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Main Activities Performed for TRIGA Reactor Core Conversion From HEU 8.5/70 / LEU 8.5/20 to LEU 30/20

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ABSTRACT

In accordance with the Global Threat Reduction Initiative (GTRI), Mexico made a agreement to carry out ININ's TRIGA reactor core conversion, within the Reduced Enrichment for Research and Test Reactors (RERTR) program, to use only low-enrichment fuel (≤ 20% U^{235}). To support this compromise, several arrangements and agreements were established. The most important was the Project and Supply Agreement among IAEA, United States of America and Mexico.

The main activities performed with this purpose at National Nuclear Research Institute (ININ) during late 2011 and the firsts months of 2012 are presented in this work.

1. Introduction

Since the beginning of last decade, there have been contacts between Mexico and United States of America representatives to establish a plan for the possible conversion of ININ's TRIGA reactor to using LEU 30/20 fuel. However, this process began in earnest as a result of the statement issued at the 2010 Nuclear Security Summit, in a trilateral announcement between Mexico, United States of America and Canada [1], which stated:
"The three countries acknowledged that this project [conversion of the TRIGA reactor] also provides an important step towards the replacement of the research reactor with a new low-enriched uranium fuelled reactor in support of Mexico's nuclear energy development."

Based on this statement, a series of meetings with technical and diplomatic personnel of several organizations of Mexico, United States of America (USA) and the International Atomic Energy Agency (IAEA) were held to specify and carry this project out in the minimum possible time.

In Mexico, the following organizations took an active part in this project: Secretary of Foreign Affairs (SRE), Ministry of Energy (SENER), National Commission for Nuclear Safety (CNSNS) and National Nuclear Research Institute (ININ). Later, due to the complexity of the activities involved, it was necessary for the involvement of other government organizations, such as: The Government Secretary (SEGOB) - National Security Investigation Center (CISEN), Federal Police (PF), Secretary of National Defence (SDN), Secretary of the Navy (SM), Secretary of Finance and Public Credit-Tax Administration System (SAT) and Customs Administration, Secretary of Communications and Transport (SCT) and Port Authority (API) of Veracruz.

Regarding the United States of America, the organizations that participated were: State Department (DOS), Department of Energy (DOE), National Nuclear Security Administration (NNSA), Idaho National Laboratory (INL), General Atomics (GA) and the fuel provider TRIGA International.

Canada provided funding to support the conversion.

IAEA provided assistance to avoid bilateral compromises between the countries and acted as an intermediary for the fuels exchange. The IAEA carried out official duties relating to the supply of the new LEU fuel elements from the USA to Mexico and the return of the fresh and spent HEU fuel elements from Mexico to the USA.

2. General activities plan

The main activities to carry out the ININ TRIGA Mark III reactor conversion project are grouped in the following sections:

- Negotiation and agreements among Mexico, USA and IAEA and between Mexican organizations,
- Activities to get authorization of operation with LEU 30/20 fuel
- Authorization for LEU 30/20 fuels storage
- Documents issued by ININ to fill the reload activities with LEU 30/20 fuels
- Quality assurance activities
- Main activities related to preparations, receipt/inspection of LEU fuels, reload and reactor tests
- Participation of different government institutions,
- Cut and packing of 28 no irradiated HEU fuels,
- Cut of irradiated HEU fuels (3 control rods and 1 instrumented element)

2.1. Negotiation and agreements among Mexico, USA and IAEA and between Mexican Organizations.

As a result of technical meetings among Mexico, USA and IAEA, it was constituted: The Project and Supply Agreement-PSA – GOV/2011/36 approved on June 7, 2011, and Project and Supply Agreement Supplement, signed on November 18, 2011, which stated the activities and responsibilities of each of the signatory countries, as well as IAEA.

Responsibilities related to the reactor conversion project were established for each organization through an agreement between ININ and NNSA and one agreement and two Statement of Works between ININ and INL.

Two agreements between SENER and ININ were established, one on November 16, 2011, and the other on December 1, 2011. In those agreements, tasks were assigned and responsibilities were specified for the organizations to fulfill obligations specified in the Project and Supply Agreement (PSA) and its supplement.

2.2. Activities to get authorization of operation with LEU 30/20 fuel.

Several meetings were held with the regulatory organization. It was proposed that a work program and information provided to serve as a basis for the respective safety evaluations and, if applicable, to get authorization of reactor operation with LEU 30/20 fuel. The regulatory basis was specified by the USNRC NUREG 1537[2], chapter 18, appendix 18.1, adapted to ININ's reactor-specific situation.

