Progress in Chile in the development of the fission $^{99}$Mo production using modified CINTICHEM


Chilean Nuclear Energy Commission, CCHEN, Amunátegui 95, Santiago - Chile
*Mechanical Engineering Faculty, Pontificia Universidad Católica de Valparaíso, Valparaíso - Chile

ABSTRACT

Fission $^{99}$Mo will be produced in Chile irradiating low-enriched uranium (LEU) foil in a MTR research reactor. For the purpose of developing the capability to fabricate the target, which is done of uranium foil enclosed in swaged concentric aluminum tubes, dummy targets are being fabricated using 130 µm copper foil instead of the uranium foil, wrapped in a 14µm nickel fission-recoil barrier.

Dummy targets using several dimensions of copper foil have been assembled; however, the emphasis is being set in targets fabricated using the dimensions of the LEU foil that KAERI will provide, i.e. 50 mm×100 mm×0.130 mm. The assembling of target using the last dimensions has not been free of difficulties.

Neutronic calculations and preliminary thermal and fluid analyses were performed to estimate the fission products activity and the heat removal capability for a 13 grams LEU-foil annular target, which will be irradiated in the RECH-1 research reactor at the level power of 5 MW during 48 hours.

In a fume hood, Cintichem processing of natural uranium shavings with the addition of different carriers were performed, obtaining recovery over 90% of the added Mo carrier. Expertise has been gained in (a) foil dissolution process in a dissolver locally designed, (b) in Mo precipitation process, and (c) preparation of the purification columns with AgC, C and HZrO.

Additionally, the irradiated target cutting machine with an innovative design was finally assembled.

1.- INTRODUCTION

$^{99m}$Tc, product son of $^{99}$Mo, is one of the most utilized radioisotopes in nuclear medicine in the world. Annually it is used in approximately 20 to 25 million procedures of medical diagnosis, representing about 80% of all the nuclear medicine procedures. In Chile, $^{99m}$Tc is applied in more than 90% of the nuclear medicine procedures (about 200,000 cases). In Santiago, $^{99m}$Tc produced by neutron activation is used in combination to that obtained from generators at present imported by a privat company; nevertheless, in remote cities $^{99m}$Tc of imported generators is only used. With the intention of supplying $^{99m}$Tc to all the country, CCHEN developed its own production
of $^{99}\text{Mo} - ^{99m}\text{Tc}$ generators using fission $^{99}\text{Mo}$ imported from Canada, production that was maintained during two years; however, currently it is not more done.

The present challenge is the production of its own fission $^{99}\text{Mo}$ irradiating low enriched uranium (LEU) in the RECH-1 nuclear research reactor. For the purpose of reaching that objective, CCHEN is participating in the Coordinated Research Project: "Developing Techniques for Small Scale Indigenous Mo-99 Production using LEU Fission or Neutron Activation" implemented by the IAEA and under the technical guidance of Dr. George Vandegrift from ANL, who is the promoter of the modified Cintichem chemical method of fission $^{99}\text{Mo}$ production.

The complete process of production of fission $^{99}\text{Mo}$ considers the following stages: a) target assembly where two concentric aluminium tubes that in the annular space take a 19.75% low enriched uranium foil (LEU) covered in both sides by a nickel foil like a fission product barrier, b) target irradiation in the research reactor for the production of the fission products, c) irradiated target disassembly in the high activity hot cell using a cutting machine to release the uranium and nickel foils, d) chemical modified Cintichem process considering the dissolution of the irradiated foils in nitric acid, recovery of $^{99}\text{Mo}$ by precipitation techniques and purification of the solution through ion exchange columns, e) various quality controls of the purified $^{99}\text{Mo}$ solution to verify if the $^{99}\text{Mo}$ is apt to medical use, and f) $^{99}\text{Mo} - ^{99m}\text{Tc}$ generators production.

This paper describes the done activities and the obtained results in each one of the stages mentioned before.

