

IMPACT MITIGATION OF A MULTIPURPOSE TRANSFER CASK DURING SPENT FUEL CANISTERIZATION

P. W. Noss
Packaging Technology, Inc.
4507-D Pacific Highway East
Tacoma, WA 98424-2633
(253) 922-1450

Joe Witte
Sacramento Municipal Utility District
Rancho Seco Nuclear Generating Station
1440 Twin Cities Road
Herald, CA 95638-9799
(916) 452-3211

ABSTRACT

During the canisterization of spent fuel, structures of the spent fuel pool, fuel, and surrounding equipment must be protected from damage should the transfer cask be dropped. Different kinds of structures exist in the path of the transfer cask, each requiring different approaches for the design of impact mitigation equipment. This paper discusses some of the design approaches used for the specific case of the decommissioning of the Sacramento Municipal Utility District's Rancho Seco Station. In that case, the existing crane was not single-failure-proof per NUREG-0554, and a failure of the crane lifting cable therefore needed to be assumed. Further, due to a revision of the plant operating license associated with plant decommissioning, the site boundary radiation dose limit was reduced, which placed severe limits on the number of fuel rods which could be damaged in an accident. Additional challenges were introduced by the fact that the site facilities were designed for a significantly lighter transfer cask than the one to be used.

For these reasons, special measures to limit impact were necessary at every position of cask travel. Issues involved the protection of the fuel stored in the pool from impact with falling equipment, protection of the spent fuel pool structure during postulated impact to ensure continued leaktight operation, and structural enhancements of steel superstructures in the transfer path. Additional attention was paid to impact mitigation between the cask and the ground outside the building, in order to avoid exceeding the cask and canister design impact limits. This paper will discuss the types of issues faced and the design approaches taken to address them.

INTRODUCTION

The Rancho Seco Generating Station of the Sacramento Municipal Utility District was shut down in June, 1989, and is presently undergoing decommissioning. As a part of this task, spent fuel is to be removed from the spent fuel pool and placed in transportable NUHOMS[®] dry storage canisters. To load a canister with spent fuel, the multi-purpose transfer/transportation cask (with canister) will be lowered into a loading pit at one corner of the pool. As a consequence, the heavy cask must be suspended over spent fuel pool structures. The turbine building gantry crane

is used to move the cask, but it does not possess either a dual load path or the required safety factor of 10:1 on the maximum lifted load as required by NUREG-0554 [1]. The Nuclear Regulatory Commission has asked the District to consider the consequences of an accidental drop of the cask at any point along the transfer path, including edge drops, from the pool loading pit to the transfer trailer. The resulting considerations led to the diverse analyses outlined in this paper.

CONTROL OF HEAVY LOADS AT NUCLEAR POWER PLANTS

NUREG-0612 [2] presents guidelines for the control of heavy loads in nuclear power plants. The objectives of the recommendations contained therein are to either make the risk of a load drop acceptably small, or to assure that if the load does drop, the following four criteria are met:

- Release of radioactive material such that doses are well within 10 CFR 100 [3] limits;
- Physical reconfiguration such that criticality is avoided (i.e., k_{eff} of spent fuel is less than 0.95);
- Damage to pool structure does not lead to uncovered fuel;
- Damage to equipment does not jeopardize safe shutdown capability.

Since the crane used to handle the spent fuel during canisterization operations is not single failure proof, the effects of a drop must be considered by satisfying the first three criteria listed above. (The fourth criterion is not applicable, since the plant is not operating). These criteria affect the Rancho Seco plant in the following way:

Release of Radioactive Material and Criticality Control

The operating license of the plant included consideration of a loss-of-coolant accident which featured damage to all of the fuel in the reactor core. Since the plant is shut down, however, a less extensive accident may be postulated. For fuel handling operations, including canisterization, the bounding accident is assumed to involve only 24 spent fuel assemblies, equal to the maximum payload of a single canister. Therefore, in any handling accident, the maximum release of radioactive material is limited to the radioactive gap gas from all of the pins represented by 24 assemblies, and the bounding criticality analysis considers the worst-case configuration of the fissile material contained in 24 assemblies. The meaning of these assumptions relative to fuel handling is that any accident may result in an unlimited amount of damage to 24 fuel assemblies, but must not damage any other fuel assemblies present in the pool.

Another accident restriction arises from the acceleration limits placed on the loaded canister, equal to 75g parallel and perpendicular to the canister axis, and 25g oblique to the axis. This places limits on the impact of a transfer cask even after it is safely clear of the spent fuel pool and associated equipment.

