Initial Shipment of MNSR Reactor HEU Spent Nuclear Fuel from Ghana to China

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INTRODUCTION

The repatriation of Russian and US origin fresh and spent, high enriched uranium (HEU) research reactor fuel has been conducted since 1996. In 2006, an IAEA coordinated research project (CRP) was initiated to study the feasibility of converting Chinese designed Miniature Neutron Source Reactors (MNSRs) from HEU to low enriched uranium (LEU) fuel. The study was concluded in 2012 with favorable results. The Ghana Research Reactor-1 (GHARR-1) was the first of five such MNSR reactors outside of China eligible for conversion and fuel return to China. Under a joint project involving China and Ghana as operating country, as well as the U.S.A and the IAEA, the HEU core was to be repatriated to China and a new LEU core was to be installed. The present paper discusses the preparation of the HEU core for removal, describes the logistics of the shipment of the HEU core, and the lessons learned which can be applied to the remaining MNSR shipments.

PROJECT INITIATION

The US Department of Energy's National Nuclear Security Administration (NNSA) and the International Atomic Energy Agency (IAEA) began working with the China Institute of Atomic Energy (CIAE) in February 2011 to convert Chinese-designed and fabricated Miniature Neutron Source Reactors (MNSR) from high-enriched-uranium (HEU) to low-enriched-uranium (LEU) fuel operations and removal of all HEU, fresh and spent, material from countries the Chinese provided MNSR reactors. Five (5) countries have MNSR research reactors. Those countries are Ghana, Nigeria, Pakistan, Syria, and Iran.

The Director General of the Ghana Atomic Energy Commission (GAEC) requested[1] in a letter to IAEA, dated July 9, 2014, assistance in the removal and transportation of their HEU from Ghana to China. The IAEA responded favorably to this request[2], and the GAEC, China Atomic Energy Authority (CAEA), DOE-NNSA, and the IAEA formed a team to conduct the preparations and planning for the project.

Fig. 1. The GHARR-1 Research Reactor

Contracting Mechanisms

The preparation and shipment operation was supported under a combination of and DOE/NNSA and IAEA umbrella contracts. The vast majority of preparations and licensing are supported by a contract between the GAEC and the Idaho National Laboratory. This contract covers project management, transport planning, facility modifications, and development of equipment to support the shipment.

An IAEA contract was initiated to cover the actual shipment. The IAEA prepared a tripartite contract which addressed liability with Ghana and China for support of their nuclear-related HEU fuel manipulations including removal and shipment operations.

Project Team

The project team consisted of representatives from Ghana, the IAEA, DOE/NNSA, the China Institute of Atomic Energy (CIAE, the HEU core manufacturer), as well as the China Nuclear Energy Industry Company (CNEIC) who was the appointed contracting party for China. The IAEA assigned a Project Manager for the MNSR removal program, who was responsible for managing the IAEA/GAEC/CNEIC contract and coordinating multiple consultancy meetings in Accra, Beijing, and Vienna.

The DOE/NNSA MNSR Gap Materials Program assigned the Program Manager and a supporting Country Officer to manage the INL/GAEC contract and provide technical support.

Ghana selected a primary Project Manager who served as the primary point of contact for the internal and external interfaces in the licensing process. In addition, a staff member was assigned as the primary contractual point of contact for the INL and IAEA contracts. This approach ensured works well, allowing for consistency in approach.

In addition to the project management team, several key vendors were included to support the project. Their roles will be delineated below.

Transport Concept

One of the earliest tasks under the INL contract was to develop the Transport Concept. This task consisted of two subtasks, one involving onsite activities related to preparing a package for shipment, and another related to offsite activities related to the shipment itself. The basic approach for removal of the reactor core, temporary storage, and packaging of the shipping package was developed, considering different options for shipping packages and means of loading the shipping package. Interim storage of the HEU core was necessary based on the desire for loading and testing the new LEU core and ensuing its viability prior to shipment of the HEU core.

