ROMANIAN PROGRAM FOR SEU/RU FUEL MANUFACTURING AT NUCLEAR SITE PITESTI

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1. INTRODUCTION

In the world the new realities in the nuclear field are the unexpectedly slow growth of nuclear energy, the escalation of back-end costs, the delay in the implementation of fast reactors, the end of the Cold War. The consequences of these realities are a surplus of uranium, a continued debate over the choice of fuel cycle, a surplus of separated plutonium, the demilitarization of plutonium and high enriched uranium weapons [1].

The nuclear fuel fabrication industry is characterized by a continuous upgrading of the end product, the fuel assembly, driven by the needs of utilities and by feedback from operating experience. Meanwhile, the safety authorities are increasing their requirements to license higher burnup fuels, asking for more representative material tests under accidental conditions, more feedback from experience with lead test assemblies, etc, before granting a licence. Meeting these more and more stringent constraints requires heavy equipment programme which must encompass a large amount of feedback from engineering and operating experience, the use of heavy testing equipment, and careful step by step licensing.

Increasing burnup, which allows the utility to get the same kWh output with a reduced tonnage of fissile material, provides a saving not only in the cost of fuel fabrication but also in the cost of disposal of the irradiated fuel. The cost of disposal of the irradiated fuel is two to four times higher than that of fuel fabrication. Reducing the quantity of irradiated fuel also has a positive impact on the environmentally acceptable solution adopted for its disposal [2].

Recovered Uranium (RU) Cycle is a way to improve Slightly Enriched Uranium resulted from LWR spent fuel reprocessing. Uranium resulted from LWR spent fuel reprocessing has 0.9-1.2% ^{235}U (dependent on the fuel history: reprocessing, burn up, reactor type) comparatively with 0.72% ^{235}U in natural Uranium.

An international collaboration between Korea Atomic Energy Research Institute (KAERI), Atomic Energy of Canada Limited (AECL) and British Nuclear Fuel plc (BNFL) to use RU was developed. Since 1991, KAERI and AECL have introduced the Canadian Flexible (CANFLEX) fuel concept. A very attractive alternative to use RU in CANDU Reactors appears. Theoretically the quantity of 25,000 t (Europe and Japan) of RU would provide sufficient fuel for 500 CANDU reactor years of operation, knowing that the annual refueling requirement for a RU fuel burnup of 13 MWd/KgU is around 50 t/year comparatively with 85 t/year for Natural Uranium (NU) [3].

The DUPIC (Direct Use for spent PWR fuel in CANDU) [4]-[6] and Mixed Oxide (MOX) [7], [8] are other fuel cycles compatible with CANDU Reactors

2. NUCLEAR SITE PITESTI

Nuclear site Pitesti is located at 150 Km north-west of Bucharest. On this site there are two nuclear objectives: the Institute for Nuclear Research (ICN) and the Nuclear Fuel Factory (FCN).

The Institute for Nuclear Research (ICN) is a subsidiary of Romanian Authority for Nuclear Activities (RAAN) pertaining to the Ministry of Industry and Resources (MIR). Nuclear Fuel Factory (FCN) is a subsidiary of "Nuclearelectrca" National Society (SNN) pertaining also to MIR.

Before 1992, ICN and FCN were together, FCN being Nuclear Fuel Pilot Plant, a section of ICN. After 1992, FCN transformed in an independent unit and is qualified by AECL as authorized producer of CANDU 6 fuel. Now, FCN is the main fuel supplier for NPP Cernavoda.

The R&D activities in nuclear field of ICN were continued. A very strong collaboration with FCN was initiated. Practically, all experimental nuclear fuel elements for irradiation in our TRGA Reactor were manufactured by FCN.

3. THE "NUCLEAR FUEL" R&D PROGRAM

ICN manages 17 programmes from the all 18 departmental programme in nuclear energy branch financed by RAAN. A very important R&D program managed by ICN is "Nuclear fuel".

