LEU FUEL ELEMENT PRODUCED BY THE EGYPTIAN FUEL MANUFACTURING PILOT PLANT

W.I. ZIDAN
Nuclear Fuel Plant,
Atomic Energy Authority of Egypt,
Cairo, Egypt

XA0055756

Abstract

The Egyptian Fuel Manufacturing Pilot Plant, FMPP, is a Material Testing Reactor type (MTR) fuel element facility, for producing the specified fuel elements required for the Egyptian Second Research Reactor, ETRR-2.
The plant uses uranium hexaflouride (UF_6, 19.75 % U^{235} by wt) as a raw material which is processed through a series of the manufacturing, inspection and test plan to produce the final specified fuel elements.
Radiological safety aspects during design, construction, operation, and all reasonably accepted steps should be taken to prevent or reduce the chance of accidents occurrence.

1. INTRODUCTION

In the 1950s and 1960s, low power research reactors were built around the world which utilized MTR-type fuel elements containing <20 wt % U^{235} enriched uranium (LEU). This value was chosen in accordance with IAEA recommendations.

As a result of the long delay to be committed to a definite and defined nuclear fuel cycle, the activities associated with nuclear fuel materials processing and characterization have been practiced in the form of discrete R & D studies.

R & D were oriented to nuclear materials rather than the fuel fabrication technology.
The Atomic Energy Authority has started a program for the integration of these activities into what could be considered as a " Nuclear Fuel Development Program".
The program aims to acquire the know how associated with fuel fabrication technology and hence the capability to support the National Nuclear Power Program.

As a result of the above-mentioned program, Egypt built the FMPP plant.
FMPP, is the first Egyptian nuclear fuel plant in a productive scale, producing an MTR-type fuel element for the Egyptian Second Research Reactor, ETRR-2.
The FMPP project started in 1995, different commissioning stages were applied, beginning with plant systems pre-operational tests in 1997, integrated performance tests, process qualifications, training with natural uranium, and finally a complete production with low enriched uranium (19.75 %) on December, 1998.

2. PLANT GENERAL DESCRIPTION

The FMPP is a MTR-type fuel element manufacturing plant, which due to its characteristics, may be associated on one side with a chemical processing (powder manufacturing), and on the other side with a light products metallurgical and mechanical processing (structural components, plates manufacturing, and final fuel assemblies).

Technological Requirements

MTR-type fuel element manufacturing involves managing and organizing a very different technological activity.
The FMPP plant has been conceived integrally regarding production, this means that it comprises all activities for obtaining MTR-type fuel elements from UF_6 and aluminium consumables.

All these activities require specific spaces with constructive characteristics defined by the type of the processes, which take place in them.

The following tasks, necessary to conduct the process, administrative activities, and support, take place in the plant:

- UF_6 reception and storage
- Non-nuclear materials reception and storage
- Conversion from UF_6 to U_3O_8
- U_3O_8 – Al powders compacting
- Fuel plates manufacturing
- Al structural components manufacturing
- Al components surface treatment
- Fuel element assembly
- Consumables, components, and final product quality control
- Intermediate nuclear materials and fuel element storage
- Administrative services
- Production support services
- Operation auxiliary services
- Radiological waste treatment
- Chemical waste treatment
- Security services

Production Capacity

The nominal production capacity of the plant is about 40 fuel element /year, with a total uranium content of 2054 g each.
The estimated annual working time is 220 days, two - 8 hours - shift.

Building General Description

The building is divided into four sectors, each with specific environmental characteristics and working conditions:
SECTOR I (Administration)
SECTOR II (General services)
SECTOR III (Production activities)
SECTOR IV (Maintenance)

3. SAFETY FEATURES

Fundamental Requirements and Safety Philosophy

The basic safety concepts applied in facilities handling uranium powders are taken into consideration during the various stages of planning and implementation of the plant.

Design, construction, and operation of the components and systems of the fuel plant are to secure that in natural operation the recommendations of the International Commission on Radiological Protection, and the basic safety standards for radiation protection of the IAEA are fulfilled with regard to radiation protection of personnel and environment.

