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NEUTRONIC ANALYSIS FOR THE FISSION ^{99}MO PRODUCTION BY IRRADIATION OF A LEU TARGET AT RECH-1 REACTOR

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Introduction

- The Chilean Nuclear Energy Commission is participating in the IAEA Coordinated Research Project: "Developing Techniques for Small Scale Indigenous ^{99}Mo Production using LEU Fission or Neutron Activation".
- Fission ^{99}Mo will be produced irradiating, at RECH-1 reactor, a LEU-foil annular target of 13 grams of metallic uranium. KAERI will provide the LEU foil.
- Neutronic and activity calculations were performed and the corresponding results will be presented.

RECH-1 general overview

- Reactor : Pool type
- Nominal Power : 5 MW
- Reflector : Beryllium
- Moderator - Coolant : Light water
- Control System : 6 absorber control plates
- Operation time at 5 MW : 24 h/week

RECH-1 general overview

- **Fuel element:**

  MTR type with 16 plates

  Enrichment: 19.75% ^{235}U

  Meat of U_3Si_2-Al

  214.80 grams of ^{235}U

- **Present core configuration: 32 LEU fuel elements**
- **LEU fuel element supplier: CCHEN**
- **Conversion program: Completed in May 2006**

Present core configuration (Nº 62)

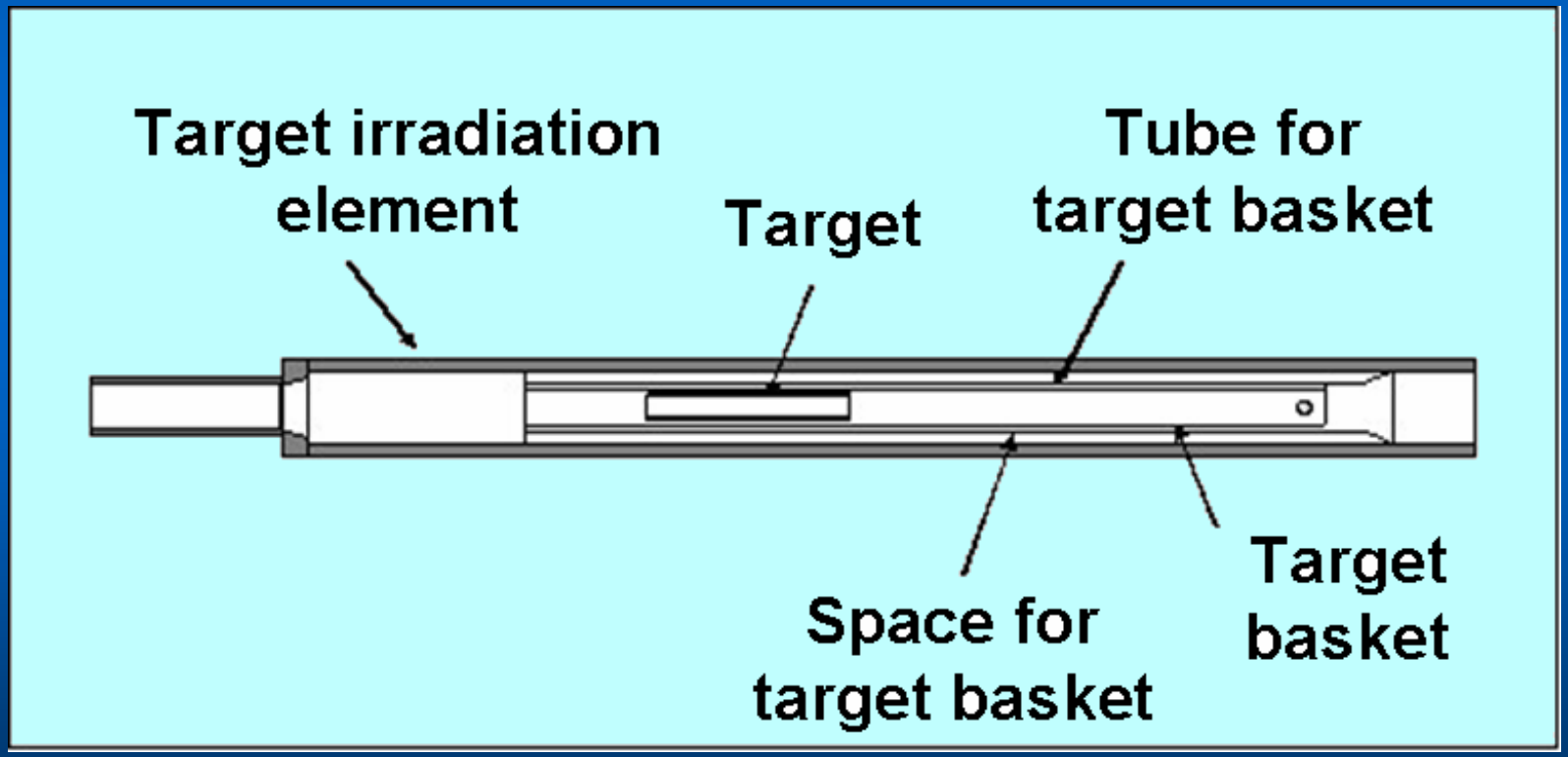
	1	2	3	4	5	6	7	8	9	10
G	Bk	Be	Be	Be	Be	Be	Be	Be	Be	Bk
F	Bk	Al	FE	FE	FE	FE	FE	FE	Al	EX
E	Be	FE	FE	FE	FE	FE	FE	FE	FE	Be
D	Al	Be	FE	FE	IP	IP	FE	FE	Be	Al
C	Be	FE	FE	FE	FE	FE	FE	FE	FE	Be
B	Be	Be	FE	FE	FE	FE	FE	FE	Be	Be
A	R_1	Al	Be	Be	IP	IP	Be	Be	IP	Be
H	Al	Bk	R_2	IP	X	X	IP	Pb	Pb	Al