Technical and scientific goals of "Nuclear fuel" R&D Program are:

- Safety analyses related to the fuel behavior during accidents that determine the increase of fuel temperature and cladding defect:
  - Upgrading and validation of computer codes and of the methodology of assessment of thermal, mechanical and chemical behavior of the fuel in accident conditions.
  - Development of in-pile and out-of-pile tests for obtaining relevant experimental data on the fuel behavior in accident conditions.
- Monitoring of fuel performances during operation in Cernavoda NPP. Maintaining and improvement of the operational performance of the CANDU-type nuclear fuel, currently fabricated in Romania
  - System for the inspection of fuel behavior in the Cernavoda reactor and for identifying defect causes and performance evaluation.

- Development and utilization of the expert system for the characterization of defect fuel status in Cernavoda NPP. Identification of methods for solving factual situations in the core management.
- Increase of operational limits of the present fuel.
- Investigation of possibilities to use CANDU-type fuel in power cycling conditions.
- Upgrading of technological processes and of equipments specific for the fabrication of CANDU-type nuclear fuel.
- Out-of-pile testing on irradiated and non-irradiated clad material in order to identify the SCC defect threshold and the related phenomena.

➢ Development of new concepts of nuclear fuels that should bring about an increase in the efficiency of uranium utilization in NPP, a cutback of the fuel cycle cost and, consequently, of the electric power produced by the NPP.

- Completion of the physics manual on the SEU CANDU core.
- Research focused on the decrease of the effects of limitative factors of fuel lifetime and on the burn up increase.
- Completion of a new fuel bundle as vehicle for advanced cycles.
- Out-of-pile testing on SEU 43 fuel bundles.
- In-pile testing on SEU 43 experimental fuel bundles.
- Development of computer codes system to analyze the behavior of SEU, MOX and DUPIC fuels.
- In-reactor tests on experimental fuel elements MOX, DUPIC.

➢ Development and support of expertise and response capability in the field of fuel behavior with the purpose to solve specific problems that occur during its utilization in NPP:

- Upgrading of computer codes system for the simulation of fuel behavior in the power reactor.
- Support irradiation experiments for the calibration and validation of fuel codes.

➢ Demonstration of the integrity of the fuel channel subject to stress generated by the axial interaction bundles column-closure plug.

4. FUEL BUNDLE MANUFACTURING

4.1. SEU 43 Fuel bundle concept

This fuel bundle type is destined to a high burn up and it is compatible with CANDU 6 Reactor systems. To this purpose, the basic overall dimensions of SEU-43 fuel bundle were designed to be the same as those of the 37-element bundle [9]. The type of assembly is welded bundles of 43 elements in circular array with brazed appendages. The major feature of SEU-43 bundle is an increase in the number of fuel elements from 37 in the standard CANDU-6 bundle to 43 elements. The SEU-43 bundle consists of 2 fuel element sizes: the 11.50 mm diameter elements (35) in the outer and intermediate ring, and the 13.50mm diameter elements (8) in the inner and center rings. The small-diameter elements in the outer ring allow the peak element ratings in the bundle to be reduced comparatively with the standard 37-element bundle. The larger-diameter elements in the inner rings of the bundle compensate for the fuel volume lost due to the smaller-diameter outer ring elements.

The fissile material is UO_2 sintered pellets with 96-97%TD and enrichment about 0.9% U^{235}. The intention is to use Recovered Uranium (RU) resulted from LWR spent fuel reprocessing.

4.2. Technological aspects

The SEU 43 fuel bundle manufacturing will be analyzed in connection with Romanian realities having in view low costs. In the Table 1 there is presented a synthetic situation of technologies and installation development or modification of a standard CANDU fuel plant devices for SEU 43 fuel bundles type manufacturing. UO_2 sinterable powder and Zircaloy 4 half finished reception can be execute by using the same methods as those applied in a CANDU Nuclear Fuel Plant (NFP). New specifications are necessary.

The UO_2 sintered pellets manufacturing can be solved easily by knowing that the UO_2 powder characteristics are near the powder processed usually in a CANDU NFP. Having two different diameters, green pellets will be pressed in new matrices that can be designed and manufactured without problems. If RU UO_2 sinterable powder is used, volatile fission products impurities like cesium can be eliminated and it is necessary to retain them. The grinding of sintered pellets can be done with the less center grinding machine usual in CANDU NFP but grinding conditions are different for each type.

The Zircaloy 4 intermediates machining are not complicate operations. The bearing pads and inter-element spacers manufacturing need new matrices for blanking press. The rest of the installation used for Zircaloy 4 intermediates machining needs only simple tools to fix the pieces in machines. All operations for Zircaloy 4 intermediates machining need new technologies and procedures.