All reasonably accepted steps shall be taken to prevent or reduce the chance of accidents occurrence.
It must be known that all safety regulations are implemented with regard to materials collection, transportation, and storage.

All safety features of an efficient ventilation system are considered. This ensures, for example, securing local Ventilation, efficient filtration and air monitoring, minimization of the amounts of respired dust, etc.

The relevant safety regulations must be applied to all types of radioactive wastes in the solid and liquid forms.

Staff Health Protection

Doses resulting from sources and practices involving exposure to ionizing radiation or a radioactive material shall be restricted by:

- a system of dose limitation which shall include justification of the practice, optimization of radiation protection, and individual dose limitation,
- responsibilities and administrative requirements, which define responsibilities of plant management, health experts and workers,
- Two working conditions, namely, work condition A and work condition B, as defined by IAEA standards shall be recognized. Working Condition A applies to areas where annual exposure might exceed three tenths of the dose equivalent, while working condition B applies to areas where it is unlikely to exceed this limit.
- planned special exposure such as working with enriched uranium is considered a working condition A, and the appropriate regulation in such case,
- a physical surveillance system to determine the nature of precautions which must be taken to ensure compliance with the system of dose limitation,
- an appropriate system of inspection and intervention.

Procedures currently used for the fabrication of uranium fuel to ensure the accountability of uranium in accordance with commercial and IAEA standards shall be implemented.

4. SPECIFICATIONS

Al-powder

The starting material for manufacturing the powder shall contain at least 99.5 % in mass of pure aluminium. The maximum impurities content are as follows:

B	< 10 ppm
Cd	< 30 ppm
Co	< 60 ppm
Li	< 40 ppm
Al_2O_3	< 1.7 wt %

The aluminium powder particles shape must be spherical with smooth surface, in a size less than 150 µm, the particles with a size < 53 µm must not exceed 80 wt %.
The aluminium powder density is 2.7 g/cm^3.

Al-6061 alloy

Al-6061 alloy is a magnesium base alloy used in the structural components manufacturing for the fuel element produced, in different geometrical shapes, as sheet, plate, rod, and rectangular bar, with the standard composition stated in U.N.S. A96061 as per ANSI H 35.1 M, and in compliance with ASTM B 209 M-95.

The plates and sheets used for covers and frames manufacturing shall be with an annealing thermal treatment (state T0). While the others shall be with a solubilizing and artificial aging thermal treatment (state T6 or T51).

The nuclear impurities must not exceed the same limits as mentioned before for the aluminium powder.

The advantage of the Al-based magnesium alloy 6061 is their increased corrosion resistance.

U_3O_8 Enriched Powder

The uranium oxide powder as U_3O_8 must fulfil the requirements of the fuel element produced for our reactor.

The uranium content shall be at least, 84.5 wt %.

The isotopic content as U^{235} in the powder must be 19.75 +/- 0.20 wt % of the total uranium.
The impurity contents shall not exceed those specified in the following table (in µg/g U):

ELEMENT	SYMBOL	CONTENT
Aluminium	Al	500
Barium	Ba	10
Boron	B	2
Cadmium	Cd	0.5
Calcium	Ca	250
Cobalt	Co	3
Copper	Cu	20
Fluoride	F	20
Phosphors	P	100
Lithium	Li	5
Manganese	Mn	5
Magnesium	Mg	100
Potassium	K	20
Silicon	Si	250
Sodium	Na	250
Vanadium	V	5
Chromium + Nickel + Iron	Cr+Ni+Fe	150

The powder particle size shall be less than 90 µm, the particles smaller than 45 µm shall not exceed 50 wt %.
The powder density shall be equal to 8.0 g/cm^3 or more.
The oxygen / uranium ratio must be in the range of 2.62 – 2.72.

