# Regulatory Licensing Pathway for a Borated Aluminum Cask Design for Onsite Used Fuel Storage

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## INTRODUCTION

Storage and cooling of used fuel is an essential component to back-end management of any nuclear fuel cycle, whether once-through, as with the case of the United States, or a fuel cycle that employs reprocessing, most notably with France, but there are a few other countries as well. This is especially important in the United States, as in the decades since the passage of the Nuclear Waste Policy Act (1982; amended 1987), while a repository site was designated at Yucca Mountain, no operational license has been granted for it. A license was granted to Private Fuel Storage, LLC, for a centralized interim storage facility on the reservation of the Skull Valley Band of Goshute Indians, a Federally-recognized Indian Tribe located in Skull Valley Utah. Opposition from State and Federal entities prevented that facility from being built and the license was eventually returned to the US Nuclear Regulatory Commission. Effectively, used fuel management policy is simply onsite storage. First, fuel is cooled in pools for up to several years for fission products to decay and lessen the heat load. Then, used fuel is moved to onsite, outdoor dry storage casks, cooled by natural convection. The water levels in the pools must be carefully monitored for occupational radiation safety. Ensuring a readily available water supply for the pools is also a critical risk mitigation requirement. During the earthquake and tsunami at Fukushima, Japan, in March 2011, both of these failed, and the loss of water in the pools resulted in partial fuel melt and the release of some fission product gases into the atmosphere.

## MOTIVATION

A collaboration led by the University of Idaho, with Boise State University, Idaho National Laboratory, and and Sakae Casting, Co., LTD (Sakae) from Tokyo, Japan began work in January 2018 to model and design a used fuel cooling cask. The intent is to develop and intermediate back end management option bridging pool storage and dry storage in order to reduce the accumulation of used fuel in the pools. Based on Sakae's unique casting expertise, the cask is comprised of borated aluminum with internal piping to cool the fuel by natural convection. The cask provides both subcriticality and occupational safety. It is a dry cask design with water removed. The gas currently is intended to be air, but modeling efforts will consider other gases if necessary. Modeling and experimental results are expected to inform the design of a prototype. Subsequent performance testing will lead to commercialization. Research consists of several directions: (1) neutronics modeling and cask design, (2) materials science experimentation, (3) heat transfer modeling and experimentation, and (4) regulatory analysis. Here, we discuss (4). Results and discussion for (1) and (2) is presented in Ref. 1.

## BACKGROUND

### Used Fuel Storage

About one third of the fuel in a nuclear reactor is replaced every 18 to 24 months due to the depletion of fissionable material and the accumulation of fission product poisons. Used fuel emits significant quantities of heat due to high levels of radiation. It is stored in onsite pools about 40 feet deep for 10 to 20 years to allow for radioactive decay to reduce the heat load as well as to provide shielding. Pumps circulate the water in the pool. Space in the pool, however, is constrained by criticality safety. Due to the lack of any repository storage in just about every country that deploys nuclear power, space is limited onsite. The pools are approaching storage capacity. Many of the pools have been reracked to optimize space, but the pool still occupies a finite volume.

Used fuel is transferred to the dry casks after the cooling period. The casks are also stored onsite, but outside behind a security fence. Dry cask storage is a robust technology, but used fuel needs to be cooled in the pools first and not transferred to the dry casks directly. A large majority of the used fuel is still stored in the pools. In a severe accident, loss of water can lead to fuel damage and possibly release radionuclides in the form of fission product gas.

In Japan, 30% of electricity generation was due to nuclear power prior to the Fukushima Daiichi accident [2]. Increasing the share of nuclear power as part of the national energy portfolio was a strategic priority. However, the natural disaster caused over 140,000 residents to evacuate within 12 miles of the plant. With the loss of onsite power and the backup diesel generators flooded, there was no power available to remove heat from the reactor core and circulate water in the used fuel pool. Subsequently, water in the pool evaporated, exposing fuel to the atmosphere. The fuel partially melted and some fission product gases were released.

Major nuclear power producing countries around the world have significant quantities of used fuel stored onsite. In metric tons, there are 13,500 in France, 19,000 in Japan, 10,900 in the Republic of Korea, and 69,000 in the USA [3], continually increasing each year. The Republic of Korea has a quickly diminishing onsite capacity to store used fuel, possibly running out of space by the end of the decade [4]. Although France and Japan reprocess used fuel, there still is a required cooling period before the fuel can be recycled. The United States and Republic of Korea adopt the once-through fuel cycle with direct disposal. Therefore, either fuel cycle requires varying cooling periods in the pool, where dwindling space is a current issue.

The share of electricity due to nuclear power in the United States is 20% with a total of about 805 TWh per year [5]. There are nearly 100 commercial power plants located in 30 states, with two under construction. Even with premature closures, and no long-term disposal option currently in place, storage of the continually accumulating stockpiles of used fuel requires attention and exploration of new solutions. Construction of additional pools onsite induces increased regulatory burden and added cost, including a large space to construct the pool, as well as the supply of additional water and a larger backup source of water, and additional monitoring equipment.

Designing a used fuel cask for intermediate storage strengthens back-end management of the fuel cycle. However, in order for this cask to be commercialized and to be considered by nuclear power operators, the design must be certified by the Nuclear Regulatory Commission (NRC). During this modeling and design phase the current NRC regulations will be analyzed for any gaps relevant to this particular storage cask design. A pathway to establishing license verification then will be developed.

### Casting Technology

Sakae Casting manufactures 'Cold Plates,' which is a water-cooled thin-type cooling plate that enables efficient temperature control of both the plate itself, and points and spaces in contact with the plate, by pumping coolant through pipes embedded in the aluminum casting. Sakae Casting will fabricate a special aluminum cast that adopts the cooling plate technology to fabricate the used fuel cask..

