Feasibility Study Part – I
Thermal Hydraulic Analysis of
LEU Target for ^{99}Mo Production in Tajoura Reactor

Bsebsu, F. M,[1], Abotweirat F.[2]
Reactor Department

and

Elwaer S.[3]
Radiochemistry Department

Renewable Energies and Water Desalination Research Center
P.O. Box 30878 Tajoura (Tripoli), Libya

Abstract

The Renewable Energies and Water Desalination Research Center (REWDRC), Libya, will implement the technology for ^{99}Mo isotope production using LEU foil target, to obtain new revenue streams for the Tajoura nuclear research reactor and desiring to serve the Libyan hospitals by providing the medical radioisotopes.

Design information is presented for LEU target with irradiation device and irradiation Beryllium (Be) unit in the Tajoura reactor core. Calculated results for the reactor core with LEU target at different level of power are presented for steady state and several reactivity induced accident situations.

This paper will present the steady state thermal hydraulic design and transient analysis of Tajoura reactor was loaded with LEU foil target for ^{99}Mo production. The results of these calculations show that the reactor with LEU target during the several cases of transient are in safe and no problems will occur

1. Introduction

The Tajoura reactor is a pool type reactor [1], moderated and cooled by light water located at the Renewable Energies and Water Desalinization Research Center (REWDRC). The reactor is designated to carry out experiments in field of nuclear physics and nuclear engineering, neutron activation analysis, solid state physics and isotope production. The reactor was put into operation at a power level of 10 MW in September 1983.
The old fuel of the reactor is of the IRT-2M type: High Enriched Uranium (HEU, 80% of ^{235}U); the fuel is an alloy (matrix) of aluminum and uranium-aluminum eutectic (UAl_x–Al) with aluminum cladding. The reactor is completely converted to Low Enriched Uranium (LEU, 19.7% of ^{235}U) fuel of type IRT-4M at the end of 2006; the new fuel is an alloy

[1] Dr. Bsebsu, Farag Muftah, Calculation Unit, Head of, Bsebso@yahoo.com
[2] Dr. Abutweirat, Faisal , Reactor Department, Head of, abutweirat@yahoo.com
[3] Dr. Elwaer, Sami, Radiochemistry Department, Head of, samiwer@yahoo.com

(matrix) of aluminum and uranium-dioxide (UO_2–Al) with aluminum cladding [2]. The moderation and core cooling are provided through forced convection of de-mineralized water.

The Tajoura reactor has 44 vertical irradiation channels (6 in the 8TFA fuel assemblies, 9 in removable Be reflector units, 19 VCR in the stationary reflector blocks, and 10 VCV in reactor core Al vessel). Figure 1 shows the Tajoura core horizontal cross section. The study of this analysis includes:

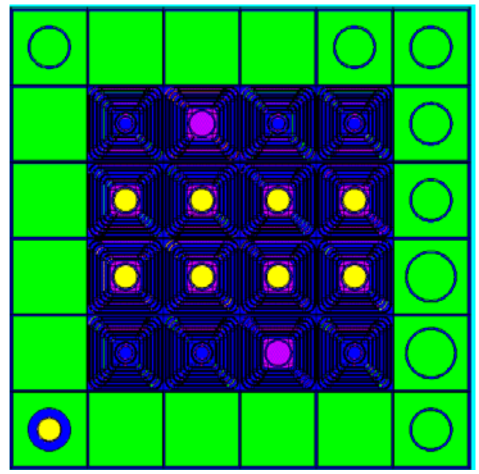

Figure 1. Tajoura Reactor Core Horizontal Cross Section.