Damage to Spent Fuel Pool Structure

If the level of water in the spent fuel pool cannot be maintained, the fuel may become uncovered. Therefore, any fuel handling accident must not result in through-wall cracking in any part of the pool floor or walls, which for purposes of analysis is assured by maintaining rebar tensile stress below the yield point.

SPENT FUEL CANISTERIZATION AT RANCHO SECO

The preceding safety criteria establish the parameters within which the safety analysis of the canisterization process took place. As safety deficiencies were discovered, design approaches aimed at mitigating the deficiencies were developed. This process was complicated by the following factors:

- The spent fuel pool and associated facilities already exist, and any changes or structural additions must be compatible with existing structures
- The available space in the transfer path is somewhat cramped, thus limiting design solutions to modest dimensions
- The spent fuel pool facilities were designed with the assumption that the transfer cask would weigh 90 tons, while the actual cask weighs 113 tons
- The pool cannot be drained for the purpose of installing modifications, greatly limiting the scope of such modifications
- In order not to multiply safety concerns, any modifications must not complicate the canisterization process.

In the analysis performed, each position along the cask transfer path was evaluated for unique circumstances relative to a hypothetical cask drop, and the consequences of such a drop determined. If the existing structure was not adequate to satisfy the safety criteria established above, some kind of modification was adopted which did satisfy the criteria. The modification might be a special restriction on travel, a change in procedure, or involve added equipment whose function was typically to absorb the transfer cask drop energy such that impact loads were below safe limits. A few of these structural modifications will now be discussed in detail. First, the path of the transfer cask inside and outside the spent fuel storage building is described.

The travel path of the cask is shown in Fig. 1. The cask moves essentially along a north-south pathway between the loading pit and the transporter. Once loaded with fuel, the cask, with the shield plug in place, is first lifted out of the loading pit and moved north onto the shelf, using a long lifting extension which keeps the crane hook dry. The cask is set down on the shelf, and the long extension is exchanged for a short extension, based on the height limit of the crane. The cask is then lifted out of the pool, and while suspended over the shelf, it is rinsed and partially drained. It then is moved over the north wall of the pool to the workstation, where it is completely drained, decontaminated, and where the canister and cask are closed. It is then lifted and moved north, outside the spent fuel storage building over the Outer Cask Catcher (OCC) at an elevation of just over 12.2 m above grade. Besides protecting the reactor's ASME Class 1 steam piping (which is now abandoned) from a cask drop accident, the OCC also protects the spent fuel pool cooling piping and equipment, which is still active. At the northern end of the OCC, approximately 11 m from the spent fuel storage building, the cask is lowered to approximately 3 m above the ground, which is high enough to clear the skid cradle as the cask transporter is backed into position beneath the cask. The cask travels a short distance to the west to facilitate downending on the transporter, and then the cask is set on the transporter and downended.