The vacuum beryllium (Be) deposition machine used for Be deposition on bearing pads and inter-element spacers is not modified but needs new supports for pieces fixing. More complicate is to adapt the take-weld machine for bearing pads and inter-element spacers fixing on sheaths. Having in mind that the tubes have smaller and larger diameters comparatively with CANDU standard tube, the machine needs new devices to fix the sheaths and to modify the tubes rotating software because the appendages have different positions comparatively with CANDU standard rods. Bearing pads and inter-element spacers brazing can be realized with no important modifications of the installation. New design for pincers of welding machine used for sheaths and end caps and end closure welding is absolutely necessary. All operations for fuel rods assembling need new technologies and procedures.

All installations presented above can operate alternatively for manufacturing of SEU 43 and standard fuel bundles by changing of devices, technologies and procedures. The machine for assembly welding used in CANDU NFP cannot be modified to weld SEU 43 fuel bundle alternatively with CANDU standard fuel bundle. It is necessary to design and manufacture especially a new machine for SEU 43 fuel bundle assembling.

4.3. Cooperation of ICN and FCN for SEU 43 fuel bundle manufacturing

The base of this cooperation is the ICN competence in nuclear fuel development and the FCN experience in CANDU standard fuel manufacturing and installation development. In the Table 2 there is presented a collaboration plan between ICN and FCN for RU SEU 43 fuel bundle type manufacturing.

The raw materials procurement (especially Zircaloy 4 tubes) is very hard to realize because they are not in mass production (on stream). It is difficult to convince a very important producer of Zircaloy 4 half-finished to manufacture especially few tens or hundreds meters of Zircaloy 4 tubes with large and smaller diameters at a reasonable price. The elaboration of quality specifications for RU UO_2 sinterable powder and Zircaloy 4 half-finished materials, purchasing and their reception testing is the ICN responsibility through "Nuclear Materials and Corrosion Department" (NMCD).

At laboratory scale (a few kilograms), UO_2 sintered pellets will be manufactured by ICN in laboratory installations of ICN–NMCD. The installation modifications, technologies, specifications and procedures elaboration will be also executed by ICN – NMCD. For industrial scale, the technologies and specifications will be transferred to FCN.

The installation modifications and technologies elaboration for sheaths, bearing pads and inter-element spacers manufacturing will be executed by FCN and the specifications for intermediates by ICN. The technologies, specifications and procedures for end caps and end support plates manufacturing will be realized from ICN–NMCD.

The design and executions of installation modification, technologies and procedures for fuel rods assembling will be realized from FCN. ICN will be elaborate the specifications.

For fuel bundle assembling it is necessary a new assembling machine. To that, a collaboration with FCN and SIMTEX, a Romanian machinery producer, to develop an assembling machine for SEU 43 fuel bundle was initiated.

The collaboration ICN-FCN already began. The devices for cutting machine and for sheaths end cap welding machine were designed and manufactured by FCN. In this year there will be designed and executed tools for take weld machine. The tests for sheath end cap welding also began.

4.4. IAEA financial and technical support

In Romania, the financial support for SEU 43 nuclear fuel developing, including collaboration with FCN, is assured by the Romanian Authority for Nuclear Activities (RAAN) pertaining to the Ministry of Industry and Resources.

The International Agency for Atomic Energy (IAEA) from Vienna sustains Romanian effort to develop the fuel bundle destined for high burn up. The IAEA grants financial and technical support through Model Project ROM/04/025 "Recovered Uranium (RU) and Slightly Enriched Uranium (SEU) Fuel Cycle Options for Cernavoda NPP". The IAEA help consists of:

- RU UO_2 sinterable powder and Zircaloy 4 tubes (with smaller and larger diameter) procurement;
- Personnel training by technical visits, fellowships;
- Installations upgrading.

The missions of IAEA specialists took place in Romania. The schedule and working plans were discussed.