FE: Fuel element
Be: Beryllium element
Bk: Blanking element
IP: Irradiation position
R_1: Pneumatic tube 1 1/8”
EX: Experimental fuel element
Al: Aluminum element
Pb: Lead element
X: Blank position
R_2: Pneumatic tube 1 1/2” (M)

Core configuration Nº 62
BOC: 13/07/2007

	1	2	3	4	5	6	7	8	9	10
G	Bk	Be	Be	Be	Be	Be	Be	Be	Be	Bk
F	Bk	Al	LR60 4.183	LR61 5.143	LR56 6.691	LR57 6.791	LR62 5.153	LR63 4.198	Al	LREX01 0.00
E	Be	LR53 5.359	LR51 7.632	LR45 15.936	LR01L 41.110	LR02L 41.882	LR46 16.543	LR50 7.880	LR55 5.447	Be
D	Al	Be	LR47 9.567	LR41 20.744	IP	IP	LR42 21.833	LR48 10.310	Be	Al
C	Be	LR52 5.352	LR49 7.177	LR44 15.703	LR03L 37.931	LR04L 37.837	LR43 16.755	LR82 7.710	LR54 5.644	Be
B	Be	Be	LR66 3.974	LR67 4.610	LR58 5.863	LR59 6.145	LR64 4.721	LR65 4.399	Be	Be
A	R_1	Al	Be	Be	IP	IP	Be	Be	IP	Be
H	Al	Bk	R_2	IP	X	X	IP	Pb	Pb	Al

Description of the target irradiation system



LEU foil annular target

- 13 g LEU metallic uranium foil
- Foil dimensions: 50 mmx100mmx0.130 mm
- Uranium foil wrapped in a thin nickel fission product-recoil barrier of 15 microns thickness.
- The thin uranium foil is held between two aluminum tubes

  Inner tube: ID=26.42 mm OD=27.99mm

  with an undercut to position the foil

  Outer tube: ID=28.22 mm OD=30.15 mm

  Length: 152 mm
- Outer and inner tubes are swaged to give good thermal contact
- Perimeter of the inner tube is not covered completely by the foil