U_3O_8-Al Compact

The fuel compact has the following dimensions and weight:
- Width, 60.5 + 0 / - 0.3 mm
- Length 69.0 + 0 / - 0.3 mm
- Thickness 8.5 + 0 / - 0.2 mm
- Weight 171.6 + / - 1.5 g

The compact density is about 4.8 g/cm^3, equivalent to 3.1 g U_t / cm^3.
The content of the isotope U^{235} must be 21.3 + / - 0.2 g for the standard fuel element produced.
The compact surface must be free of any defects such as, large pores, cavities, fissures, scaling, cracks, and / or any other type of material discontinuity.

Fuel Plate

Two types of fuel plates are produced in the plant. The only difference between the two types is the overall length, which is 1010 mm in the case of external plate instead of only 840 mm in the case of internal one.

The fuel plate has the following specifications:

Fuel meat thickness	0.7	mm
Fuel meat width	64.5	mm
Fuel meat length	800	mm
Fuel plate thickness	1.5	mm
Cladding thickness	0.4	mm
U^{235} isotope content	21.3	g

The surface contamination with uranium in the finished fuel plate must have an activity less than 2 * 10^{-4} Bq / cm^2.
The finished fuel plate must be free of any internal defects.

Fuel Element

Standard fuel element of the ETRR-2 is a MTR-type of a square section 80 * 80 mm.
Each one has 19 fuel plates, 17 inner plates and 2 outer ones.
The gab spacing between each two-fuel plate is 2.7 mm (coolant channel).
The end box has a centered cylindrical hole to allow the coolant flow. In its lower part, it has four chamfered parts in each corner to allow the insertion and griping of the clamp that fix the fuel element in the reactor core grid.
Total mass of U^{235} in the standard fuel element produced is 404.7 g.

5. MANUFACTURING PLAN

Wet Process

Uranium hexaflouride (UF_6, 19.75 wt % U^{235}), is a solid material at room temperature, heated above its triple point to increase its vapor pressure.
Uf_6 is then added to a desired amount of demineralized water produced in the plant in a special closed agitated vessel (Hydrolizer).
A solution of uranyl fluoride and hydrofluoric acid produced.
Uranyl fluoride solution is then precipitated by ammonia solution, 25-wt %.
Washing and filtration steps are also applied by adding ethanol, and 1 wt % ammonia solution, to produce a clean and dry Ammonium Diurinate (ADU).

Dry Process

The ADU obtained from the last stage is calcinated in 800°c furnace to produce U_3O_8 powder, after that, milling and sieving treatment occurs.
A second grain growth furnace at 1400°c is applied to get the dense powder at a required particle size after another milling and sieving processes.

Mixing and compacting

U_3O_8 and Al-metal powders are mixed together in a rotating device at 16 rpm for 3.5 hrs, the mixing ratio is, 48 volume % of U_3O_8, and 52-volume % of Al-metal powder.
The mixture is then compacted by applying a 4.5 Ton / cm^2 pressure to produce the fuel compact with the mentioned specifications.

Framing and welding

The fuel compact is then put in the 6061-aluminium alloy frame; two covers of the same material cover the frame with the compact inside.
Welding of the above mentioned set, which is called (sandwich), takes place by means of TIG method from the four sides, except a small distance from the two sides in the rolling direction, to allow the release of gases in the rolling stage.

Plate Manufacturing

The set of 10 sandwiches are put in a furnace at 500°c, passing through a 9 hot rolling steps, in order to reduce the thickness from the initial of 18.1 mm to 1.65 mm.
Blister test takes place in the same furnace at 490 °c for one hour, the furnace temperature will decay after that, while the plates are still inside.
One pass of cold rolling is then applied to reach the required thickness of 1.5 mm.
Before cutting the plate to the required dimensions, X-ray has to be applied to help in the proper marking on the plate surface. Another one has to be applied to assure the correctness of the cutting process. Straightening process is also applied to improve the flatness of the plate. Then the last X-ray takes place for quality purposes (homogeneity).

