Proceedings of the 18th International Symposium on the
Packaging and Transportation of Radioactive Materials
PATRAM 2016
September 18-23, 2016, Kobe, Japan

Paper No. 6009

Shipment of Contaminated Fresh Fuel from Closing Nuclear Reactor Facilities

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Abstract

Over the past five years, several nuclear reactors worldwide have closed unexpectedly, after fresh fuel for the next fuel reload had been delivered to the reactor. The fresh fuel is frequently stored in locations at the reactor facility, such as the spent fuel pool, where the fresh fuel can become surface contaminated. As the fresh fuel can be used in other reactors still in operation of the same design, or the uranium fuel itself can be recovered and used in other reactors, the contaminated fresh fuel must be transported to those other locations for future use.

In 2013, AREVA Inc. successfully transported contaminated fresh fuel from the San Onofre Nuclear Generating Station to the AREVA Richland facility for recovery of the uranium fuel and use in other reactors. AREVA Inc. is also transporting contaminated fresh fuel in 2016 and 2017 from the Crystal River #3 Plant to the Oconee Nuclear Station where that fresh fuel will be used in future reloads, and will be transporting contaminated fresh fuel from the Krümmel Nuclear Power Plant in Germany to the AREVA Richland facility for recovery of the fuel in 2017.

For these transports, AREVA has evaluated the certificates of licensed shipping containers to determine which containers can be used for these transports. The 51032-2 containers are being used for US-only transportation, while the ANF-10 container will be used for the international shipments. For the Crystal River shipment, AREVA has obtained a Letter Authorization from the US Nuclear Regulatory Commission to authorize the transport, and for Krümmel AREVA will be obtaining a US validation of the German certificate for the container. To execute the shipments, AREVA provides on-site personnel to the shipping facilities. Those personnel oversee the loading of the shipping containers, confirm appropriate closure of each container, prepare the transportation documentation for the shipment, and perform the shipment.

This approach has been very successful to recycle the fuel material so it is not wasted. This has also provided some much-needed revenue for facilities undergoing decommissioning.

Introduction

A number of nuclear reactors world-wide have been closed over the last several years. In some cases fresh fuel had already been delivered to the reactor and placed in the reactor, contaminating the exterior of the fresh fuel. Instead of disposing of this fresh fuel, AREVA has developed an approach where the contaminated fresh fuel is shipped from the closing reactor to either an AREVA facility for recovery of the uranium or to another reactor of the same design to use the fuel.

Nuclear Power Plants Closing

Over the last three years, several nuclear power plants have made the decision to shut down permanently. Included in that list are the San Onofre Nuclear Generating Station (SONGS), Crystal River #3 Plant, and the Krümmel Nuclear Power Plant. Those facilities had already had fresh reactor fuel delivered as part of in-progress core reloads that were suspended when the decision to permanently close the reactor was made.

Since this fuel had not yet gone critical, there is still significant economic value in that fresh fuel. The Nuclear Operators have decided to recover as much of that economic value from the fresh fuel as possible, either by finding another user for the fuel assemblies or by recovering the uranium oxide for other uses. In order to recover or reuse the fuel assemblies, the contaminated fresh fuel must be transported to either a nuclear reactor willing to use the fuel or to a fuel fabrication facility that can recover the fuel.

Selection of Shipping Container

Most fresh fuel shipping containers are either Type IF or Type AF containers, although there are some Type B(U)F containers available too. The United States does not utilize the Type IF configuration, so shipments of contaminated fresh fuel in the US must be made in a Type AF or a Type B(U)F container. In order to make the shipments in a timely manner, only containers that were already certified for shipment of the clean fresh fuel were evaluated. Then the specific contents that are going to be shipped, including the contamination, must be determined and compared against the allowable contents for the shipping container. If the specific contents are bounded by the allowable contents, no further action is required and the shipment can proceed. If there are differences between the specific and the allowable contents for the container, then additional licensing activities are necessary.

Unirradiated Uranium Determination

Since most of the shipping containers under consideration are Type AF containers, one aspect of the container selection process is confirming that the uranium in the fuel assemblies still meet the definition of unirradiated uranium. If the fuel assemblies qualify as unirradiated uranium, the fuel contents can be classified per US Nuclear Regulatory Commission (NRC) regulations in 10CFR71

[1], and international transportation regulations like SSR-6 [2], as “U (enriched to 20% or less)” which has an unlimited A_2 value, making shipment in Type AF containers acceptable. Per those regulations, the definition of unirradiated uranium is “uranium containing not more than 2×10^3 Bq of plutonium per gram of uranium-235, not more than 9×10^6 Bq of fission products per gram of uranium-235, and not more than 5×10^{-3} g of uranium-236 per gram of uranium-235.”