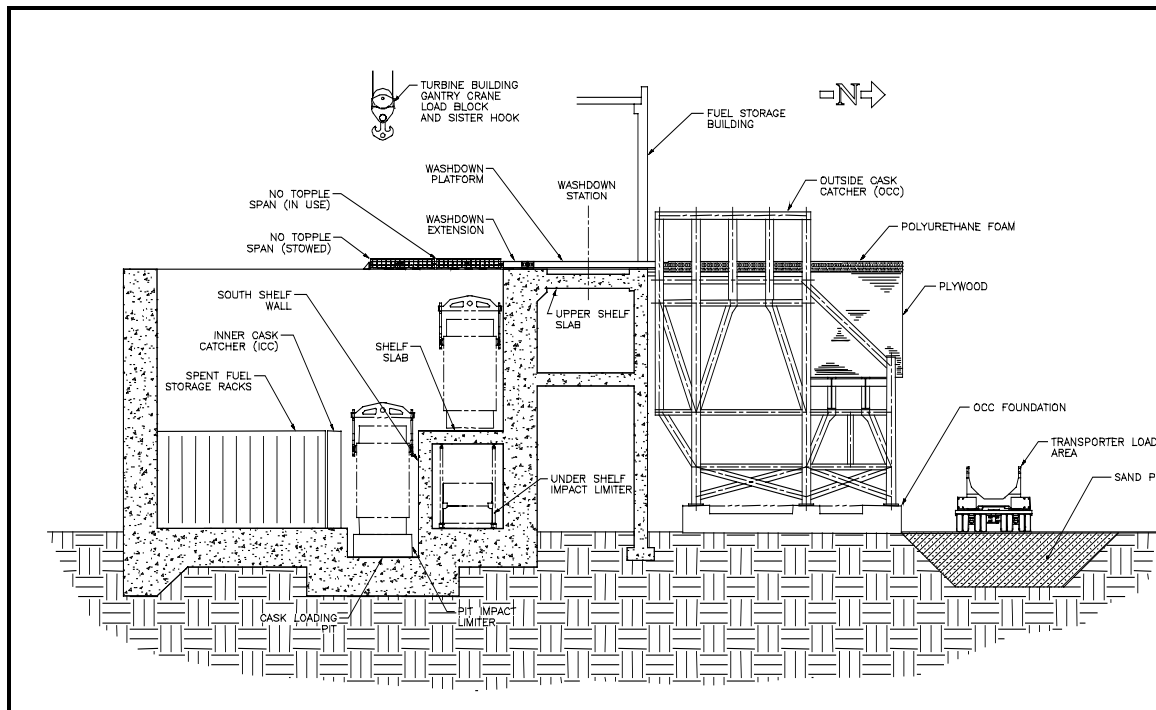


Figure 1 Transfer Cask Path from Fuel Storage Building to Transfer Trailer

SPECIFIC ANALYSIS EXAMPLES AND DESIGN SOLUTIONS

Risk to Stored Fuel due to Falling Crane Load Block

Problem: The spent fuel in the pool is kept as far as possible from any lifting operations through the use of an exclusion zone. The nearest that the transfer cask ever comes to the fuel is when the cask is placed in the underwater loading pit. In this location, the cask must be lifted with a long extension to avoid wetting the crane hook. If the crane fails by a parting of the cable, the cask, lifting extension, and crane load block fall to the pool floor. After the initial impact of the cask with the floor, the crane load block, weighing about 4.5 tons, is perched at the top of the relatively long and slender lifting extension. (The impact of the heavy cask with the pool floor is discussed below.) Since the length of the extension required (approximately 7.6 m) is greater than the distance to the nearest stored fuel (approximately 4.6 m), the crane load block could be catapulted over into the stored fuel by means of the long, rigid extension.

Solution: The extension has been redesigned to be flexible, thus eliminating the possibility that the load block could be catapulted into the stored fuel. This was done by replacing the rigid extension with an elastomer sling. The sling is an eight part braided polyester design of approximately 280 mm diameter, used in a basket hitch configuration as shown in Fig. 2. Polyester was chosen due to its compatibility with borated water. In the hypothetical accident, the load block is allowed to fall straight down rather than being catapulted to one side. The

kinetic energy of the falling load block is largely dissipated during the impact of the block with the cask through the losses associated with the internal collisions of the working parts and by the plastic deformation of the block's structural components. However, some of the energy is stored elastically, and when released, can cause a rebound of the load block, possibly endangering stored fuel. An analysis was performed to estimate the maximum amount of energy that could be stored elastically in the load block during a collision, and this energy was assumed to be converted into a trajectory towards the nearest stored fuel. Due to the relative stiffness of the load block structural components, the amount of energy which can be stored elastically is small, and the maximum trajectory of the load block was approximately 2.4 m. Therefore, the risk of damaging the stored fuel is eliminated.

Impact of Cask with Spent Fuel Pool Floor

Problem: The loaded cask is lifted out of the loading pit a distance of 6.1 m above the pit floor. Since the cask weights 113 tons, the kinetic energy of impact with the pit floor, should the crane fail, is enormous. Fluid resistance with the water consumes only about 16% of the energy. Due to the rigidity of solid concrete and steel, the impact force applied to the pit floor in an accident would be extremely large, exceeding the floor capacity. This could lead to loss of pool water and exposure of spent fuel.