1. Steady state thermal hydraulic analysis and heat transfer characteristics.
2. Accident Analysis.

2. LEU Target Material and Size

The LEU target is made of a piece of uranium foil covered with nickel foil [3,4], held and compressed between two aluminum cylinders. The annulus type LEU target assembly as shown in Figure 2 consists of:

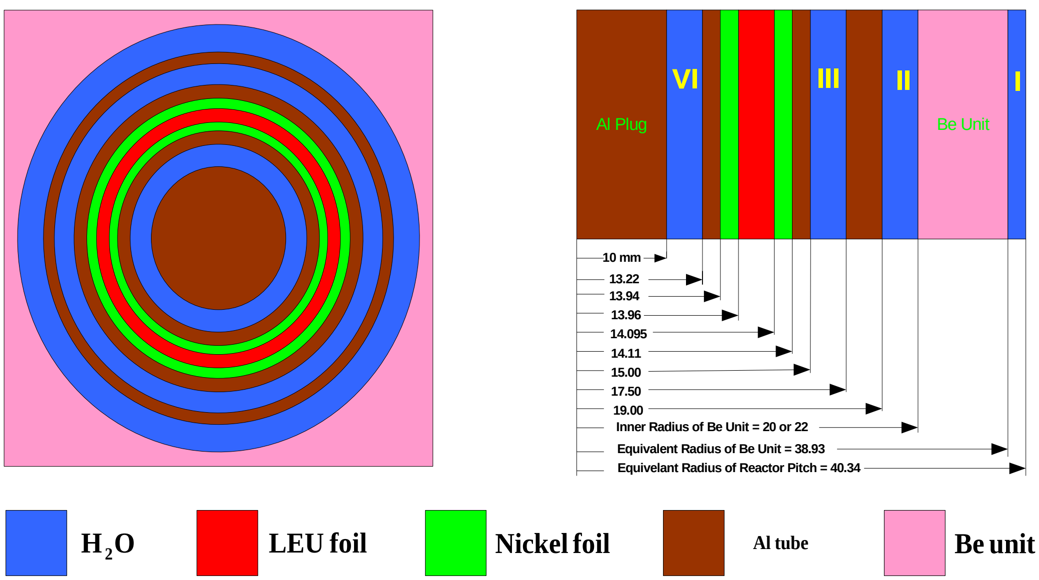

Figure 2. Removable Be Unit with LEU Target and Irradiation Device Horizontal and Vertical Cross Sections.

1. Two aluminum cylinder having 15.5 – 17.5 cm length and outside diameters of 27.99 and 30 mm, and inside diameters of 28.22 and 26.21 mm, respectively.
2. One foil of uranium (LEU) of 7.6±0.2 × 4.4±0.2 × 0.0125 cm.
3. Coating nickel foil of 0.0013 cm thickness.
4. Uranium mass of 8 grams with 19.7 % enrichment of ^{235}U.

5. Irradiation cylinder (rig) of 19 mm radius.

3. LEU Target Neutronic Characteristics

The main LEU target assembly neutronic parameters with irradiation device are given in Table 1.

Table 1.
LEU Target Assembly Neutronic Parameters

Parameter	Value
LEU Target Volume, cm^3	0.418
Uranium mass, gm	8
Uranium density, kg/m^3	19.14
LEU Target Volumetric Heat Source $\times 10^6$, kW/ m^3	17.11
LEU Target Power Generation, kW	7.15
^{235}U Number Density $\times 10^{21}$, nuclei/cm^3	8.51
Thermal Neutron Flux $\times 10^{14}$, n/cm^2 .sec	1.60
Linear Heat Source, kW/m	162.56

4. LEU Target Steady State Thermal Hydraulic Characteristics

The main thermal hydraulic parameters of LEU target are calculated using IRTM code with some assumptions:

1. The heat transfer coefficient was calculated using Bsebsu correlation [5], this correlation is suitable for narrow channels and this correlation as follow: $Nu = 0.045 Re^{0.74} Pr^{0.35}$ and other international correlations.

