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NIGERIAN NUCLEAR REGULATORY AUTHORITY EXPERIENCE ON NIRR-1 CORE CONVERSION FROM HEU TO LEU FUEL

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Background

- Fuel from February 2004 and December 2018.
- Plans for the conversion of MNSR to LEU and the return of the HEU spent fuel to China were initiated in 2006 when the IAEA established a CRP to coordinate individual activities.
- In February 2011, following the conclusion of the CRP, an International MNSR group was established to continue the coordination of these activities

Background

- .In August 2011, NNRA commenced pre-conversion activities by nominating Officers for IAEA Fellowship at the ANL on Practical Knowledge in the field of Regulatory Infrastructure on Nuclear Safety.
- NNRA verified and validated the conversion safety analysis carried out at the ANL.
- NNRA Officers participated actively in conversions related meetings, conferences, etc between 2014 and 2021.

Background

- In view of the international efforts at reducing the use of HEU fuel in civilian reactors, the facility's conversion was concluded in December 2018.
- The regulatory oversight of nuclear safety and radiation protection was carried out by the NNRA in line with sections 4 and 6 of the Act.
- The safety submittals received and the review process were discussed along with lessons learnt from the regulatory oversight

Inspections and Meetings

- NNRA conducted inspections to ascertain the analysis captured in the submittals to allow for clarity and to ensure that preparations were in line with the reviewed procedures & assessments.
- Inspectors were assigned to various verification activities to assist in regulatory decision making.
- Inspectors witnessed the implementation of the various phases of the Conversion exercise.
- Meetings were held with the Authorized Person to discuss requirements, additional information requested & find common grounds for ensuring effective implementation of the conversion.

Authorization

- The authorizations issued for the Core Conversion include permits, certifications, & licenses with relevant hold points & licensing conditions.
- Each of the Authorization was based successful enabled regulatory review and assessment.

The permits issued for the Core Conversion are

✓Import Permits for ES3100

✓TUK/MNSR-C with SKODA cask

✓ ITC

✓LEU fuel

✓Export Permits for TUK/MNSR-C

✓HEU fuel

✓ES3100

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Authorization

Certificates were given for

✓ES3100,

✓TUK/MNSR-C with SKODA cask

✓ITC

✓Environmental Radiation and Certificate of Compliance.

Authorization

- The licenses issued for the Core Conversion are for;

✓Core Removal and Storage of HEU Core

✓Beryllium Shim Storage Cask

Oversight

- During the Core Removal Phase, regulatory inspectors supervised the conduct of activities associated with the Core Removal and storage in the Interim Storage Cask.
- Inspectors observed the unpacking of equipment for the Dry Run, assembling and mounting on the Training Facility and the reactor building entrance by the Experts and staff of CERT.

Oversight

- Security personnel on duty during the dry run were allowed to have a view of the process by which the core was removed from the reactor vessel.
- The NNRA ensured that the Remove & Convert Teams followed all the procedures that had earlier been submitted to it for review
- NNRA staff conducted independent radiation monitoring to verify and validate result of the radiation protection team

Oversight

- NNRA verified submittals for safety, security and safeguards to ensure compliance of the Authorized Person with national and international requirements for the transport of radioactive materials.
- The crane, trailer and backup trucks were inspected by the staff of NNRA to confirm their readiness for the exercise prior to the movement.

Safeguards Verification of Core Conversion

- The purpose of the exercise was;
- to verify core conversion from High Enriched Uranium (HEU) to Low Enriched Uranium (LEU)
- Applying seals on the HEU in the Cask
- Physical Inventory Verification (PIV) of fuel pins (HEU) in pool using a camera before discharge and the three (3) fresh fuel before shipment for update of record and further ascertain correctness and completeness.

Safeguards Verification

- NNRA Inspectors observed the Safeguards Exercise & confirmed that;
- an expert from the Oakridge Lab. USA opened up the LEU fuel Pins container in the presence of Officials from CERT & the IAEA/NNRA Safeguards Inspectors.
- The LEU container enclosed two (2) cans with number 1#A & 1#B respectively & an empty container.
- The enrichment of the LEU was checked using the HM5 to be 12.63%. A zirconium is used for the cladding of the LEU.