Solution: To keep impact loads at suitable levels, an impact limiter is installed in the bottom of the loading pit, as shown in Fig. 2. The energy absorbing material is closed-cell polyurethane foam of approximately 110 kg/m^3 density, encased in a water-tight stainless steel shell. Besides protecting the pit floor in the case of crane failure, the limiter must also support the cask during normal loading operations due to its location on the pit floor. Therefore, the height of the limiter, and consequently its available energy absorbing stroke, is severely limited. The impact limiter design constraints therefore were, first, the maximum allowable load transferred to the pit floor,

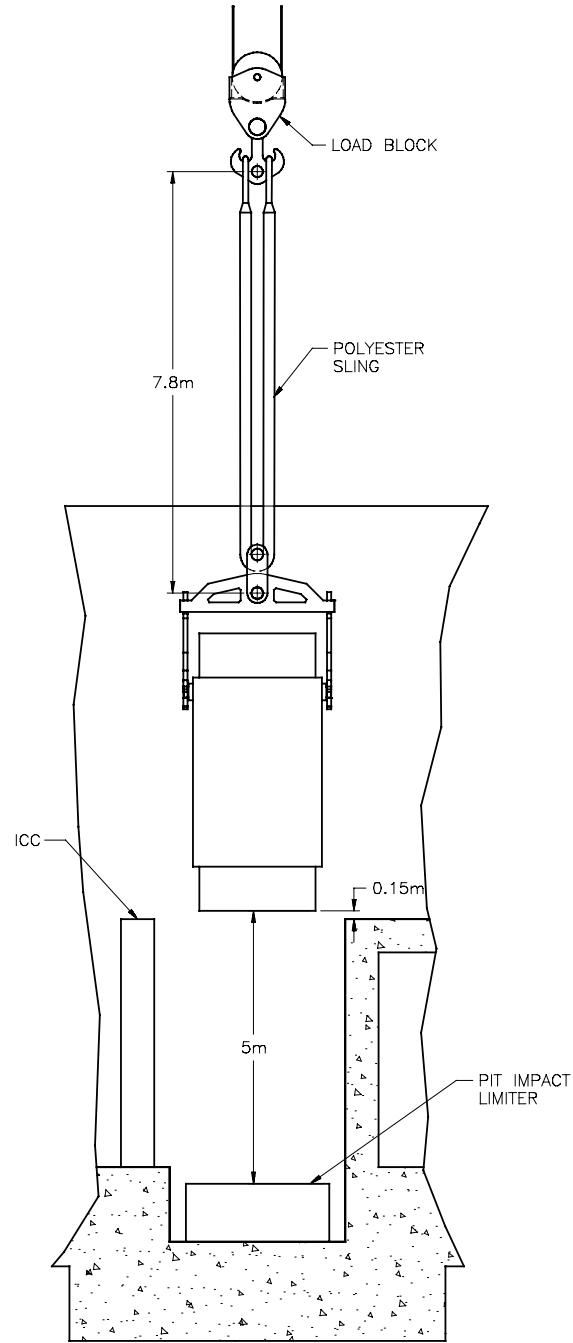


Figure 2 Cask Suspended Over Fuel Loading Pit

and second, the maximum allowable crush stroke. Because these constraints turned out to be fairly narrow, special design features were added to the limiter. To ensure proper function of the limiter in the case of off-center or oblique impact, the top surface of the limiter is covered with a well-reinforced steel strike plate, whose purpose is to uniformly distribute the crush load to the entire limiter. This maximized the efficiency of the crushable material and allowed the treatment of all credible orientations in the same way. Two other design challenges were faced: one, the desire for a leak-tight enclosure which would reduce contamination and eventual disposal costs. Since the limiter is loaded by the cask weight during normal use, the enclosure design had to consider the repeated flexure, and possible fatigue, of the enclosure components as a consequence of the elastic compression of the foam under the cask load. A second challenge related to the considerable buoyancy of the limiter assembly, which required the addition of significant amounts of steel ballast.

To protect the pit floor during an accident, the maximum impact limiter crush load must be less than the capacity of the floor, defined as the load at which the rebar reaches the yield point. If the rebar remains elastic, any cracks (some of which may be existing curing cracks) will close after impact, and leakage, if any, will be minimal. Therefore, the shear, moment, and punch capacities of several reinforced concrete sections in and near the pit were calculated using the methods outlined in ACI 349 [4]. The corresponding shear, moment, and punch loads which resulted from the predicted impact limiter design were evaluated using a finite element model of the spent fuel pool. In this way, an impact limiter was designed and constructed for the fuel loading pit which can absorb all of the kinetic energy of the falling cask without jeopardizing the leaktight integrity of the pool structure.

Impact of Cask with Lightly Designed Structures in the Washdown Area

Problem: Once out of the spent fuel pool, several operations must be carried out before the transfer cask may leave the fuel storage building. These operations should take place as close to the pool as possible, and for this purpose a concrete shelf was provided just to the north of the pool at the upper (12.2 m) elevation. However, if the cask were dropped on this shelf, even from the modest height of 178 mm, it could crash through. Not only would the spent fuel possibly spill out into the open, but the falling cask could endanger piping and equipment related to the spent fuel pool water level.