2. The coolant flow through the Be unit with irradiation device containing LEU target is equal to 15.95 m^3/hr.

3. The power generated in target is equal to 7.152 kW at neutron flux equal to 1.6 $\times 10^{14}$ n/cm^2.sec.

4. No axial heat conduction through the target.

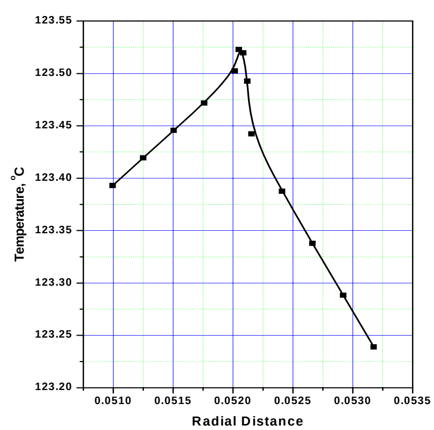

Figure 3. *Radial Temperature Distribution in LEU Foil Target at Reactor Core Power Level of 10 MW.*

The main thermal hydraulic parameters of LEU target at reactor rating power level of 10 MW_{th} with primary coolant volume flow rate 1350 m^3/hr and coolant inlet temperature 45 ^{o}C are given in Table 2. The total mass flow rate through LEU target assembly is 4.39 kg/sec and volume flow rate is 15.95 m^3/hr.

At the reactor core power level (design) of 10 MW_{th} (1.6×10^{14}, n/cm^2 .sec), the radial temperature distribution in LEU foil target is shown in Figure 3 and the maximum centerline temperature is 124 ^{o}C, and at the reactor core power level

Table 2.
IRTCO Code Results for LEU Target Assembly Thermal Hydraulic Parameters

Parameter	Sub-channel			
	I (b/w Be Units)	II	III	IV
V, m/sec	3.87	3.82	3.84	3.90
$\dot{m}$, kg/sec	1.35	1.16	0.97	0.91
P_{out}, MPa	0.12	0.12	0.12	0.12
T_{out}, ^{o}C	45	45	50	50
CHF, MW/m^2	0.0	0.0	2.73	2.74

of 5 MW_{th}, the maximum centerline temperature is 90 °C.

The LEU foil target cover surface, ONB, and boiling temperatures as a function of reactor core power level is shown in Figure 3, also the ONB factor and LEU foil target cover surface heat flux is shown in Figure 5 with saturation temperature of 107.24 °C. The main thermal hydraulic parameters of LEU target and the reactor fuel assemblies at different reactor power levels are given in Table 3.

Table 3.

Reactor Core Fuel Assemblies and LEU Target Maximum Temperatures (°C) and Safety Factors

Parameter	Reactor Core Power Level, MW								
	10			8			5		
	LEU Target	8TFA	6TFA	LEU Target	8TFA	6TFA	LEU Target	8TFA	6TFA
T_{fuel}, °C	124	116	108	115	104	97	91	84	79
T_{clad}, °C	123	115	107	115	103	96	91	83	79
$T_{boiling}$, °C	135	131	130	134	129	128	130	125	123
T_{ONB}, °C	136	120	119	122	118	118	119	116	116
T_{sat}, °C	107.2								
DNBR	1.4	2.3	2.5	1.7	2.9	3.1	2.8	4.6	5.0
ONBF	1.2	1.2	1.4	1.3	1.5	1.6	1.9	2.1	2.4

6TFA=Six Tube Fuel Assembly, 8TFA=Eight Tube Fuel Assembly, and ONBF= Onset of Nucleate Boiling Factor

5. LEU Target Accidental Analysis

This work presents the thermal hydraulic analysis of the Tajoura reactor core loaded with LEU target for ^{99}Mo production at reactor core with power level (max.) of 5 MW. In this study we consider the active length of the LEU target is the same as the active length of the fuel element (60 cm) The PARET [6] computer code and standard correlations have been employed to calculate different parameters such as: coolant, cladding and centerline temperatures, and other thermal hydraulic critical parameters at steady state conditions are shown in Figure 4. Also, detailed accident analysis was performed for Tajoura reactor core configuration and its response to anticipated reactivity insertion accident scenarios were studied as follow: [7]

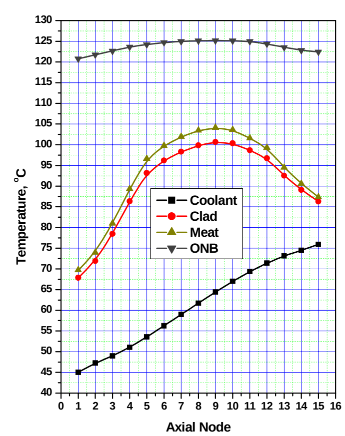

Figure 4. Coolant, Cladding Surface, Centerline, and ONB Temperatures Axial Distribution of LEU Foil Target.