2.- NEUTRONIC AND THERMAL-HYDRAULIC CALCULATIONS

The neutronic and thermal-hydraulic calculations were done considering a LEU (19.75% of $^{235}\text{U}$) foil target of 50 mm x 100 mm and 130 microns of thickness, covered by both sides with a nickel foil of equal dimensions but of 15 microns thickness. The uranium foil with its nickel coverings surrounds an aluminium tube of 152 mm in length, 27.99 mm outer diameter and 26.42 mm inner diameter, which has a reduction to take the uranium and nickel foils. This set, as well, is surrounded by an aluminium tube of 28.22 mm inner diameter, 30.15 mm outer diameter and 152 mm in length. By means of a tool specially designed the inner tube is become deformed to produce a good contact between the different materials that constitute the target.

The neutronic calculations were done using the WIMS-D spectral transport code [1], [2] and the diffusion code CITATION [3]. The multigroup nuclear constants for the different zones have been generated by means of WIMS-D, whereas the neutronic calculations have been done using CITATION in two and three dimensions with a structure of 5 and 3 groups of energy, respectively.

Preliminary calculations were done using 13 grams LEU foil target of tubular shape. The results show that when it is irradiated in the RECH-1 research reactor with a thermal neutron flux of $6.6 \times 10^{13}$ n/cm²s it generates about 7.2 kW, representing a heat flow of 144 W/cm², with an increase of reactivity of the reactor core in the order of
The results of the neutron analysis are given for the target irradiation system formed by the element to irradiate targets, the target basket and the target itself.

On the other hand, calculations done with ORIGEN-S, included in the SCALE-4.4a package, show that the irradiation of 13 grams LEU foil target with a thermal neutron flux of $6.6 \times 10^{13}$ n/cm$^2$'s during 48 hours produces an activity of 127 Ci of $^{99}$Mo and a total fission products activity of 25,200 Ci at end of irradiation (EOI). Considering that the beginning of the production of generators is 24 hours after the end of irradiation, the initial theoretical activity of $^{99}$Mo is 98.8 Ci, and of total fission products 1,410 Ci.

In relation to the thermal-hydraulic calculations, the approved limits and conditions for the RECH-1 research reactor stipulate that the fuel element plates never have to reach the temperature of onset of nucleate boiling (ONB). This limitation also is made extensive to the target to irradiate.

The thermal-hydraulic calculations were done using COSMOSFLOWORKS code, utilizing as a graphical platform the software SOLIDWORKS to obtain a virtual model of the target. To run the COSMOSFLOWORKS code it is necessary to give the boundary conditions such as type of fluid, pressure, mass flow, volumetric flow, etc.

It is noticed that due to the wide of the uranium foil of only 50 mm, it does not reach to cover all the perimeter of the inner tube and approximately 43% of the perimeter of this inner tube is not covered by the uranium foil. This zone without covering will lodge air that could affect the heat transfer adversely, reason why in the process of manufacturing of the target it will be carried out avoiding caught air. Additionally the air gap effect in heat transfer has to be studied.

Fig. 1 shows the target holder in its irradiation position. The design of the target holder was done to maximize the target heat dissipation by the coolant flow inside the target.

The coolant flow that cools the target was established putting as boundary condition that the differential pressure in the irradiation position has to be the same that is had in the rest of the fuel elements in the reactor core; that is, a differential pressure of 1.72 kg/cm$^2$. The flow will distribute mainly between the central and the annular zone; a small fraction of the coolant will flow through the space is left between the basket holder and the tubing that lodges the basket (see Fig. 1).
Fig. 2 shows the distribution of speed of the coolant in the central channel and in the outer channel (annular channel) of the target. This figure also shows that the speed of the coolant in the central channel is greater than the one of the annular zone. The mean speed for the central channel is 2.84 m/s, and for the annular channel is 2.46 m/s.

![Fig.2 Flow velocity distribution in the target zone](image1)

![Fig.3 Wall temperature distribution on the inner surface of the target](image2)

Also, Fig. 2 shows that a fraction of the coolant is flowing with speed of the order of 1 m/s in the zone is left between the irradiation element and the tube that lodges the irradiation basket; this velocity seems very high since the only objective to allow water circulation is to avoid have a watertight zone. Thus, and with the intention of improving the cooling of the target, it will carry out the changes that allow have a smaller flow in that zone.

Fig. 3 shows the temperature distribution that was obtained on the inner surface of the target; this figure shows that it does not have a uniform temperature distribution. The maximum temperature in the target was on its inner surface, and it was 384 °K (111 °C), with a margin of 12 °C respect to the onset of nucleate boiling. The maximum temperature is located approximately 10 cm from the top end of the target; that is, 6.9 cm from the top edge of the uranium foil.