The contaminated fuel assemblies being considered for shipment were either loaded into the core next to fuel that had already been partially used or were stored in the spent fuel pool at these reactors next to spent fuel. While stored in those locations, the fuel was exposed to a neutron flux, so it was necessary to evaluate the fuel to determine how much plutonium, uranium-236, and fission products had been created due to exposure to that neutron flux. AREVA prepared a calculation using SCALE 6.0 [3] and its ORIGEN-ARP module to evaluate the amounts of those radionuclides in the contaminated fresh fuel. That calculation concluded that all of the radionuclides under consideration were under the limits, so the contaminated fresh fuel could be classified as unirradiated uranium. This calculation was included in the submittal to the NRC and was accepted by the NRC during their review.

Fuel Characteristics

With the conclusion that fuel still consists of unirradiated uranium, the characterization of the fuel contents is very straightforward. However, the contamination on the surface of the fuel still needs to be evaluated. Based on the water chemistry of the spent fuel pools, the radioisotopes present in the contamination are primarily cobalt-60, cesium-134 and -137, manganese-54, and antimony-125. The precise characterization of the contamination does require more field and engineering work.

As part of the contaminated fresh fuel recovery process, the Nuclear Operators at the originating facility have implemented a wash process where as much of the loose contamination on the surface of the fuel as possible is removed. That wash process is designed to remove the contamination from all surfaces of the fresh fuel, including those on the interior of the fuel assembly. After washing, the fuel is moved to a dry storage location so the fuel can dry prior to shipment, which ensures there is no liquid present inside the shipping container.

After washing, the contamination on the surface of the fuel is measured. Two different methods have been used to measure that contamination. One method is to take representative swipes of each fuel assembly to determine the worst-case surface contamination on each fuel assembly. That worst-case value is then multiplied by the total surface area of each fuel assembly to determine the total contamination on each assembly. That value is then conservatively compared to the A_2 limits for alpha emitters and beta/gamma emitters. Using that approach, the external contamination on the fuel was determined to be well under 1% of the A_2 limit, and shipment in a Type AF container would be acceptable.

The second approach was used when only dose rate data was available for the contaminated fresh fuel. First the dose rate of the washed fuel was measured. Then the contributions to the dose rate from background and from the fresh fuel itself were then subtracted, leaving the dose rate caused by the contamination. A Monte Carlo N-Particle (MCNP) model [4] was developed of the fuel assembly with the contamination assumed to be cobalt-60 that is evenly distributed on the surface of that assembly. A table was developed from that model that compared the measured dose rate to the quantity of cobalt-60 on the fuel. Relative amounts of the other radionuclides present in the fuel pool were then added to determine the total amount of contamination present on the fuel. This approach also determined that the total amount of radioactivity was several orders of magnitude below the A_2 limit and shipment in Type AF would be acceptable.

Shipping Containers Selected

For the shipment from SONGS in late 2013, AREVA had only one shipping container with the length capable of handling the CE 16x16 Long fuel used at SONGS. That container was the Model 51032-2, USA/9252/AF [5], and nine of those containers are available for use. The Model 51032-2 is authorized to ship one or two Pressurized Water Reactor (PWR) fuel assemblies with a maximum enrichment of 5.0 wt% of uranium-235. The Model 51032-2 containers are “previously approved” containers under 10CFR71 that were fabricated before April 1, 1999, and only limited changes to the design and authorized contents are authorized by the NRC. The Model 51032-2 containers had recently been used to transport some of the un-contaminated fresh fuel assemblies from AREVA Richland to SONGS. So, based on the above determinations about unirradiated uranium and the quantity of contamination on the fuel assemblies, the SONGS fuel was already authorized to ship in the container without any licensing action required.

For the Crystal River #3 fuel, the Model 51032-2 containers were selected for use, although the MAP-12 containers [6] were also considered. Since all MAP-12 containers are currently being used for on-going fuel deliveries, new MAP-12s would have to be fabricated for this shipment, so the decision was made to focus on the Model 51032-2 containers. However, close to half of the fuel assemblies at Crystal River exceeded the maximum enrichment authorized in the NRC Certificate of Compliance (CoC) for the Model 51032-2 containers, so licensing action was required.

For the shipment of fuel from Krümmel to AREVA Richland, AREVA determined that the ANF-10 container was the most appropriate container to use for this shipment. The ANF-10 container [7] is designed to ship one or two Boiling Water Reactor (BWR) fuel assemblies with a maximum enrichment of 5.0 wt% of uranium-235. Originally, the ANF-10 container only had a German Type IF certificate that was validated in several European countries, but not in the United States.

In addition, Type IF certificates are not recognized in the United States. So, two licensing actions are required before this transport can occur. First, a German Type AF certificate must be obtained for the ANF-10 container. Then, that German Type AF certificate must be validated in the United States.