5.1 Control Rod Follower Disengagement

The results of this case are shown in Figure 5 and Figure 6, respectively. The reactor core power level increases from 5 MW to 5.75 MW at the time of 0.195 sec and the control rods start into the reactor core 0.5 sec later (0.22 sec) at which time the power level has reached 5.842 MW and the reactivity insertion into the system is 0.146 $. During this time the peak coolant and cladding surface temperatures has reached 77 °C and 102 °C, respectively. The minimum reactor period in this case is 3.784 sec. The other transient trips for this case are shown in Table 4.

Table 4.
Tajoura Reactor Core at Several Transient Trips in the Case of Control Rod Follower Disengagement

	Steady State	Overpower Trip	Max. Power Trip	-ve ρ insertion Trip	−ve ρ_{max} insertion trip
Time, sec	0	0.19	0.22	0.69	10.01
Power, MW	5	5.76	5.84	5.33	0.28
Reactivity,	0	0.14	0.15	-0.25	-32.71
DNBR	5.58	5.17	5.08	4.79	106.28
T_{cool}, °C	75.74	76.34	76.57	79.24	46.70
T_{clad}, °C	100.68	101.39	102.19	105.13	48.43
T_{fuel}, °C	104.15	105.23	106.09	109.11	48.62

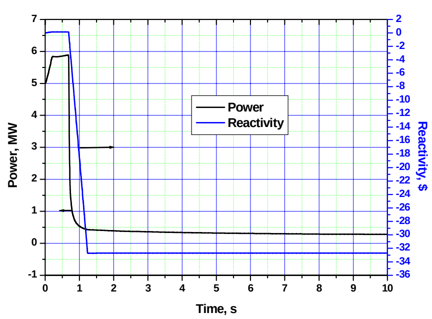

Figure 5. Reactivity and Power as a Function of Transient Time in the case of CR Follower Disengagement

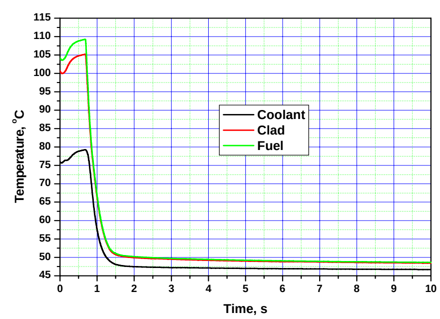

Figure 6. Fuel, Clad and Coolant as a Function of Transient Time in the case of CR Follower Disengagement

5.2 Loss of Flow Accident

The results of this case are shown in Figure 7 and Figure 8, respectively. There is no initial temperature increase since the decrease in coolant flow rate is slow and the control rods are moving into core 0.5 sec after start of coolant flow rate decrease, the maximum cladding surface temperature decreases during the power decrease. As the coolant flow rate approaches to zero, the maximum cladding surface temperature rises, peaking to 117°C, which is higher than the cladding surface temperature before transient by 16 °C. The other transient trips for this case are shown in Table 5.