Safeguards Verification

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Loading of LEU Core, Detectors installation & instrumentation connection & Criticality Test

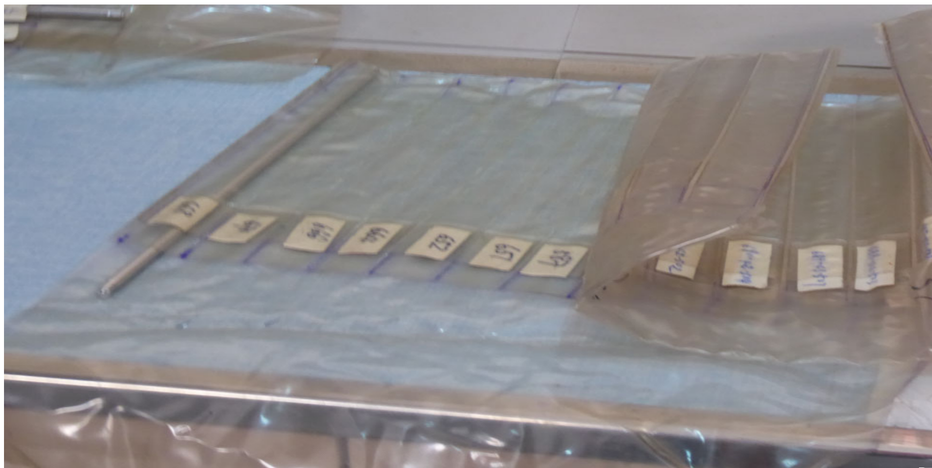
The purpose of the exercise was;

- to witness and assess the compliance of CERT with preliminary core loading & criticality experiment procedure
- to request for a comprehensive technical report of the LEU core loading activity
- to record the pool water & reactor water pH, reactor power at criticality
- to request for radiation dose during core loading before & at attainment of criticality
- to witness the criticality state & subsequent shut-down & taking of independent radiation measurement at different location within the facility

Loading of LEU Core, Detectors installation & instrumentation connection & Criticality Test

- NNRA Inspectors observed the Core loading Exercise & confirmed that;
- the installation of the control rod and its mechanism was successfully done on the 31st October 2018 at 2:20 pm
- the preliminary criticality test was started at 5:20 pm on 31st October 2018 by introduction of the AmBe source through one of the irradiation channel to activate a nuclear reaction
- no documents were received from CERT at completion of the exercise, because preliminary reports were done by the Chinese counterpart in Chinese language, therefore the need for translation to English language before submission

Preliminary core loading & criticality experiment procedure



Reactivity Adjustment Exercise I

- NNRA Inspectors observed the Commissioning Exercise and confirmed that;
- Based on initial excess reactivity, reactivity regulators & guide tubes were used to adjust excess reactivity to the designed value & worth of Cadmium Rabbit, String & Irradiation Tube.
- The items used were Reactor Control System, Reactivity regulators, Cadmium Rabbits & String.
- The reactor safely reached criticality under initial loading & the water level of reactor & pool water met designed requirements

Reactivity Adjustment Exercise I

- Cadmium absorbers 1, 2, 3 & the emergency Cadmium string were all taken out of the reactor
- Control rod and reactivity regulators were fully inserted
- Cadmium rabbits were available & Cadmium string inserted in the inner irradiation tube 5 in accordance with the approved procedure.
- The reactor was started in auto mode at neutron flux of $5x10^9$ n/cm^2s & the position of the control rod was measured to be 88mm,which was taken as the critical height

Reactivity Adjustment Exercise I

- The control rod was lifted at different positions to determine the worth of Cadmium strings, regulators, Cadmium rabbits & irradiation tube using Period Method
- The period was not below 15 sec & above 2 min. It was between 15 sec & 2 min in line with the regulatory requirements of China. Therefore, no measurement in each case took place until the necessary adjustments were done to ensure that the periods were within the range of interpolation & extrapolation.

Reactivity Adjustment Exercise

- At the beginning of each day & any break session the experiment conducted prior to the day or session was repeated & the values were the same as first measured.
- The worth of reactivity of the Cadmium rabbit, Emergency Cadmium string and irradiation tube ranges in the various positions range from 0.66 to 2. 42.

Recommendation after Observance of Commissioning Test

- Request CERT to provide the comprehensive report of the excess reactivity adjustment, the calculation of the shutdown margin & the relationship between the excess reactivity & the critical rod position.
- Take note of the result generated from the Onsite ZPT in area of reactivity adjustment and compare with the Offsite ZPT conducted in China for the LEU core

Reactivity Adjustment Exercise II

- witnessed the adjustment of the Reactivity in the vessel of the reactor core & measurement of reactivity as the Core Rod changes/moving either from down to up & vice versa.
- observed that reactor power was doubled for the increment of the neutron count at different changes of the Control Rod Position which is taken at **Zero Power** to attain **34KW** in the Fission Chamber.
- observed that the Cadmium rabbit or string is inserted to determine the neutron flux that heat up to determine either low/high reactivity in the vessel so as to know the worth of the neutrons present

Reactivity Adjustment Exercise II

- observed that NIRR-1 assembly is composed of a reactor core, beryllium reflectors & a centrally located control rod made of 3.9mm diameter & 266mm long cadmium having a stainless steel cladding of 0.5 mm thickness reactivity equivalence of about 7mk
- observed the core consists of 335 fuel pins arranged in concentric arrays & forms a square cylinder with a diameter of 231mm & a height of 230mm.
- aware total fuel loading in the fresh core is about 1.4kg of U-235.