Licensing Actions

Model 51032-2 Letter Authorization

The NRC has a developed a process that allows the temporary amendment by letter of NRC CoCs for discrete shipping campaigns, with a clearly defined number of shipments and time frame for those shipments. AREVA concluded that such a Letter Authorization was the most appropriate licensing action for the Crystal River #3 fuel shipment campaign. Prior to submission of the Letter Authorization request, AREVA had a public meeting with the NRC to review the planned approach, and the NRC identified that this approach appeared reasonable.

The Letter Authorization was required because some Crystal River #3 fuel assemblies exceed the maximum uranium-235 enrichment of 4.80 wt% listed in the Model 51032-2 CoC. More than half of the fuel assemblies to be shipped contained 4.55 wt%, while the rest contained 4.95 wt%. The request for the Letter Authorization proposed that each Model 51032-2 would be loaded with no more than one 4.95 wt% fuel assembly, either shipped with a 4.55 wt% assembly in the other side of the container, or with the other side of the container empty. A detailed criticality analysis using SCALE 6.0 was prepared and included with the request to demonstrate these configurations met all applicable criticality standards. The unirradiated uranium determination was also included with the request upon the recommendation of the NRC. A listing of process steps that would be implemented to ensure that each shipping container was properly loaded and to prevent the possibility of loading two 4.95 wt% assemblies into a single Model 51032-2 package were also included in the request. The original Letter Authorization [8] was issued by the NRC within four months of initial submittal after one round of Requests for Additional Information. One revision to the Letter Authorization has been issued subsequent to the initial issue [9], but that was only to modify the timing for some of the shipments.

ANF-10 Validation

The first step for obtaining the US validation for the ANF-10 is obtaining a German Type AF certificate for the container. Since the last issue of the German Type IF certificate in 2014, SSR-6 has been adopted by the German Bundesamt für Strahlenschutz (BfS), so part of this effort included updating the Safety Analysis Report to address the changes from that regulatory change. Advanced Nuclear Fuels (ANF) has submitted the request for a Type AF certificate to the BfS and expects that certificate soon. Once the German Type AF certificate is available, a validation request for the ANF-10 container will be submitted by AREVA to the US Department of Transportation (DOT).

Shipment Execution

All of these contaminated fresh fuel shipments have been or will be managed by AREVA TN. Detailed transport plans are developed for each shipment campaign. Those plans identify the roles and responsibilities for all parties involved with the shipment, including preparation of the fuel for loading, physically loading the fuel into the containers, required oversight and checking of operations, preparation of all required shipment paperwork, and final peer review of that documentation. Physical protection agreements between all involved parties are also implemented that clearly identify AREVA TN as responsible for the physical protection while shipments are in transit.

SONGS

A total of 108 contaminated fresh fuel assemblies were shipped from SONGS to AREVA Richland in 17 shipments in November and December 2013. Since there are only 9 Model 51032-2 containers, those containers were the critical path in the performance of the shipping campaign. SONGS is about a 24-hour drive from the AREVA Richland facility, so two trucks, both with team drivers, were used to minimize the downtime on each container. Each shipment consisted of four or less containers to ensure there were always containers available to be loaded by the work crews at SONGS, since it was more expensive to have an idle work crew than to use team drivers. As soon as the Model 51032-2 containers were unloaded in Richland, they were immediately returned to SONGS. Those truck drivers were essentially on-call for the complete duration of this successful shipping campaign.

Crystal River

A total of 76 contaminated fresh fuel assemblies are being shipped from Crystal River to Oconee. Approximately half of those assemblies were shipped in one campaign in July and August 2016, while the remainder of those assemblies will be shipped in another campaign in early 2017. The distance between these two facilities is about an 11-hour drive. Once again two trucks, both with team drivers, will be used for these campaigns to minimize the duration of each campaign.

Krümmel

A total of 12 contaminated fresh fuel assemblies will be shipped from Krümmel to AREVA Richland in late 2017 or early 2018. All of the ANF-10 containers will be loaded into an ISO container for this shipment. There will be ground transport to a European port, shipment by vessel on a maritime company that accepts fissile material, followed by ground transport from the North American port to Richland.

Conclusions

With recent decisions to close several nuclear reactor sites, there has been a need to ship contaminated fresh fuel from those sites to other facilities that can reuse or recycle the uranium fuel. AREVA has developed a global approach where the fresh fuel assemblies are cleaned to the maximum extent practicable, loaded into fresh fuel shipping containers, and shipped to other nuclear reactors or fuel fabrication facilities where that uranium fuel can be downloaded and reused. This approach has required some engineering and licensing work to ensure that the fresh fuel shipping containers are authorized to ship these contaminated contents. To date, this approach has been successful in removing and reusing contaminated fresh fuel from SONGS, is currently in progress at Crystal River, and will be done at several other facilities over the next few years.

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