### Current Regulations

The nuclear power industry in the United *States* is known to be heavily regulated but still considered to be the gold standard in nuclear safety worldwide. 10CFR72 provides the current regulatory structure to certify used fuel casks of this nature - 'Licensing Requirements for the Independent Storage of Spent Nuclear Fuel, High-level Radioactive Waste, and Reactor-Related Greater Than Class C Waste.' This regulation includes certification of casks for dry storage of used nuclear fuel at independent storage installations, the site of an operating nuclear power plant, or away-from-reactor storage, which is clearly applicable to this used fuel storage cask.

A 'Standard Review Plan for Dry Cask Storage Systems' is contained in NUREG-1536. This provides guidance to NRC staff for approving the Certificate of Compliance of a dry storage system at a general license facility. Here, only onsite storage at the nuclear power plant is considered. The NUREG contains guidelines for evaluation of the design criteria, cask structure, heat transfer, shielding, subcriticality, materials properties, and quality assurance. Technical Review Guidance is provided for the application of computational modeling software. Though the NRC does not endorse any specific code or vendor, the regulation requires that the validation of the software be validated by the applicant.

## DESCRIPTION OF THE ACTUAL WORK

### Cask Design Guidance

Both SCALE and MCNP will be used to simulate used fuel composition and design the cask. Both of these computational tools should meet the requirements under NUREG-1536. During the modeling and design phase, the relevant Subparts of 10CFR72 are F - General Design Criteria, G - Quality

Assurance, and K - General License for Storage of Spent Fuel at Power Reactor Sites.

Subpart F contains criteria for both nuclear criticality safety and radiological protection. For criticality safety, the cask must be based on permanently fixed neutron absorbing materials. The cask design meets this requirement because it is essentially a box of Cold Plates welded together and comprised of the borated aluminum with embedded piping. The use of boron of course provides the neutron absorbing materials. For radiological protection, the most important criteria is to shield any personnel from radiation exposure. The cask is designed currently for a conservative estimate of of 20 mSv (2 rem) per year [6]. This is a conservative estimate of 10 μSv/h for a standard year of 2000 working hours and below the NRC limit of 5 rem required in 10CFR20 which is a 25 μSv/h . Based on materials science and engineering research for the borated aluminum composition [1], actual cask design will undergo several iterations. Therefore, the 10 μSv/h provides a safety margin of to 15 μSv/h for the design. Section 72.128 also requires the cask to exhibit appropriate heat removal capability, and this is part of the current experimental effort.

Subpart G contains criteria for quality assurance such that the cask will perform safely in operation. Several sections of Subpart G relevant to the current conceptual design phase are discussed here. A potential licensee is required to assure quality applicable to design, fabrication, and testing of the task. While this is directly related to the eventual prototype that will be manufactured after the current modeling and simulation phase, we still want to develop a pathway to performance testing that will satisfy quality assurance, and this must be considered early in the conceptual design and modeling phases. Applicable sections in Subpart G include the establishment of the quality assurance program itself, which will begin with the establishment of the appropriate laboratory space for performance testing. The requirements for the quality assurance program is based on the complexity and proposed use of structures, systems, and components. Part of this is the training of personnel, which will be partially conducted by the industry partner as part of the fabrication and casting process. Measures must also be established to maintain specifications, drawings, and procedures. These are readily produced by MCNP and through standard laboratory procedures for both the materials science and engineering of the borated Al solution and heat removal experimentation. Procedures already exist for casting and can be modified for the prototype design. Maintaining control of purchased material, equipment, and services has actually been completed through the detailed budget required for the project.

Other criteria that are more relevant to after the prototype is fabricated is the establishment of a test program. Section 72.162 is fairly open ended on the requirements for such a test program that the cask ‘performs satisfactorily in service.’ The main performance measures for the cask are heat removal, subcriticality, and occupational safety. Similarly, and control of measuring and test equipment required in Section 72.162, can be consider when the final design is determined. An important requirement will be to document any corrective actions, including the cause of any failures and malfunctions.

Subpart K addresses storage of spent fuel at power reactor sites, and this is the intent of our cask design. Most importantly, a safety analysis report will be required as part of the license application. The NRC must be allowed to inspect the locations where the cask will be designed and tested. Facilities have not yet been built for this, and this will have to be considered. There is space available for prototype testing, which can be inspected. From a technical standpoint, specifications are required for content of the used fuel to be stored in the cask in Section 72.236. This includes type of fuel, burnup, enrichment, and cooling time, as well as subcriticality safety. These constraints are determined in the current conceptual design phase and are addressed in Ref. 1.

## EXPECTED RESULTS AND IMPLICATIONS

Regulations will be studied in depth to provide a matrix of design metrics for the used fuel cask based on the Subparts discussed. The current phase of research is to model and simulate the used fuel cask in order to assess which potential designs can be fabricated into a full-scale prototype for performance testing. An array of casks will be established in order to demonstrate the maximum number that can be stored to maintain criticality safety for an optimal quantity of used fuel to be stored. This is a concurrent research direction to provide design guidance as modeling and simulation progresses.

## UPCOMING WORK

Regulations will be studied to identify any gaps, including NUREG-1536. This will be applied to develop a performance testing procedure. While preparation of a safety analysis report is premature currently, an outline can be prepared in parallel. We will draw upon lessons learned from the Safety Analysis Report on the Hi-Star 100 Cask System by Holtec International, of which the author has direct experience [7]. This is a storage and transport cask , and therefore could offer insight. Additionally, Section 72.128 requires design concepts that ensure safety under normal and accident conditions. A preliminary hazards and failure modes and effects analysis will be formulated after a final cask design is determined, as part of performance testing.

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