The chapters of the Reactor Safety Report (ISR) that were revised to support the authorization were: Chapter 1 – General Description of the Installation, Chapter 4 – Description of Reactor, Chapter 12 – Operations Direction, Chapter 13 – Analysis of Accidents (in its section 13.1 Maximum Hypothetical Accident), and Chapter 14 – Technical Specifications of Operation;

After reviewing the information presented, the regulatory organization generated 63 requests for additional information, which were fully completed, on March 16, 2012. Authorization was obtained to operate the reactor with LEU 30/20 fuel under the same terms and general conditions of the previous license.

2.3. Authorization for LEU 30/20 fuels storage.

The work plan authorized the receipt of 125 LEU 30/20 fuel elements which made it necessary to carry out the corresponding criticality safety analysis. This analysis was presented to the regulatory organization, which issued the authorization for temporary storage of the fuel on December 5, 2011.

Later, when considering the removal of unirradiated HEU fuel elements from the storage installation, new analyses were made to allow the store of the spare 30/20 LEU fuel that wouldn't be used during the initial core loading. This new analysis was checked and accepted by the regulatory organization, granting the respective authorization.

2.4. Documents issued by ININ to fill the reload activities with LEU 30/20 fuels.

To develop of core conversion activities, the main documents issued were:

Document	Revision	Topic
P.UR(REC)-02	1	Reload of core with LEU 30/20 fuels.
P.UR(REC)-03	0	Measuring of reactor core operating parameters with LEU 30/20 fuels.
P.UR(REC)-04	0	Receipt and inspection of LEU 30/20 fuels.
I.UR(REC)-01	0	Cut and packing of fresh flip (HEU no irradiated) fuels.
I.UR(REC)-02	0	Reactor core fuels unloading.
I.UR(REC)-03	0	Fitting out and move of irradiated fuels to transportation container.
I.UR(REC)-04	0	Determination of multiplication factor during LEU 30/20 fuel loading.
I.UR(REC)-05	0	Control bar calibration during and after LEU 30/20 fuel loading.
I.UR(REC)-06	0	Radiological coverage during HEU movements to transportation container.

2.5. Quality assurance activities

During development of activities in this period, there was a close watch/check by ININ Quality Assurance Management, which performed the next audits:

Audit	Date	Topic
A.GC/UR-4/2011	7, 8, 9 and 15-Dec-2011	To verify planning and organization of reload, inspection and storage of (LEU 30/20) new fuel for Reactor.
A.GC/UR-1/2012	24, 25 and 26-Jan-2012	To verify activities related to cutting and packing of fresh flip fuels, as a part of TRIGA Mark III Reactor reload activities.
A.GC/UR-2/2012	10 Feb-26 Mar-2012	To verify activities of: cut and fitting-out for transportation of irradiated HEU fuels, receipt and inspection of 40 LEU 30/20 fuels and reload of reactor core with LEU 30/20 fuels.

2.6. Main activities related to preparations, receipt/inspection of LEU fuels, reload and reactor tests.

Date	Topic/Task
16-Nov-2011	Reactor operation was concluded, with a mixed core (HEU 8.5/70 and LEU 8.5/20).
5-Dec-2011	26 HEU fuel elements were removed from reactor core and placed in a circular support at the pool bottom.
6/9-Dec-2011	In the reactor installations, 18 containers with 85 LEU 30/20 fuels were received and checked.
6/9-Dec-2011	29 irradiated HEU fuel elements with an underwater camera and several zones of reactor pool walls were inspected.
12/14-Dec-2011	The (8.5/20) standard LEU fuel elements were removed from core and relocated in vertical shelves of reactor walls. 29 of 35 graphite elements that did not present any trouble to get out of the core were removed and relocated in the circular support, near to HEU fuel elements.
4/6-Jan-2012	Maneuvers to take troubled graphite away were made, and 5 of 6 were taken away. On January 6, the last graphite was disassembled and removed by pieces from the reactor core.
13/19-Jan-2012	The visual inspection of several zones of reactor pool walls was carried out from the upper edge to an approximate depth of 4 meters, determining that there were not any corrosion problems.
11-Feb-2012	Container NAC-LWT and 3 containers with special tools was received at ININ.
14-Feb-2012	Not irradiated HEU fuel elements (28 elements in 10 containers, and an empty container) were taken out from ININ.
14-Feb-2012	In reactor installations, 9 containers with 40 fuel elements (second and last LEU 30/20 set to complete 125) were received and checked.
17/18-Feb-2012	Irradiated HEU fuel elements (29 elements) were transferred to ITS containers and later taken out from reactor building to be placed in an NAC-LWT container.
23-Feb-2012	Irradiated HEU fuel elements (29 fuel elements in NAC-LWT container plus 3 containers with special tools) were taken from ININ.