Table 5.
Tajoura Reactor Core at Several Transient Trips in the Case of Loss of Flow Accident

	Steady State	Overpower Trip	-ve ρ insertion Trip	–ve ρ_{max} insertion trip
Time, sec	0	10.015	10.595	71.047
Power, MW	5	5.041	5.028	0.179
Reactivity,	0	0.0028	-0.00002	-33.064
DNBR	5.575	5.615	5.561	71.596
T_{cool}, °C	75.958	74.735	75.260	115.041
T_{clad}, °C	100.686	97.898	98.707	117.398
T_{fuel}, °C	104.153	101.394	102.181	117.527

6. Conclusions

From the steady state calculations for the Tajoura reactor core with LEU target at different power levels (Table 3) and from safety point of view, we conclude that the permissible reactor core operating power level is 5 MW.

Finally, from the all cases of transient analysis results for Tajoura reactor core loaded with LEU target for ^{99}Mo production, we conclude that the cladding surface temperature still remains much lower than the temperature at which clad damage might occur, when operate the reactor core at power level of 5 MW only.

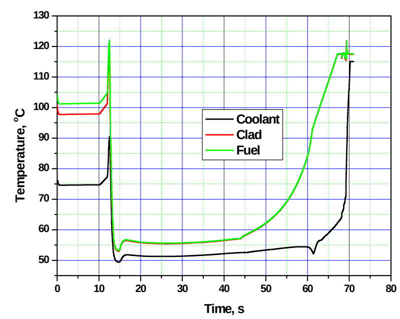

Figure 8. *Fuel, Clad and Coolant as a Function of Transient Time in the case of Loss of Flow*

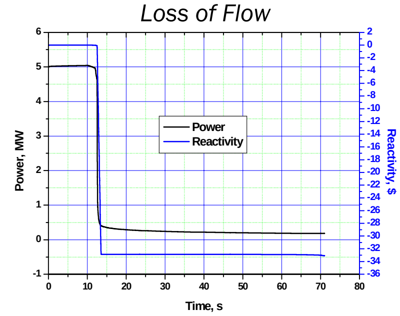

Figure 7. *Reactivity and Power as a Function of Transient Time in the case of Loss of Flow*

Acknowledgments

The authors express their thanks to the REWDRC for supporting this work, and to the Dr. Charlie Allen, Missouri University Research Reactor (MURR), Columbia Research Reactor for reviewing this manuscript and also we appreciate his opinions about it.

7. References

1. KNOW-HOW DOCUMENTATIONS: "***Tajoura Nuclear Research Design***", Building 1, Design Features of the Control Rod Arrangement in the Reactor Ensuring Replacement with the Fuel Charge Pattern in the Core, 622-1-KH-151 (9), 1979.

2. Bsebsu, F. M.:"***IRT- 4M Fuel Assembly Design and Calculation Parameters***", Technical Report, REWRDC: R-CU2-01-2005, Tajoura (Tripoli) Libya, 2005.01.31.

3. University of Missouri Research Reactor: "*Feasibility Study – Part 1, Production of Fission Product ^{99}Mo Using the LEU-Modified Cintichem Process*", TDR-0102, USA, July 2006.

4. Toma C., Iorgulis C., Busuice P., Negut Gh., and Covaci St.:"*Progress in Technology Development for ^{99}Mo Isotope Production*", The RERTR-2006 International Meeting on Reduced Enrichment for Research and Test Reactors, Cape Town, South Africa, Oct. 29 – Nov. 2, 2006.

5. Bsebsu, F. M. and Bede G.: "*Theoretical Study in Single-Phase Forced-Convection Heat Transfer Characteristics for Narrow Annuli Fuel Coolant Channels*", Periodica Polytechnica Ser. Mech. Eng 46 (1), pp. 15-27, Budapest University of Technology and Economics, Budapest Hungary. 2002.

6. C. F. Obenchain: *"PARET-A Program for the Analysis of Reactor Transients*", ACE Research and Development Report, IDO-17282, January 1969.

7. Bsebsu, F. M., P.L. Garner, and N. Hanan: ***"Reactivity-Induced Transient Modeling for Tajoura Nuclear Reactor with HEU and LEU Fuels"***, The RERTR-2006, International Meeting on Reduced Enrichment for Research and Test Reactors, Cape Town, South Africa, Oct. 29 – Nov. 2, 2006.