Solution: The shelf area is protected from impact with the cask by means of a bridge structure which spans it, as shown in Fig. 3. The bridge has a very low profile, so that the elevation at which the washdown activities take place is not seriously affected. Each end of the bridge rests on a structure which is capable of absorbing the load which could be generated by a cask drop anywhere on the bridge.

The bridge is fabricated from 305 mm high H-beams, welded flange-to-flange. The axis of the beams is parallel to cask travel. The south end of the bridge rests on the north wall of the pool, and the north end rests on a steel superstructure known as the Outer Cask Catcher (OCC). The behavior of the bridge in a drop accident is bounded by the relatively stiff ends and the flexible middle. For impact at the ends, the design must ensure that the impact acceleration does not exceed that which can be safely carried by the underlying structure, and for impact at the middle, it must be strong enough to absorb all of the drop energy of the falling cask with a relatively small, controlled permanent deflection.

For the end resting on the top edge of the pool wall, the cask energy is absorbed by deformation of the webs of the H-beams. For the end resting on the OCC, the load into the steel structure is limited by means of two aluminum honeycomb pads. The pads are designed to absorb all of the

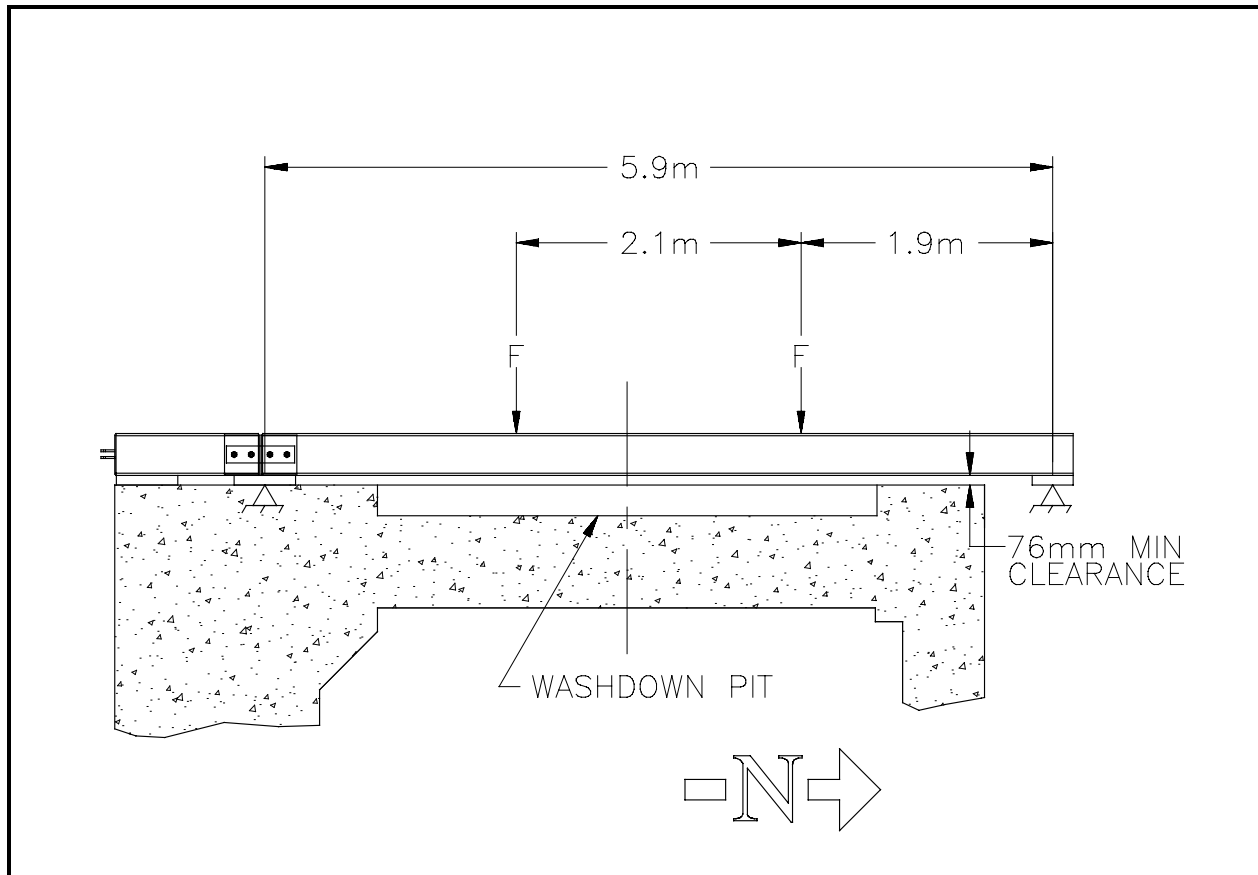


Figure 3 Cask Washdown Station Bridge

cask drop energy within the maximum load limit imposed by the capacity of the structure as well as within the deformation limit imposed by the small clearance between the bridge and the shelf. At the center of the bridge, where maximum deflection is the governing criterion, the energy is absorbed by the permanent bending deformation of the H-beams. For each of the bounding impact configurations, the spent fuel pool and related equipment is protected from damage which could lead to exposed fuel.

Impact of Cask with Outer Cask Catcher

Problem: Once the cask is ready for transport, it must be lowered from the elevation of the washdown shelf (12.2 m above grade) to the ground, but must first be moved far enough away from the fuel storage building to clear plant equipment. The OCC was designed to protect this safety related equipment while the transfer cask was carried overhead. However, due in part to the increased weight of the transfer cask over the weight which was projected at the time the plant was built, the OCC was no longer adequate, based on analysis using ANSI/AISC N690 [5].

Solution: The OCC, shown in Fig. 1, is itself not critical to safety, since there is no limit to the damage it may sustain in an accident, as long as it performs its twofold function of protecting spent fuel pool equipment and maintaining transfer cask accelerations within established bounds.

