow loads. There have been many high wind events over the years that the WRAP roof panels have withstood. In order for the panel to fail under wind load a panel would have to have significant delamination over the panel width.
Roof Live Load:

The code requires a uniform roof live load of 20 PSF or a concentrated roof live load of 300 lbs. The 300 lbs concentrated force accounts for a single worker. The primary component of current concern is the ability of the roof panel to resist the weight of an individual. However, because it is a concern that there are portions of the panels that are delaminated it is anticipated that the access of an individual on the WRAP roof could cause a local unacceptably large deflection directly below the individual that would be unsafe. Because the panels are 30' long and supported at 5' centers, and each 30' long panel segment is attached to the adjacent up or down slope panel, a complete collapse of a panel resulting in an individual falling through the roof structure is not anticipated. Throughout the service life of the WRAP facility the roof has been intermittently accessed and no large concerning deflections were reported.

Recommendation:

This technical evaluation makes the following recommendations:

1. The WRAP roof can perform its safety function, and may be utilized for its current mission, for a period of five years in its current state even though partial delamination of the panels is suspected. Because there is no nationally accepted structural design code for the foam filled panels this conclusion is based on engineering judgement rather than structural analysis. This judgement is based on the following factors:
   1.1. The foam within the panels is at least at minimum 90% closed cell foam as apposed to an open cell foam. Closed cell foam does not soak up water as open cell foam does. Thus, it is anticipated that the majority of the water that is penetrating into the panels flows through them and does not freeze resulting in delamination.
   1.2. There is reserve capacity within the panel. The capacity of the panel is greater than code required seismic, wind, snow, and roof live loads.
   1.3. The panels have performed acceptably with no signs of unacceptable deflection over the life of the structure, (1995 until present). It was observed in 1997 and 2018 that there was water within the panels. Since then, the panels have withstood walking on them as well as significant wind and snow load events.
   1.4. If delamination were to be present it is anticipated that the panels are only partially delaminated, and that a partially delaminated panel can, (with the exception of a concentrated roof live load), safely carry the design uniform forced applied to it. Full panel failure under wind or snow loads would be precipitated by observable deterioration which should be noticed in the ongoing preventive maintenance process.
2. No access should be made to the WRAP roof without fall protection or load spreading device approved by engineering prior to use. It is believed that if delamination is present, only part of the panel width is effected. Because the panels are 30' long, are supported on 5' centers, and the ends of the panels are connected to one another, it is not anticipated that the weight of an individual will result in the panel completely giving way, resulting in an individual falling through the roof structure. A localized unacceptability large local deflection of the roof panel is envisioned. This results in an unsafe walking surface.

3. Within 12 months from when this report is issued the WRAP structural design authority should perform an inspection of the top surface of the WRAP roof. The purpose of this inspection is to aid in the ability of the structural design authority to assess the magnitude of the possible panel delamination. Additionally, it should be ascertained if flashing and calking around roof penetrations and panel joints are the possible cause of leaking. It is understood that all individuals must be in fall protection to perform this inspection. The roofing expert should be a registered design professional, (generally an architect), who specializes in roof maintenance and repair projects.

4. Currently the roof is inspected on a once every five year basis. Based on the results of the initial inspection, this inspection frequency should be shortened to once a year if significant areas of delamination observed. The design authority should perform the inspection. The inspection should require roof top access. Each bay, (bay meaning each panel segment between roof purlins), of the roof should inspected directly. the inspection should include the calking and flashing between panel segments as well as the calking and flashing adjacent to all roof penetrations.

5. The WRAP roof should be repaired or replaced at this as soon as practical and within 5 years of this report. It is understood that it is planned to move the WRAP facility from it's current stand-by mode into waste processing service in future years. It is anticipated that suspending processing to perform significant roof repairs is a significant administrative concern. Although the present roof is currently acceptable, it is not judged to able to last the required 25 years. Several important issues associated with this roof repair or replacement should be considered:

5.1. The Request For Information, (RFI), process should be utilized to help develop a design service agreement between the prime onsite contractor and the roof replacement or repair design subcontractor. Because of the structural complexity of this roof system, a firm specializing in re-roofing projects of this scale and magnitude should be chosen.

5.2. Several issues with respect to roof replacement or repair should be understood by all concerned onsite prime contractor staff and be communicated to any potential design sub-contractor:
5.2.1. Because this is a nuclear facility with stringent administrative controls, roofing repair or replacement work must be done from the outside, not the inside, to as great a degree as possible. The process area in particular is a dense mechanical space that cannot accommodate the necessary scaffolding to perform roofing work from below.

5.2.2. There is a potential for contamination on the underside of the roof panels in the process area which may make removal of the inner panel more difficult.

5.2.3. Because of the significant magnitude and extent of the collateral equipment suspended from the roof purlins, replacement of the roof purlins is not feasible.

5.2.4. If an option were chosen to repair the existing roof structure by attaching sheathing materials on top of the existing roof, that newly placed sheathing should be structural as well as create a weather barrier. The existing roof panels should not be counted on to carry load. The newly placed panels should be supported directly by the existing roof purlins.

5.2.5. The current structural roof framing system only accounts for the weight of the existing foam filled panels. It does not account for the addition of a newly placed structural sheathing system above the existing one. However, the original design does allow for collateral load, (HVAC equipment, lighting, electrical trays, etc). By ascertaining the actual applied collateral load to the roof framing system, there should be sufficient reserve capacity for the structure to safely support a new sheathing system that is to be placed above the current one.