The given values of temperature consider a uniform distribution of the heat generated in the plate, reason why the maximum plate temperature that would be obtained considering a not uniform heat distribution would be greater than the one shown here. Taking into account the maximum wall temperature obtained, the non-uniform heat distribution, the air gap in the target, and the limits and conditions authorized, it is necessary to improve the coolant conditions, or in the worst case, to move the target in a position of lower thermal neutron flux.

The air gap; i.e. the zone not covered by the uranium foil which is approximately 43% of the target perimeter, has at least two adverse effects: (1) it will lodge air that will affect adversely the heat transfer, and (2) it does not take advantage of the coolant capacity of the coolant flow around the target. The solution is not easy if the dimensions of the uranium plate are due to maintain, and would be necessary to look for the best
solution using the machines and tools already made that will be used in the target assembly.

3. - MANUFACTURE OF THE TARGET

The different stages of preparation and assembly of the targets were done, receiving real importance the manufacturing of machines and tools, selection of components and beginning of operation that allowed obtaining exact knowledge of the involved operations.

The parameters of target assembly were settled down working with prototypes using copper foil instead of uranium foil. The tests were done using foils of 130 µm of thickness, with dimensions of 44 x 76; 50 x 100 and 76 x 88 mm for simulation of different LEU targets of 8, 13 and 16 grams, respectively. The Fuel Elements Production Plant (PEC) designed and constructed the three machines necessary to execute the processes of targets assembly, and the cutting machine for irradiated targets that will be installed in the high activity hot cell, in which will be made the chemical modified Cintichem process for obtaining the fission product $^{99}$Mo.

Finally, a technical procedure was elaborated to carry out the tasks including records that allows to select the suitable expansor to execute the action of target assembly according to the "Draft Instructions for Assembling 8 g or 16 g Ni Foil Wrapped LEU Metal Foil Annular Targets" [4].

3.1. – Expansion tool

Fig. 4 shows the expansion tool and accessories necessary to execute the sealing of the targets. Five expansors were machined and polished to external diameter of 26.33 – 26.41 – 26.48 – 26.55 - 26.62 mm.

Fig. 4 Expansion tool

3.2. - Machine for rotation of targets in welding process

Fig. 5 shows the rotatory machine designed to weld the targets; a rotation speed of 3 rpm is needed to obtain a homogenous fillet weld.
3.3. – Plate–roller for target diameter sizing

Fig. 6 shows the machine for rolling of the targets that roll the inner and outer edges of the weldings in its ends.

3.4. – Target cutting machine

Fig. 7 shows the cutting machine for irradiated targets that will settle in the high activity hot cell; its objective is to make the process of irradiated targets disassembly. The machine is designed to make two defined cuts: first, both ends of the tubes, in the internal sector of the weldings, and the second is a longitudinal cut of the external tube, process that is made turning first in 90° the system of subjection of the target. The machine has an electronic system to command in remote the operation of the three motors.
3.5. – Preparation of components for targets

**Machining of external and internal body of the Target**
The machining of the tubes for the assembly of the targets was done according to drawing PEC-M19-01-21, which is derived from drawing CMT-C1518-1/-2 Rev. 01. The significant modification was the dimensions of the external cavity of the internal aluminium tube that will take the uranium and nickel foils, for 8, 13 or 16 grams of uranium of the target.

**Cleaning of the tubes**
The cleaning of the tubes, showed in Fig. 8, was done according to information in reference [4].

![Fig.8 Cleaned target](image)

**Assembly of targets**
Once selected the components that will be part of the target, it comes to its assembly and the choosing of the expansor according to the established specifications; Fig. 9.

![Fig.9 Target assembling](image)

**Welding of targets**
The welding is done following instructive [4]. The recommended operation parameters were: DC 40 Amp current, gas mixture 90% He and Ar balanced, flow 9-10 l/min, Tungsten 2% Thorium, diameter 1/16", rotation advances 3 rpm, nozzle Nº 8.