CRITICAL CORE LOADING	
22-Feb-2012	First LEU 30/20 fuel was placed in the core (control rod with fuel follower of C-10 position).
23-Feb to 8 Mar 2012	In place two temporal channels for monitoring fuel loading (bottom and source counts are obtained). The three additional control rods were placed, fuel loading rings B, C, D and part of ring E. Total number of fuels in the core (including followers of control rods) = 51.
9-Mar-2012	2 elements to complete ring E were loaded. Total number of fuels in the core (including followers of control bars) = 53. Sub-criticality conditions were kept (multiplication factor K=**0.9880097**). The criticality level was predicted with 53.429 fuel elements.
16-Mar-2012	Once the regulatory organization granted authorization to operate the reactor, reloading activities to reach criticality were followed. 2 elements of ring F were loaded, a criticality estimate was made, and it was determined that the core was supercritical. The number of fuels in core (including followers of control rods) = 55.
17-Mar-2012	One fuel was removed and a criticality estimate was made, and it was verified that the reactor was slightly supercritical and that the prediction of a bit more than 53 fuels was correct. Number of fuels in core (including followers of control rods) = 54. **Critical core loading ended.**

OPERATIVE CORE LOADING	
Mar 17-23 2012	Fuel loading was done in different stages, according to approved methodology. STAGE OF LOADING 1 --- +5 fuels in ring F (the fuel of position F-16 and 4 more were loaded again). TOTAL LOADING IN CORE = 56 fuels + 3 followers = 59 REACTIVITY EXCESS = 1.3897 $ STAGE OF LOADING 2 --- +6 fuels in core F TOTAL LOADING IN CORE = 62 fuels + 3 followers = 65 REACTIVITY EXCESS = 3.3515 $

STAGE OF LOADING 3 --- +4 fuels in ring F.
TOTAL LOADING IN CORE = 66 fuels + 3 followers = 69
REACTIVITY EXCESS = 4.7162 $

STAGE OF LOADING 4 --- +3 fuels in ring F
TOTAL LOADING IN CORE = 69 fuels +3 followers = 72
REACTIVITY EXCESS = 6.1505 $

STAGE OF LOADING 5 --- +2 fuels in ring F
TOTAL LOADING IN CORE = 71 fuels + 3 followers = 74
REACTIVITY EXCESS = 6.7540 $

STAGE OF LOADING 6 --- +1 element in ring F
TOTAL LOADING IN CORE = 72 fuels + 3 followers = 75
REACTIVITY EXCESS = 6.9785 $

Lazy Susan moved to its higher position (Lazy Susan was the basis of detectors of channels of measuring of critical core loading).

TOTAL LOADING IN CORE = 72 fuels + 3 followers = 75
REACTIVITY EXCESS = 7.4271 $

STAGE OF LOADING 7 ---- + 2 fuels in ring F.
Fuels of positions F-19 and F-27 were returned to their original positions, 2 fuels were loaded to get the work core proposed.

TOTAL LOADING IN CORE = 74 fuels + 3 followers = 77
REACTIVITY EXCESS = 7.91 $

OPERATIVE CORE LOADING WAS COMPLETE.

MEASURE OF REACTOR CORE OPERATION PARAMETERS WITH 30/20 FUELS.	
Mar 23- to Apr 27- 2012	March 23-26, measure of reactor core operation parameters and initial calibration of control rods. March 27-28, irradiation test of 20 hours at 1 MWt. Rods calibration and determination of power by the calorimetric method. April 10-11, An adjustment of linear and logarithmic channels response for a power adjustment. April 16-18, test irradiation of 36 hours, to evaluate reactivity loss for poisons.

April 23-27, Final test of reload stage, operation of reactor to 1 MWt for 20 hours. Final calibration (of test stage) of control bars, getting the following values:

VALUE OF SHIM ROD = 3.10 $
VALUE OF SAFETY ROD = 2.83 $
VALUE OF REGULATING ROD = 4.06 $
VALUE OF TRANSIENT ROD = 3.00 $

TOTAL VALUE OF CONTROL RODS = 12.99 $

TESTS WERE ENDED AND NORMAL OPERATION OF REACTOR WITH LEU 30/20 LEU FUEL BEGAN.

2.7. Participation of different government institutions.

During this stage, there were several meetings with Mexican government organizations (SRE, SENER, CNSNS, SEGOB-CISEN, SHCP-SAT-CUSTOMS, SCT, SDN, SM, API and PF) to establish plans, programs, agreements, safety measures, controls, permissions and authorizations that should be carried out considering all movements inside Mexico with nuclear materials, and radioactive and special tools to be used.