Core configuration with LEU target system in D2 position

	1	2	3	4	5	6	7	8	9	10
G	Bk	Be	Be	Be	Be	Be	Be	Be	Be	Bk
F	Bk	Al	LR60 4.183	LR61 5.143	LR56 6.691	LR57 6.791	LR62 5.153	LR63 4.198	Al	Bk
E	Be	LR53 5.359	LR51 7.632	LR45 15.936	LR01L 41.110	LR02L 41.882	LR46 16.543	LR50 7.880	LR55 5.447	Be
D	Be	LEU Target System	LR47 9.567	LR41 20.744	IP	IP	LR42 21.833	LR48 10.310	Be	Al
C	Be	LR52 5.352	LR49 7.177	LR44 15.703	LR03L 37.931	LR04L 37.837	LR43 16.755	LR82 7.710	LR54 5.644	Be
B	Be	Be	LR66 3.974	LR67 4.610	LR58 5.863	LR59 6.145	LR64 4.721	LR65 4.399	Be	Be
A	R_1	Al	Be	Be	IP	IP	Be	Be	IP	Be
H	Al	Bk	R_2	IP	X	X	IP	Pb	Pb	Al

Core configuration with LEU target system in D5 position

	1	2	3	4	5	6	7	8	9	10
G	Bk	Be	Be	Be	Be	Be	Be	Be	Be	Bk
F	Bk	Al	LR60 4.183	LR61 5.143	LR56 6.691	LR57 6.791	LR62 5.153	LR63 4.198	Al	Bk
E	Be	LR53 5.359	LR51 7.632	LR45 15.936	LR01L 41.110	LR02L 41.882	LR46 16.543	LR50 7.880	LR55 5.447	Be
D	Al	Be	LR47 9.567	LR41 20.744	LEU Target System	IP	LR42 21.833	LR48 10.310	Be	Al
C	Be	LR52 5.352	LR49 7.177	LR44 15.703	LR03L 37.931	LR04L 37.837	LR43 16.755	LR82 7.710	LR54 5.644	Be
B	Be	Be	LR66 3.974	LR67 4.610	LR58 5.863	LR59 6.145	LR64 4.721	LR65 4.399	Be	Be
A	R_1	Al	Be	Be	IP	IP	Be	Be	IP	Be
H	Al	Bk	R_2	IP	X	X	IP	Pb	Pb	Al

Codes

- **Neutronic calculations**

  WIMS-D Spectral Transport Code

  CITATION Diffusion Code

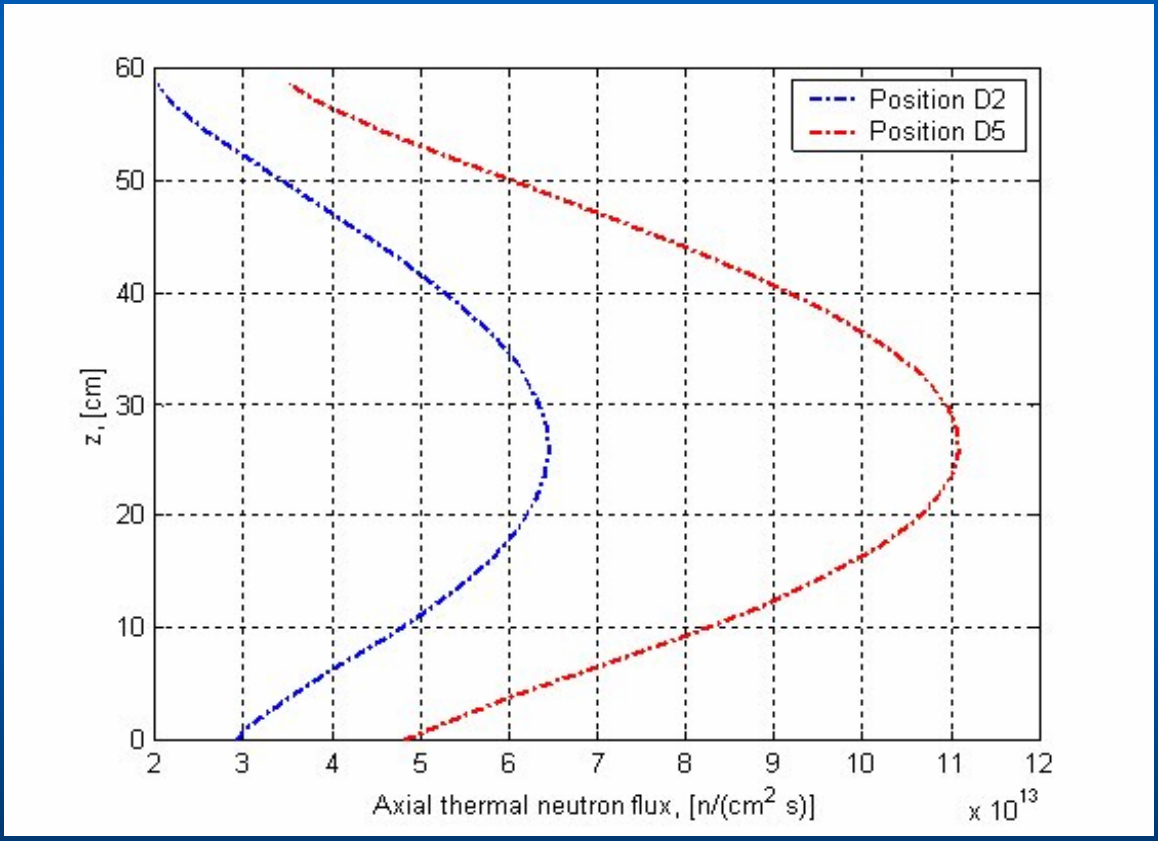
- **Fission product inventory calculations**