With these parameters not good results were obtained because in our TIG equipment the polarity cannot be changed. It was decided to change some operation parameters according to the acquired technical knowledge in our processes in the Fuel Elements Production Plant (PEC). The parameters are: 40 Amp AC current, gas mixture 5% He (trade name Indurtig-Indura), flow 9-10 l/min, Tungsten 2% Thorium, diameter 1/16",
rotation advances 3 rpm, nozzle N° 8. Tests were done with prototypes obtaining excellent results of fillet welding. Finished targets showing welding are shown in Fig.10

![Fig.10 Finished targets](image)

**Inspection by means of industrial X-ray**
The X-ray inspection allows demonstrating the position of the foils inside the target. Two radiographies are taken, before and after the expansion process, and the efficiency of this process is visually verified. The operation parameters of the X-ray equipment are: 100 kV, 8 mA and 8 seg of exhibition.

![Fig. 11 Radiography before (left) and after (right) expansion operation](image)

4. - MODIFIED CINTICHEM PROCESS

The stages that take part in the modified Cintichem process are the dissolution of the irradiated target in nitric acid, the recovery of the $^{99}$Mo by precipitation with alpha-benzoin-oxime, the dissolution of the precipitate and purification of the $^{99}$Mo solution by means of two ion exchange columns. After, the various quality controls of the pure sample of $^{99}$Mo are done; it has to fulfill the specifications that will allow its use in producing $^{99}$Mo-$^{99m}$Tc generators for medical applications.

4.1. - Experiences of application of the Cintichem process

14 experiences have been done applying the modified Cintichem process, following the procedure described in [5], with some modifications (addition of HCl after step 31; first purification column with CAg/C). The experiences were done preparing non-radioactive synthetic solutions, that is, without irradiated uranium. The synthetic solutions obtained from uranyl nitrate equivalent to 1.8 g and/or 12 g of uranium shaving dissolved in 40 ml of HNO$_3$ 1.87 M and/or 8.12 M, and 0.1 g and/or 1.9 g of nickel powder dissolved in 0.3 ml of concentrated HNO$_3$, respectively. Carriers were added to the mixture of the solutions: 5.0 mg of Mo (10 mg/ml), 10.0 mg of Ru (5 mg/ml), 12 mg of Rh (8 mg/ml)
and 4.0 mg of NaI (1 mg/ml) that corresponds to equal amount of carriers described in the Cintichem procedure [5]. 0.5 ml of AgNO₃ to 10 % in HNO₃ 0.1M and 0.3ml of HCl 1N were added, and the process was continued following the 61 steps described in reference [5]. In reference [6] there are details about the experiences done, the procedures used and the results obtained.

4.2. - Preparation of the purification columns

The activated charcoal (AC) and the activated charcoal with silver (AgC) were prepared following the instructions in reference [7]. The compound HZrO was prepared following the procedure described in [8] which takes a time between 1 to 1.5 days. The process was started working with 19 g of ZrOCl₂ in 9.2 ml of deionized water, obtaining +/- 6 g of end product. The produced HZrO is stored in NaOH 0.2 M solution, and when using it is due to assure that pH is >12, because if not the efficiency of the compound is reduced, and the Mo will be adsorbed instead of circulating through the column with the product.

In order to fill the columns a small glass wool cork is placed. The resin contained in the storage solution is spilled in the column and a second glass wool cork is placed. If a second resin is loaded the procedure is the same, and it is finalized with a top glass wool cork, and both ends of the column are covered. The column was prepared with NaOH 0.2 N solution until the pH of the eluate solution reaches an approximated value to 12. Before using the column one becomes to verify pH of the eluate solution equal or over 12. The first column of purification (CAg/C) was filled with 5 cm of CAg and 5 cm of C, and the second column (AgC/HZrO/C) was filled with 3.3 cm of AgC, 3.3 cm of HZrO and 3.3 cm of C. It was prepared conditioned with NaOH 0.2 N solution.

4.3. - Results

The results of concentration of the solutions of experiences Nº 1 to 6 were obtained by the technique of Neutron Activation Analysis, with a level of confidence of 95%, and the analysis of the experiences after, were done by the technique of Inductive Coupled Plasma – Optical Emission Spectrometry. The different samples were:
1-A: dissolution solution of the Mo precipitate at exit of the column with frit
2-A: exit solution of 1st purification column of AgC
1-B: exit solution of 2nd purification column of AgC/HZrO/AC → End Product
The following Table shows the analytical results of 9 experiences.