Surface Treatment

The produced fuel plates, as well as, the structural Al-6061 components are passed through different steps in order to remove the lubricants, oils, greases, or any other materials, and the oxide film which may attack the aluminium on the surface, as follows:

1- cleaning with TCDE (tricloro diethylene)
2- pickling in an alkaline hot NAOH solution
3- washing with normal water
4- neutralization by cold HNO_3
5- washing with normal water
6- final washing with hot demineralized water
7- repeating, if necessary, from step 3, one or two times
8- drying in air stove

Fuel Element Assembly

The type and quantity of the components required to produce one fuel element are as follows:

External fuel plates	2
Internal fuel plates	17
Side plates	2
End box 80 * 80 mm	1
Screw M6 * 9	6
Handling pin	1

The 19 plates are mechanically fixed to the 2 side plates by a roll of swaging technique .The two side plates and the outer fuel plates are fixed to an end box by means of screws. Handling pin with the fuel element identification connects the two side plates by means of TIG welding.

6. INSPECTION AND TEST PLAN

6.1 Fuel compact

U^{235} isotope content

The content of the isotope in each fuel compact is determined by weighing the compact, and then multiplying the obtained weight by three factors; the fuel compact U_3O_8 content, the total uranium content in the U_3O_8, and the total uranium content of the isotope.
The last two values are obtained from the release certificate of the powder. The fuel compact weight must be with a minimum accuracy of + / - 0.05 g.

Dimensional and geometrical control

The fuel compact dimensions and geometry must be controlled to assure the required values mentioned before.

Visual control

The fuel compact visual control must be done carefully, to verify the absence of any surface defects or hair cracks.

6.2 Fuel plate

Blister test

The most effective quality check on bonding is the blister test. The blister test must be performed before the cold rolling, to verify the metallurgical bond between the fuel compact and its cover.
The heating temperature is 490°c during one hour, followed by slow cooling inside the furnace, then visual inspection occurs.

Radiographic inspection

Radiographic inspection must be applied in order to:

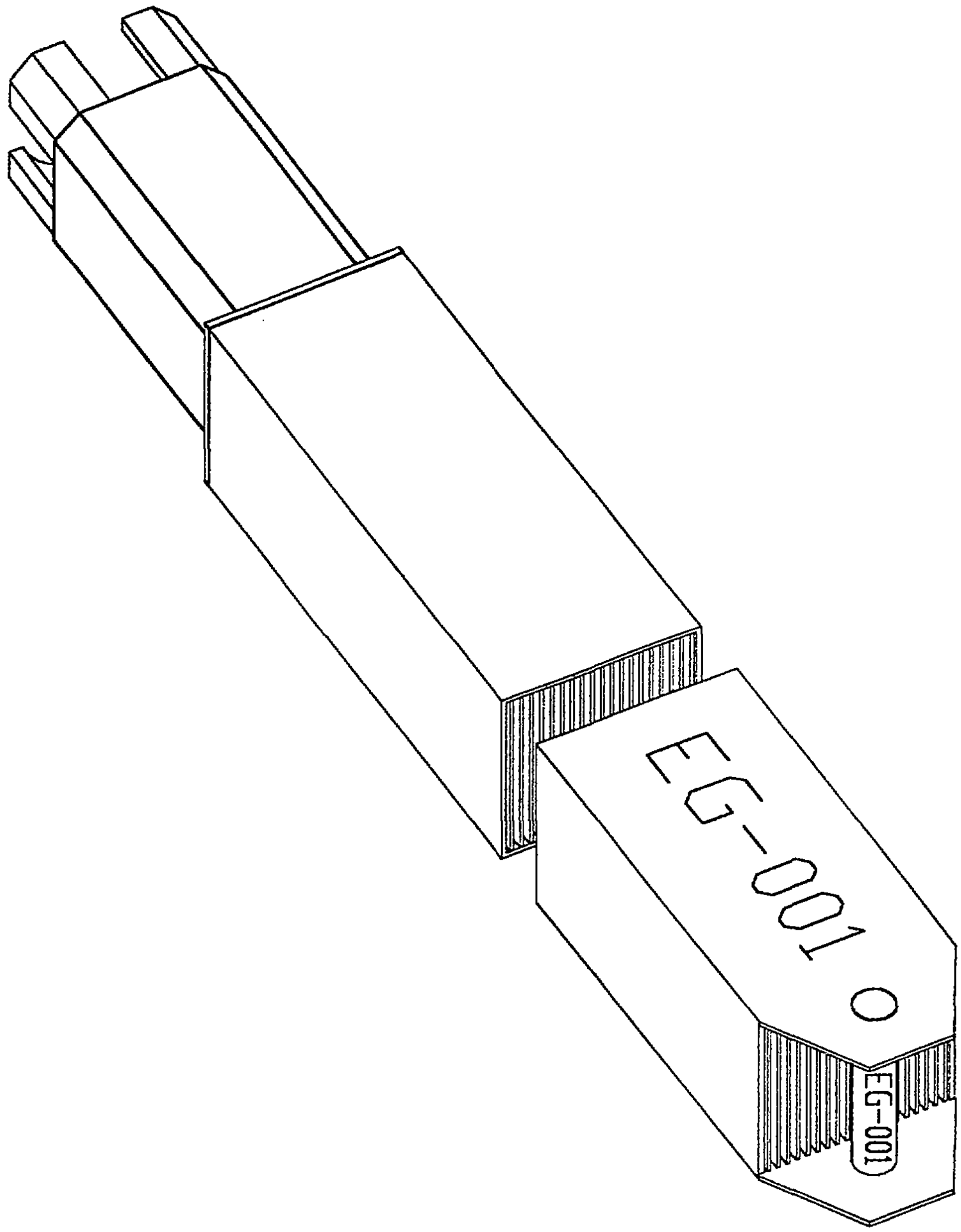
- determine the fuel core position
- verify that the core dimensions and geometry are in compliance with the required specifications
- check the presence of any internal defects, or homogeneity problems inside the fuel core
- check the presence of any nuclear materials outside the core (white spots)