  ORIGEN-S (SCALE 4.4 a)

Broad group energy structure in diffusion theory calculations, eV

Group	5-group energy structure 2D calculations	3-group energy structure 3D calculations
1	0.821 E+06 - 1.000 E+07	0.821 E+06 - 1.000 E+07
2	5.530 E+03 - 0.821 E+06	0.625 - 0.821 E+06
3	2.100 - 5.530 E+03	0.000 - 0.625
4	0.625 - 2.100	
5	0.000 - 0.625	

Axial thermal neutron flux in D2 and D5 without target irradiation system



Neutronic results

k_{eff}	ρ pcm	Φ_{th} n cm^{-2} s^{-1}	P kW	Position
1.031625	3,066	5.37 E+13	4.96	D2
1.037912	3,653	8.06 E+13	7.44	D5

Average power densities, W/cm^3
LEU target system in D2 position

	1	2	3	4	5	6	7	8	9	10
G	Bk	Be	Be	Be	Be	Be	Be	Be	Be	Bk
F	Bk	Al	LR60 49.41	LR61 59.82	LR56 64.61	LR57 64.92	LR62 60.76	LR63 50.59	Al	Bk
E	Be	LR53 50.50	LR51 57.28	LR45 64.37	LR01L 62.59	LR02L 62.68	LR46 65.79	LR50 59.25	LR55 48.22	Be
D	Be	LEU Foil 7080.87	LR47 66.30	LR41 71.71	IP	IP	LR42 73.46	LR48 66.36	Be	Al
C	Be	LR52 52.44	LR49 57.44	LR44 61.72	LR03L 60.21	LR04L 60.93	LR43 63.49	LR82 60.23	LR54 51.29	Be
B	Be	Be	LR66 47.25	LR67 52.58	LR58 53.96	LR59 54.58	LR64 54.69	LR65 52.21	Be	Be
A	R_1	Al	Be	Be	IP	IP	Be	Be	IP	Be
H	Al	Bk	R_2	IP	X	X	IP	Pb	Pb	Al

Average power densities, W/cm^3
LEU target system in D5 position

	1	2	3	4	5	6	7	8	9	10
G	Bk	Be	Be	Be	Be	Be	Be	Be	Be	Bk
F	Bk	Al	LR60 50.20	LR61 60.55	LR56 64.88	LR57 64.72	LR62 60.10	LR63 49.80	Al	Bk
E	Be	LR53 47.65	LR51 58.93	LR45 66.09	LR01L 62.79	LR02L 62.85	LR46 65.25	LR50 58.35	LR55 47.40	Be
D	Al	Be	LR47 66.02	LR41 73.87	LEU Foil 10632.5	IP	LR42 73.03	LR48 65.41	Be	Al
C	Be	LR52 49.58	LR49 59.16	LR44 63.54	LR03L 60.60	LR04L 61.19	LR43 62.99	LR82 59.30	LR54 50.40	Be
B	Be	Be	LR66 48.15	LR67 53.52	LR58 54.47	LR59 54.49	LR64 54.10	LR65 51.35	Be	Be
A	R_1	Al	Be	Be	IP	IP	Be	Be	IP	Be
H	Al	Bk	R_2	IP	X	X	IP	Pb	Pb	Al