The offsite portion included selection of a shipping package, selection of routes, and identifying means of transport. In this case, shipment by air was selected as the primary option based on the significantly lower risk associated with rapid air transport.

Shipment Mode

Air shipment was selected for this operation based on the substantial reduction in in-transit time, and therefore the time at risk for the shipment. Air shipment costs are not unreasonably higher than other transport modes.

Selection of an airport provides a certain challenge as well. Large cargo aircraft, such as the Antonov AN-124 used in similar shipments, require substantial airports with long runways and higher levels of emergency preparedness. Use of primary airports means that the shipment must be scheduled so as not to interfere with commercial traffic. In addition, adequate space is necessary to facilitate the loading of the shipping package from vehicular transport to the aircraft.

Cask Development

The TUK-145/C Type C shipping package was initially selected by the team based on its suitability for air transport of spent nuclear fuel. This system was developed by the SOSNY R&D Company, a privately owned Russian Federation company, under contract to INL. The package is made up of three separate components, and is designed to meet the Type C TS-R-1 requirements for transport of spent nuclear fuel by air. The TUK-145/C is comprised of an Energy Absorbing Container (EAC) designed by SOSNY that is used as an overpack for the ŠKODA VPVR/M cask[3], minus the shock absorbers normally installed on the ŠKODA cask for Type B shipments of spent nuclear fuel.

Fig. 2. The ŠKODA VPVR/M cask inside the TUK-145/C Energy Absorbing Container

The ŠKODA VPVR/M cask uses an inner basket specific to the physical configuration of the fuel being shipped. Development of a basket suitable for shipment of fresh MNSR fuel pins and the spent HEU MNSR core was required for the MNSR Gap Materials Program. The new basket was designed and manufactured by the original cask vendor, ŠKODA J.S. of the Czech Republic.

In order to facilitate the core removal and interim storage, a technical equipment set (TES) was developed by the SOSNY under contract to GAEC. SOSNY has extensive experience with development of transfer casks for the ŠKODA and other spent fuel casks. The TES consists of an interim transfer cask (ITC) and associated handling and support equipment for removal, storage, and installation of the reactor core. The ITC (Fig. 3) consisted of a cask with a sliding bottom shield plug and an internal hoist with grapple. By placing the ITC over the core, a grapple can be lowered to retrieve the core.

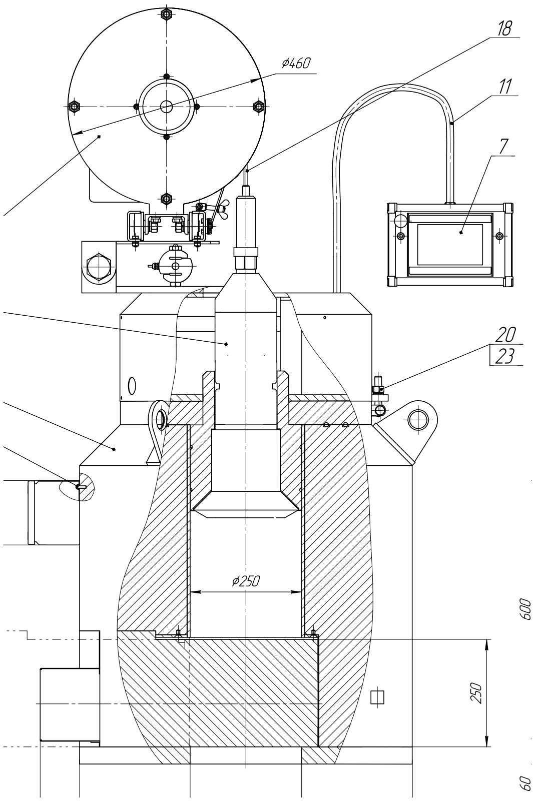

Fig. 3. Cross section of the Interim Transfer Cask

The MNSR core uses a simple bayonet bail to facilitate installation. This bail represents a very small target for a remotely operated grapple. To address this situation, SOSNY developed a mushroom shaped adapter pintle (Fig. 4) that can be manually affixed onto the bayonet and locked in place. This provides a much more robust target for the grapple device to grasp as it is lowered onto the core.