Within the activities, which demanded the participation of all or some of the organizations mentioned, we can point out the following:

- On December 6, 2011, transportation from International Airport of Toluca to National Nuclear Research Institute (ININ), of 18 containers with 85 LEU 30/20 and 10 empty containers, to be used in the transportation of not irradiated HEU fuel, in its return to USA.

- On December 9, 2011, transportation of the 18 empty containers, from ININ to International Airport of Mexico City (IAMC).

- On February 10, 2012, transportation of 4 ISO containers, one of them containing the CASK NAC-LWT of 30 tons (used for irradiated fuel transportation), as well as accessories, equipment and tools; from customs of Veracruz port to ININ.

- On February 14, 2012, transportation of 11 containers (10 of them containing 28 not irradiated HEU fuels, one of them empty), from ININ to International Airport of Toluca.

- On February 14, 2012, transportation from International Airport of Toluca to ININ of 9 containers with 40 LEU fuels.

- On February 17, 2012, transportation of the 9 empty containers, from ININ to IAMC.

- On February 23, 2012, transportation of irradiated fuel (29 HEU) from ININ to Veracruz Port customs, in the CASK NAC-LWT, together with 3 containers (tools and equipment used).

Transportation services and loading and unloading activities of fuel elements and tools involved in this project were entrusted to ININ (under its responsibility or supervision); in spite of complexity, a limited time for its preparation and the constant adjustments required by several organizations, all the services involved were opportunely carried out and specified requirements fulfilled.

2.8. Cut and packing of 28 no irradiated HEU fuels

Date	Topic/task
Sep-Dec-2011	The work environment was prepared and tests conducted with different tools to proceed – just at the right moment – to no irradiated HEU fuel elements cut.
Jan 20 - 2012	Removal of 28 not irradiated HEU fuel elements from nuclear material warehouse, to reactor building, to have them available for cut activities.
Jan 23/24 -2012	Identification of each transfer container (received on December 6, 2011). Maneuvers for cut and pack of not irradiated HEU fuels. Every container was sealed with two IAEA labels and two USA-DOE-Y12 labels.

2.9. Cut of irradiated HEU fuels (3 control rods and 1 instrumented element)

Date	Topic/task
Dec-2011 / Jan-2012	Suitable conditions in order to carry out trials with different tools (cut, disassemble and top end-fixtures) for the 4 irradiated HEU fuel elements (3 control rods and 1 instrumented element).
Jan 30 / Feb 2 - 2012	The studies, “ESTIMATE OF DOSE EQUIVALENT DURING THE CUT OF THREE CONTROL BARS AND CHANGE OF A CONNECTOR OF THE INSTRUMENTATED FUEL ELEMENT” and 10 CFR 50.59, were ended for the 4 irradiated HEU fuel elements.
Feb 10 - 2012	Activities to cut three HEU control rods with followers and to uncouple the instrumented HEU fuel were done along with activities to place top end-fixtures and mechanisms to each one, for their handling.

3. Results

Extract from press release from Mexican Energy Ministry[3] “With the cooperation and technical assistance of IAEA, Mexico concluded the fuel substitution process of ININ TRIGA Mark III reactor” (Con la cooperación y asistencia técnica del Organismo Internacional de Energía Atómica, México concluyó el proceso de sustitución del combustible del reactor TRIGA Mark III, del Instituto Nacional de Investigaciones Nucleares)**.**

The main result of all the tasks carried out in order to accomplish TRIGA reactor core conversion to operate with LEU 30/20 fuels was to accomplish all the tasks within the time scheduled, with nuclear, radiological and physical safety, and to have the reactor back in proper operation.

The comparison between experimentally measured values and calculated/proposed values in Operation Technical Specifications is shown in the following table:

Table I Comparison values

PARAMETER		VALUE in ETOs	Experimental Value	DIFFERENCE
Control rods value	Transient	3.08 $	2.96 $	- 3.9%
	Safety	2.80 $	2.83 $	+ 1.07 %
	Shim	2.82 $	3.05 $	+ 8.16 %
	Regulating	4.05 $	4.06 $	+ 0.2 %
Excess of reactivity.		6.96 $	7.95 $	+ 14.22%
Shutdown margin.		0.26 $	0.91 $	3.5 times greater than limit
Fuel temperature.		400 C	432.2 C	+ 8.05 %
$\Delta\rho$ COLD-HOT		2.05 $	1.83 $	- 10.7 %

4. References

1. Trilateral Announcement between Mexico, the United States, and Canada on Nuclear Security, April 13 2010. The White House, office of the Press Secretary
2. NUREG 1537 Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors USNRC.
3. Press Release 029, March 26, 2012, Ministry of Energy, Mexico.