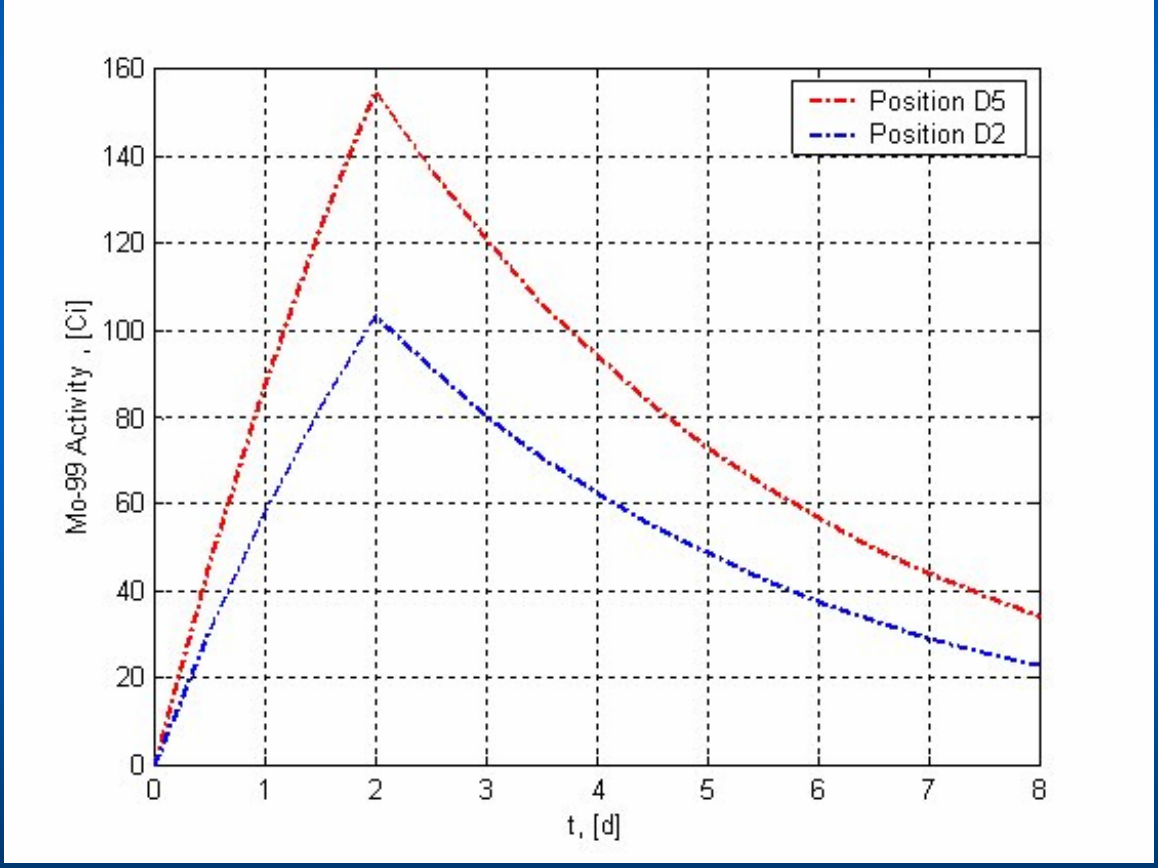
Activity results

Φ_{th}, n cm^{-2} s^{-1}	5.37×10^{13}	6.63×10^{13}	8.06×10^{13}
$A_{Mo\text{-}99}$, Ci (EOI)	103	127	155
A_{fp}, Ci (EOI)	20,600	25,200	30,800
$A_{Mo\text{-}99}$, Ci (t_d = 24 h)	80.4	98.8	121.0
A_{fp}, Ci (t_d = 24 h)	1,150	1,410	1,720