Fig. 4. The adapter pintle installed on the core

Once connected to the grapple, the core is raised by the internal hoist into the cask and the bottom valve is then closed. The ITC has sufficient shielding to allow for handling of the cask with reasonable dose rates.

FACILITY PREPARATIONS

Preparation of the facility for the shipment is a critical step. Unlike commercial reactors, shipments from research reactors are few and far between. At the time this effort was initiated, no MNSR reactor had ever shipped a spent core. As part of the Transport Concept development, facility modifications were identified that would ensure the smooth transfer of the HEU core from the reactor to the shipping package. This includes refurbishment or replacement of systems critical to the safe transfer of fuel.

Facility Modifications

One of the most significant needs identified was the ability to handle the 40 ton TUK-145/C package. A suitable platform was necessary to facilitate the manipulation and loading of the TUK-145/C package adjacent to the reactor building. A loading area pad of 28 x 15 meters was constructed of concrete adjacent to the Reactor Building for this purpose. Roadways were also refurbished to allow for access by cranes and the dedicated EAC trailer to the site.

For Ghana, a reliable power supply was essential, so a dedicated 90kVA diesel generator was installed to ensure a continuous power supply during the critical core loading operations.

Procurement of underwater radiation resistant cameras was also necessary to allow for observation of the core loading process. One camera was of the pencil type, allowing for a right-angle view that could be turned 360 degrees. The second camera was of the pan/tilt/zoom variety which allowed for movement of the lens rather than the whole camera. This feature was a critical factor based on limitations on camera placement due to the very congested periphery of the core.

SHIPMENT LICENSING

Shipment of spent nuclear fuel is governed by the individual nations involved, and typically follow the guidance provided by the IAEA[4]. Authorization of shipments typically includes development of several licenses and certifications.

The first of these is the certification of the shipping package used, which ensures that the shipping package is capable of withstanding accident conditions specified in TS-R-1. In addition, a Transportation License is prepared which assures the safety of the ground shipment between the facility and the airport. Import and Export permits are also developed to ensure the shipment is duly authorized and preparations are complete.

Cask Certification

Shipping packages are typically certified by the country of manufacture. In this case, the TUK-145/C was comprised of the EAC overpack and the ŠKODA VPVR/M cask, which were fabricated by the Russian Federation and the Czech Republic, respectively. The composite shipping package was licensed in the Russian Federation, an effort managed by SOSNY, the developer of the package. Although the TUK-145/C was previously certified for use as a Type C package, re-certification with the specific MNSR cask basket and Ghana content was required. This certification is referred to as the TUK-145/C-MNSR package. The Russian Federation cask certification was completed in April 2016.

The Ghana certification involved validation of the Russian Federation certification, and was received in August 2016.

Cask certification in China involved validation of the Russian Federation certification as well as internal validation of the cask design and construction. This effort was managed by CNEIC and supported by Ghana and SOSNY. The cask certification was issued in January 2017.

Shipment Licensing

Ghana preparations include development of a Transport License and an Export Permit. The Transport License covers the transfer of the TUK-145/C MNSR package from the GAEC facility to the Accra airport. The Transport License describes the transport modes and routes, physical security, radiological protection, and emergency response aspects of the proposed shipment. The Export License clarifies the origin, ownership, and title transfer protocols to be used as the basis for governmental approval of the shipment.

The Chinese Licensing effort also involved development of a Transport License and an Import License. The Transport License covers the transfer of the TUK-145/C-MNSR package from the airport to the CIAE facility.

As in Ghana, the Transport License describes the transport modes and routes, physical security, radiological protection, and emergency response aspects of the proposed shipment, but from the airport to the CIAE facility. An Export/Import License was also developed. This document clarifies the origin, ownership, and title transfer protocols to be used as the basis for governmental approval of the shipment.