Reactivity Adjustment Exercise II

- observed the central lattice is used for the central control rod guide tube, which is provided to facilitate the movement of the control rod
- observed that the Cadmium rabbit or string is inserted to determine the neutron flux that heat up to determine either low/high reactivity in the vessel so as to know the worth of the neutrons present
- observed excess reactivity is adjusted to achieve initial criticality by slight withdrawal of the measured rod, so its reactivity worth cannot be measured for its full length.

Reactivity Adjustment Exercise II

- observed moving a reference control rod a few steps into the reactor core, an amount of negative reactivity is inserted & the neutron flux signal begins its exponential decline thereby reducing the excess reactivity

Power Calibration

- First, the reactor was raised to 1% of the nominal operational power (340W) by presetting the neutron flux to , the average temperature difference between the inlet and outlet was 1.2.
- The reactor power was later adjusted to half of the nominal power by presetting the neutron flux to 5.0, the inlet and outlet temperature difference was 10.

TUK-145/C-MNSR Delivered to Nigeria

Delivery of TUK-145/C-MNSR cask to the site using a truck with a semi-trailer.

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NIRR-1 Reactor Spent HEU Core Removal

- The Nigeria Research Reactor-1 (NIRR-1) is the second reactor that sent its irradiated HEU core back to China after GHARR-1.
- Technology developed for removal of the HEU core from Ghana was used
  - TUK-145/C-MNSR cask
  - Transfer cask
  - Air shipment using AN-124 cargo plane

Outer and inner gates
Ramp without a horizontal platform near the gate

Reactor pool mounting on the floor

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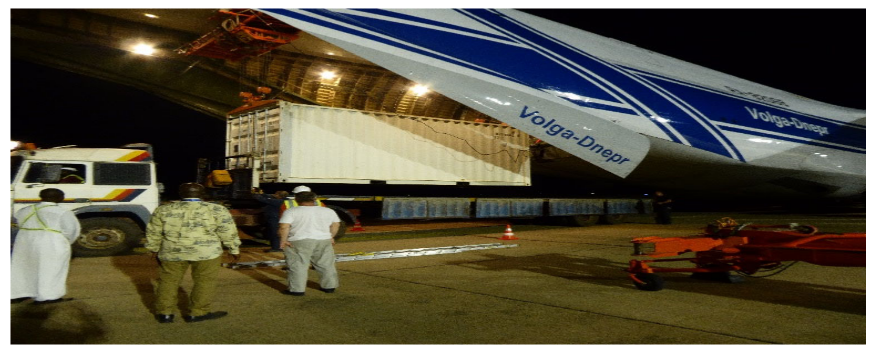
HEU Removal from Nigeria

- Four ISO containers with special equipment and the TUK-145/C-MNSR transportation cask were delivered from Ghana to Kaduna airport at 3:00 am on October 23, 2018.
- By 6:00 am all equipment was delivered to the CERT facility in Zaria.

Offloading of TUK-145/C-MNSR cask



Offloading of ISO containers

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HEU Removal from Nigeria

- By 6:00 pm the HEU core was removed from the reactor and packaged into the SKODA internal container.
- By 10:00 pm the TUK-145/C-MNSR cask was sealed by the IAEA inspector.

Equipment installation over the reactor pool

Transfer cask installation

Transfer cask with HEU inside

HEU Removal from Nigeria

- On December 6, 2018, the HEU core was delivered to China.
- In March 2019, the HEU core was discharged from the TUK-145/C-MNSR cask and stored at the spent fuel pool at CIAE.
- In April-May 2019, all 4 ISO containers and TUK-145/C-MNSR were returned to Ghana.

$3.24 \times 10^{19}\ n/cm^2$

NIRR-1PARAMETERS WITH LEU

Type :Tank-in-pool

- Nominal Power: 34kW
- Core fluence lifetime > 3.2 * 1019 n/cm2
- Coolant/Moderator: Deionised light water
- Reflector: Metallic Beryllium
- Fuel material: 13% enriched UO_2
- Control rod: 1, Stainless steel clad, Cadmium absorber
- Reactor operation mode: Manual and Automatic

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Lessons Learned

- a smooth process depended much on good coordination among all parties involved both locally and internationally.
- There is need for the establishment of a project management team even in Regulatory Bodies providing oversight for Core Conversion

Conclusion

- The regulatory oversight of the Core Conversion was provided by the NNRA to ensure effective implementation of the Conversion Exercise.
- Submittals were received from the Authorized Person, CERT and reviewed by staff of the Authority based on IAEA Safety Standards.
- The Conversion assisted in revealing some of the anticipated challenges for oversight activities associated with other nuclear installations such as the planned Nuclear Power Programme in Nigeria.
- Top priority of the NNRA is the safety of the nuclear facility, personnel and the environment before, during & after the conversion process