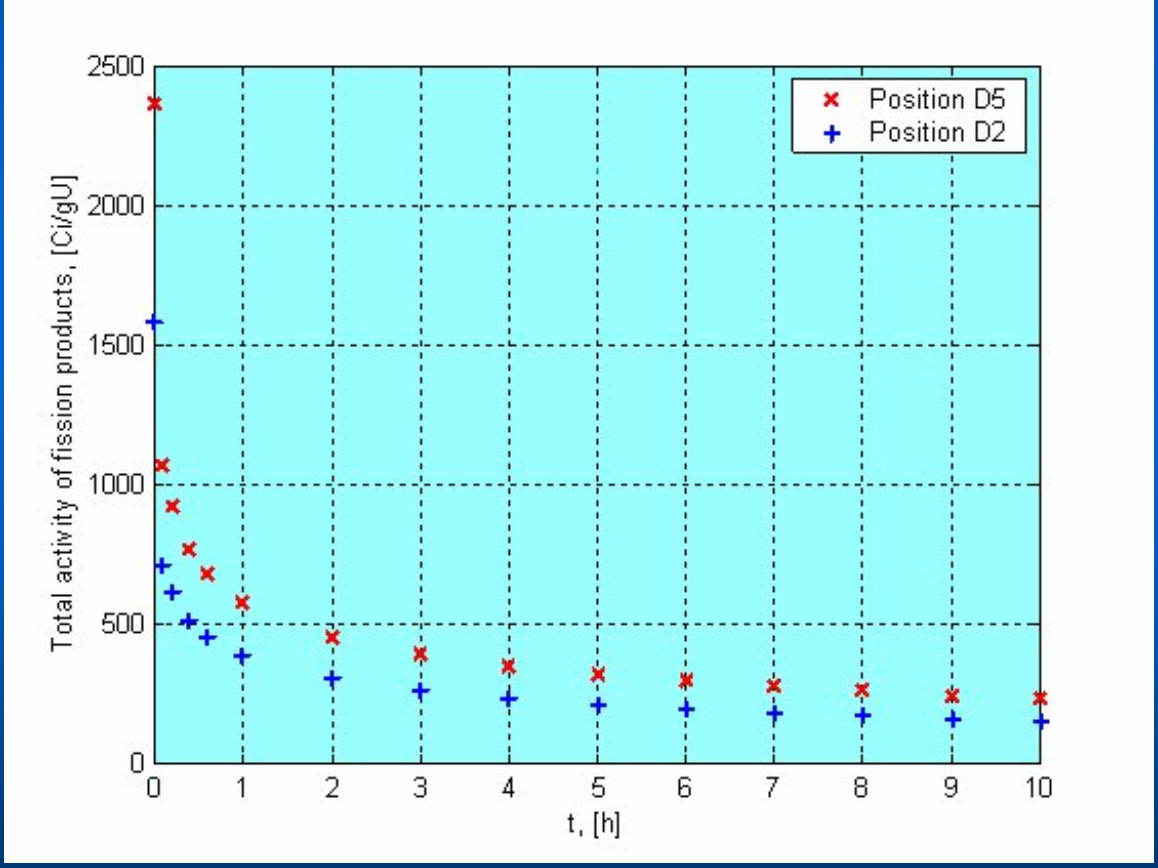
Activity and specific activity of ^{99}Mo

	Φ_{th}=5.37 E+13 n cm^{-2} s^{-1}		Φ_{th}=8.06 E+13 n cm^{-2} s^{-1}	
t_i h	A_{Mo-99} Ci	A_{sp} Ci/mg Mo	A_{Mo-99} Ci	A_{sp} Ci/mg Mo
12.0	30.92	147.24	46.42	147.04
24.0	58.09	134.44	87.37	134.79
36.0	82.09	124.44	123.37	124.62
48.0	103.00	115.97	155.0	116.24