SHIPMENT PREPARATIONS

Preparation for the shipment was carried out in several stages based on the above discussed desire to verify the viability of the new LEU core prior to shipment of the HEU core. This included training of the operating crew, removal of the HEU core, loading of the HEU core into the shipping package, and the subsequent shipment.

Training and Dry Run

While operation of the research reactor is familiar to the staff of the GHARR-1 Reactor, the irradiated core had never been removed. Training of the crew using the newly developed TES was conducted by SOSNY and representatives of the Nuclear Research Institute (UJV) in Rez, the owner and operator of the ŠKODA cask, at the GAEC site utilizing a concrete basin of the size of the reactor basin developed for this purpose. Operators utilized the TES to raise a mock core and safely load it into the ITC. They also trained on manipulating the ŠKODA cask. Operation of the ITC requires a single operator using a touch screen controller. The controller provides indication of grapple open/closed, grapple location, shield plug position, and load on the grapple.

Fig. 5. Crew Training on ITC operations

Once proficiency was achieved by the operating crew, a dry run was conducted to ensure all systems functioned appropriately. This is a critical step, as discovery of a technical issue whilst moving the core is that much more difficult to overcome.

Core Unloading

In August 2016 preparations for removal of the reactor core were complete. Clearing of the protective plastic cover and framework and the railing surrounding the reactor allowed for access to the reactor vessel. The pneumatic rabbit hoses and unnecessary instrumentation were then disconnected from the top of the reactor vessel, and the vessel lid and beryllium reflector were then removed with the technical assistance of CIAE's experts.

Additional Cadmium absorbers were installed peripheral to the core to ensure deep subcriticality. Additional instrumentation was installed peripheral to the core to allow for better measurement of neutron flux during the operation. Once the core was exposed, a frame was installed over the reactor to support the ITC (Fig. 6). The framework supports a guide tube that directs the grapple over the core, as well as the ITC itself. Both the framework and the ITC are placed using the overhead crane.

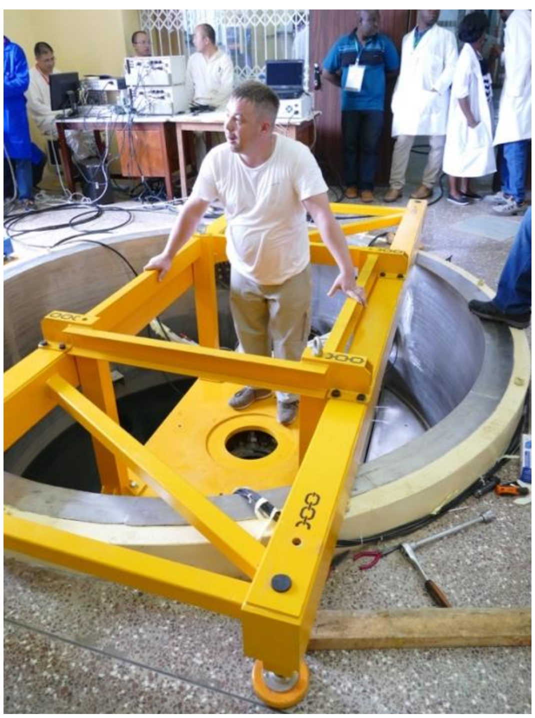

Fig. 6 The ITC Support Frame

The core was then grappled, raised into the ITC, and then secured by closing the sliding plug under the core. Dose rates in the vicinity of the core were lower than expected and well within limits. The operation was completed within a day and a half, with no major issues arising.

IAEA seals were placed on the sliding plug to provide continuity of knowledge for the core. The ITC was then taken by forklift to a secure storage facility while awaiting loading into the shipping package.

Overpack Loading

Delays in the receipt of licenses led to a decision to maintain the previous schedule for loading the core into the shipping package. This would allow for a more secure situation while awaiting receipt of licenses, as the shipping package is significantly more difficult to move than the ITC.

In October 2016, the ITC was removed from secure storage and loaded into the ŠKODA cask using the adapter ring designed to mate the ITC with the ŠKODA cask. Once loaded, the cask was closed and leak tested. IAEA seals were placed on the ŠKODA cask.