Dimensional and geometrical control

The fuel plate dimensions and geometry must be controlled to assure the required values mentioned before.

Visual control

The fuel plate visual control must be done carefully to verify the absence of any surface defects or scratches.



Surface contamination

A sweep test must be performed to measure the fuel plate surface contamination with uranium.
If the fuel plate surface is contaminated, the surface must be cleaned and inspected again to verify that the contamination is removed.

Destructive testing

Fuel plate sample must be taken either from the rejected plates or one plate from each 100 accepted ones. The samples must be extracted from the edges of the plate, as well as any place including any defects needs to be studied.
The main benefit is to measure the thickness of the cladding, as well as, the fuel core.

6.3 Fuel element

Coolant channel gap spacing

The gab spacing between each two-fuel plates has to be measured, to assure the design value at 2.7-mm (coolant channel).

Dimensional and geometrical control

The fuel element parallelism, flatness, and concentricity must be controlled, using CMM, three – axes - machine, to assure the required design values.

Visual control

The fuel element visual control must be done carefully, to verify the absence of any surface defects.

Surface contamination

A sweep test must be performed to measure the fuel element surface contamination with uranium.
If the fuel element surface is contaminated, the surface must be cleaned and inspected again to verify that the contamination is removed.

7. CONCLUSION

FMPP is a new MTR-type fuel element facility. It produces the required fuel assemblies for the Egyptian Second Research Reactor, ETRR-2.
The plant is considered as a success of the R & D program in the field of nuclear fuel fabrication in Egypt.
The plant has a capacity to produce fuel assemblies for any other customers, with the same type, and enrichment percent or lower, as well as, the conventional tasks in the industry, mainly due to the advanced computerized machines and quality control laboratories.

REFERENCES

1. Safety Series No. 50 - C – QA, "Quality Assurance in the Procurement, Design, and Manufacture of Nuclear Fuel Assemblies," IAEA, Vienna, 1988.

2. INVAP SE, Safety Analysis Report of the FMPP. 0766 7302 3MADP 001 10. ARG., 1998.

3. INVAP, Quality Assurance Manual of the FMPP. 0766 7102 3MFDP 001 10. ARG., 1998.

4. IAEA-TECDOC-467, "Standardization of Specifications And Inspection Procedures for LEU Plate-type Research Reactor Fuels"
IAEA, Vienna, 1988.