However, to have any confidence that it can do these tasks effectively, it must behave in a determinate manner, i.e., it must not experience buckling in any of its critical members. Therefore, the criteria of ANSI/AISC N690 was applied. Forces in the members and in the bolted and welded joints of the OCC were determined using a beam element FEA model, applying the cask impact load at 11 different potential impact locations. To limit overall impacts to the structure, a 0.5 m thick layer of light density polyurethane foam (approximately 80 kg/m³) was placed on the top, limiting the maximum impact to 3g. If the resulting forces in a member or joint exceeded the limits imposed by ANSI/AISC N690, the FEA model was rerun with that member or joint missing, which simulated its failure. If the loads then redistributed in such a way that the structure remained stable (i.e., all of the other components passed the test criteria), then the failure of the component in question was considered acceptable in an accident. However, such was not always the case. Some components could be allowed to fail, but others needed reinforcements, such as added cover or box plates.

Impact of the Cask with the Ground Beyond the OCC

Problem: Once the transfer cask has reached the end of the OCC, it must be lowered to the ground from a height of 12.2 m. In the case of crane failure, the target is the ground surface at the northern end of the OCC, which consists of an uncharacterized soil and a railroad line. Stringent impact limits for the cask preclude the adoption of overly conservative assumptions regarding the hardness of the target area under impact.

Solution: Since the area below the OCC is limited by nearby equipment, an analysis was performed to determine the zone of impact, since in one scenario, instead of a straight drop, the cask topples from an unstable position at the end of the OCC. Once the size of the target zone was determined, a finite element model of the ground was constructed. Due to the possibility of a topple drop, a range of impact orientations needed to be considered. Since the exact nature of the soil below the OCC was not known, and conservative assumptions led to unacceptable results, a 2.4 m deep pit was dug and backfilled with soil of known properties and compaction, as shown on the right side of Fig. 1. To facilitate use of the transfer trailer, the backfill is covered with a layer of asphalt. The FEA model of the backfill, base soil, and asphalt was used to evaluate the maximum impacts for the transfer cask falling from the OCC in any orientation.

SUMMARY

During spent fuel canisterization at commercial power plants, extremely heavy loads are lifted over structures and equipment which are important to safety. If the crane and other lifting devices are not single failure proof, consideration of crane failure must be made. At SMUD's Rancho Seco site, a detailed analysis was performed for the lift of the transfer cask at every position along its travel path from the spent fuel pool loading pit out to the downending on the transfer trailer. As a result of the analysis, several modifications were made to the facility to ensure that impact levels remained within safe limits. Modifications took the form of impact limiting devices which were added to the facility, or reinforcements of existing equipment.

REFERENCES

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