Following preparation of the ŠKODA cask, the EAC top half was removed and the ŠKODA cask was loaded into the bottom half of the EAC. The top half was then placed and the EAC was bolted. An additional set of IAEA seals was placed on the EAC in order to eliminate the need to open the EAC to verify the IAEA seals on the ŠKODA cask. The EAC package remained at the Ghana facility for several months pending authorization of the shipment.

Shipment

Authorization of the HEU shipment was contingent upon delivery of the LEU core, which was completed in July 2017. Following issue of the required licenses and permits, the HEU core shipment process commenced in late August 2017. The process started with the loading of the EAC onto its specially designed trailer at the Ghana facility. From there the TUK-145/C package was transported to the Ghana airport, where it was loaded onto the Antonov AN-124. Transport to China involved stops for refueling and crew change at two locations, resulting in a 42 hour duration for the shipment.

Fig. 7. Removal of the TUK-145/C from the Antonov


Fig. 8. Airport Cask Transfer

Upon arrival, the trailer was removed from the Antonov and moved onto the adjacent tarmac (Fig. 7). A crane was utilized to move the TUK-145/C package from the trailer onto a Chinese trailer (Fig. 8). At this point the formal transfer of title from Ghana to China was completed[5]. The TUK-145/C was then secured to the Chinese trailer for transport.

From the airport the package was shipped by ground to the Chinese Institute for Atomic Energy (Fig. 9). The core was subsequently transferred from the TUK-145/C package to a second ITC. The empty TUK-145/C was then shipped back to Ghana for subsequent use.

The core was transferred from the ITC to a storage pool in a facility at CIAE, where it will remain until a disposition path is identified.


Fig. 9. Receipt at the CIAE

SUMMARY AND CONCLUSIONS

Eliminating the threat associated with weapons-useable fissile materials requires significant planning, preparation, and extensive authorizations. Use of a multi-disciplined team comprised of facility, regulatory, and project management personnel is essential to handling the many aspects of conducting such a shipment. Subsequent shipments under the MNSR Gap Materials Program will benefit from the resolution of the many "first of a kind" issues that arose with the Ghana shipment.

The use of the TES and TUK-145/C MNSR shipping package is advantageous in that they are well suited to the loading and shipment of the MNSR core. In addition, the package is readily transportable by air, further reducing the time at risk for the shipment.

Acceleration of the shipping operation to the greatest extent possible will continue for subsequent shipments. This, along with utilization of rapid transport modes, will minimize the risk associated with the shipment of highly enriched spent nuclear fuels.

Another significant lesson learned relates to the government support of the shipments. Although political commitments have been made by the relevant governments in support of the repatriation of the fuel, no biding legal bilateral document was signed by them prior to the project inception. On of the main lessons learned is that the high level political commitments do not replace legal bilateral document on export/import issues and ownership transfer, thus the two participating countries should conclude a binding legal document early in the implementation phase of the project.

Fig. 10. The Ghana MNSR Transport Team

REFERENCES

1. Ghana Atomic Energy Commission, Request for Technical Assistance for MNSR Core Removal and Transportation Activity, A.6/SF6/Vol.30/48, 9 July 2014.
2. International Atomic Energy Agency, Request for Technical Assistance for MNSR Core Removal and Transportation Activity, 5653-T3.30.GHA-(35029151), 30 July 2014.
3. Tyacke, M.J. et. Al, Development of a New Transportation/Storage Cask System for use by the DOE Russian Research Reactor Fuel Return Program, Proceedings of PVP2007, ASME, PVP2007-26279, July 2007.
4. IAEA, 2009, Regulations for the Safe Transport of Radioactive Material, 2009 Edition Safety Requirements, TS-R-1, Vienna.
5. IAEA's press release issued on 29 Aug'17: https://www.iaea.org/newscenter/news/supporting-nuclear-non-proliferation-ghana-converts-research-reactor-from-heu-to-leu-fuel