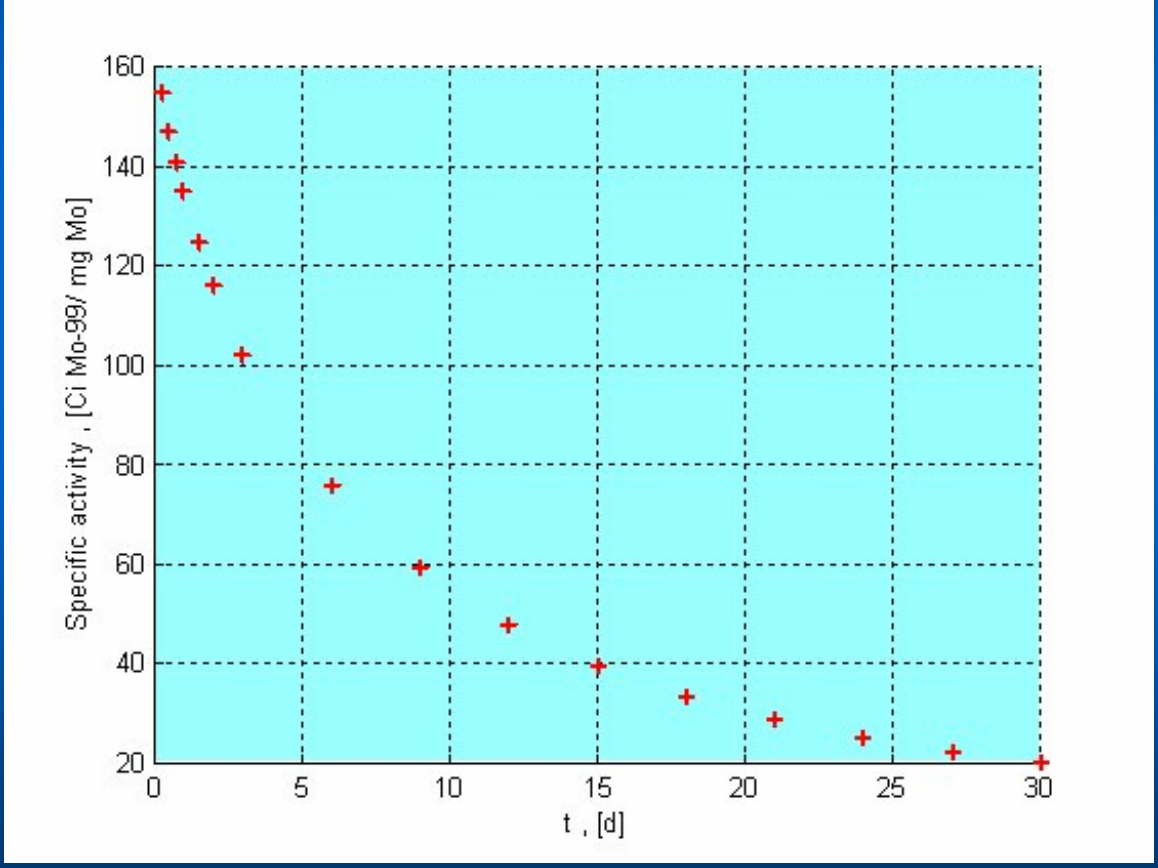
^{99}Mo activity for 13 grams of 19.75% enriched uranium



Total activity of fission products after 48 hours of irradiation



Specific activity of ^{99}Mo for different irradiation times



Conclusions (1)

- The present analysis has been based on the present core configuration of the RECH-1 reactor, with some modifications. The neutronic calculations were performed using WIMS-D and CITATION codes, supposing that the target would be introduced in the D2 or D5 positions of the reactor grid.

- The results of the 3D neutronic calculations show that the target irradiation system could be introduced in the position D5. Nevertheless is necessary to review the analyses and to consider a position of lower thermal neutron flux.

Conclusions (2)

- The fission product activities have been calculated using ORIGEN-S, considering irradiations at constant thermal neutron flux, taking into account different irradiation and decay times. The LEU foil has been located where the axial thermal neutron flux is maximum.

- The obtained results show that irradiating a LEU-foil annular target of 13 grams of metallic uranium during 48 hours at 5 MW, the produced ^{99}Mo activity would be sufficient to satisfy the demand.