5. REMARKS

Development of Romanian SEU 43 fuel bundle concept can be continued by the manufacturing of fuel assembly. The manufacturing can be realized by a collaboration of our institute with FCN, authorized CANDU standard fuel producer. The modifications of FCN installations are minor, practically they only need new devices. The exception is the assembly welding machine, equipment that will be developed by ICN in collaboration with FCN and SIMTEX (Romanian machinery producer). In this conditions, after technologies have been established, specifications and procedures elaboration, on nuclear site Pitesti, SEU 43 and CANDU standard fuel bundles can be manufactured alternatively.

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Table 1. Technologies and installation development or modification for RU SEU 43 fuel bundles type manufacturing

Items	NEEDS			
	Main equipment	Equipment modifications	Technologies modifications	Specifications/ Procedures modifications
RU UO_2 sinterable powder and sintered pellets				
RU compounds rece+ption	Usual for UO_2 powders	No	No	Yes
UO_2 sinterable powder manufacturing	Reduction furnace	No	Yes	Yes
UO_2 sintered pellets manufacturing	Sintering furnace, press	New tools	Yes	Yes
UO_2 sintered pellets grinding	Grinding machine	New tools	Yes	Yes
Columns formation	-	No	No	Yes
Zircaloy 4 intermediate machining				
Zircaloy 4 half-finished materials reception	Mechanical testing machine, autoclaves	Upgrading	No	Yes
Sheaths manufacturing	Cutting machine	New tools	No	Yes
Bearing pads and Inter-element spacers manufacturing	Blanking press	New tools	No	Yes
End caps manufacturing	Lathe	New tools	Yes	Yes
End support plates manufacturing	milling machine	New tools	Yes	Yes

Fuel rods assembling				
Be deposition on bearing pads and inter-element spacers	Vacuum beryllium deposition machine	New tools	Yes	Yes
Bearing pads and inter-element spacers take-weld	Take-weld machine	New tools	Yes	Yes
Bearing pads and inter-element spacers brazing	Brazing machine	New tools	Yes	Yes
Sheaths grafting		No	Yes	Yes
Sheaths and end caps welding	Welding machine	New tools	Yes	Yes
UO_2 sintered pellets loading	Manual	No	No	Yes
End closure welding	Welding machine	New tools	Yes	Yes
Fuel rods profiling	Profiling machine	New tools	Yes	Yes
Fuel bundles assembling				
Assembly welding	Welding machine	Upgrading	Yes	Yes

Note: ***ICN*** - Institute for Nuclear Research
FCN - Nuclear Fuel Plant

Table 2. Collaboration plan between Institute for Nuclear Research (ICN) and Nuclear Fuel Plant (FCN) for RU SEU 43 fuel bundle type manufacturing

Items	Who execute				
	Tackles, devices, verifiers	Design	Manufacturing	Technologies	Specifications/ Procedures
RU UO_2 sinterable powder and sintered pellets					
RU compounds and Zircaloy 4 half-finished materials purchasing					ICN
RU UO_2 sinterable powder	ICN	ICN	ICN	ICN	ICN
UO_2 sintered pellets	ICN	ICN	ICN	ICN	ICN
UO_2 sintered pellets grinding and columns formation	FCN	ICN	FCN	FCN	FCN +ICN
Zircaloy 4 half-finished materials machining					
Sheaths	FCN	ICN	FCN	FCN	FCN +ICN
Bearing pads	FCN	ICN	FCN	FCN	FCN +ICN
Inter-element spacers	FCN	ICN	FCN	FCN	FCN +ICN
End caps	ICN	ICN	ICN	ICN	ICN
End support plates	ICN	ICN	ICN	ICN	ICN

Fuel rods assembling					
Be deposition on bearing pads and inter-element spacers	FCN	ICN	FCN	FCN	FCN +ICN
Bearing pads and inter-element spacers take-weld	FCN	ICN	FCN	FCN	FCN +ICN
Bearing pads and inter-element spacers brazing	FCN	ICN	FCN	FCN	FCN +ICN
Sheaths and end caps welding	FCN	ICN	FCN	FCN	FCN +ICN
UO_2 sintered pellets loading	FCN	ICN	FCN	FCN	FCN +ICN
End closure welding	FCN	ICN	FCN	FCN	FCN +ICN
Fuel rods profiling and Helium leak testing	FCN	ICN	FCN	FCN	FCN +ICN
Fuel bundles assembling					
Assembly welding	ICN	ICN	ICN	ICN	ICN