### Results of molybdenum purification experiences

<table>
<thead>
<tr>
<th>Date of experience</th>
<th>Sample</th>
<th>Sample Volume (ml)</th>
<th>[ Mo ] mg</th>
<th>[ Ru ] mg</th>
<th>[ Rh ] mg</th>
<th>[ I ] mg</th>
<th>[ U ] mg</th>
<th>[ Ag ] mg</th>
<th>[ Ni ] mg</th>
<th>Yield %Mo</th>
</tr>
</thead>
<tbody>
<tr>
<td>24/11/06</td>
<td>1-A</td>
<td>23</td>
<td>4.42</td>
<td>1.8</td>
<td>2.71</td>
<td>0.513</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2-A</td>
<td>31</td>
<td>3.38</td>
<td>0.8</td>
<td>1.21</td>
<td>0.357</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1-B</td>
<td>50</td>
<td>3.5</td>
<td>&lt;0.07</td>
<td>&lt;0.10</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20/03/07</td>
<td>1-A</td>
<td>28</td>
<td>4.1</td>
<td>0.67</td>
<td>3.10</td>
<td>0.59</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2-A</td>
<td>43</td>
<td>4.39</td>
<td>&lt;0.06</td>
<td>2.20</td>
<td>0.19</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1-B</td>
<td>59</td>
<td>3.84</td>
<td>&lt;0.08</td>
<td>2.20</td>
<td>---</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>04/04/07</td>
<td>1-A</td>
<td>31</td>
<td>5.08</td>
<td>0.14</td>
<td>3.0</td>
<td>0.59</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2-A</td>
<td>41</td>
<td>5.33</td>
<td>&lt;0.20</td>
<td>2.00</td>
<td>0.19</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1-B</td>
<td>57</td>
<td>4.04</td>
<td>&lt;0.26</td>
<td>---</td>
<td>---</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>07/06/07</td>
<td>1-A</td>
<td>29</td>
<td>5.45</td>
<td>0.51</td>
<td>&lt;0.044</td>
<td>&lt;0.29</td>
<td>0.001</td>
<td>&lt;0.003</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2-A</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1-B</td>
<td>45</td>
<td>3.53</td>
<td>0.02</td>
<td>&lt;0.014</td>
<td>1.08</td>
<td>0.09</td>
<td>0.013</td>
<td>&lt;0.003</td>
<td></td>
<td></td>
</tr>
<tr>
<td>18/06/07</td>
<td>1-A</td>
<td>39</td>
<td>4.2</td>
<td>0.09</td>
<td>&lt;0.07</td>
<td>0.49</td>
<td>&lt;0.002</td>
<td>0.02</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2-A</td>
<td>49</td>
<td>3.6</td>
<td>0.05</td>
<td>0.02</td>
<td>0.12</td>
<td>&lt;0.002</td>
<td>0.001</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1-B</td>
<td>61</td>
<td>3.6</td>
<td>0.05</td>
<td>0.02</td>
<td>0.12</td>
<td>&lt;0.002</td>
<td>0.001</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13/07/07</td>
<td>1-A</td>
<td>28</td>
<td>4.61</td>
<td>2.36</td>
<td>&lt;0.081</td>
<td>&lt;0.37</td>
<td>0.001</td>
<td>&lt;0.005</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2-A</td>
<td>37</td>
<td>4.20</td>
<td>0.46</td>
<td>0.081</td>
<td>&lt;0.37</td>
<td>&lt;0.003</td>
<td>&lt;0.005</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1-B</td>
<td>54</td>
<td>3.70</td>
<td>0.18</td>
<td>&lt;0.081</td>
<td>&lt;0.37</td>
<td>&lt;0.003</td>
<td>&lt;0.005</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>22/08/07</td>
<td>1-A</td>
<td>31</td>
<td>3.47</td>
<td>0.25</td>
<td>&lt;0.07</td>
<td>0.37</td>
<td>0.04</td>
<td>0.005</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2-A</td>
<td>39</td>
<td>3.49</td>
<td>0.06</td>
<td>&lt;0.07</td>
<td>0.15</td>
<td>&lt;0.002</td>
<td>&lt;0.005</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1-B</td>
<td>46</td>
<td>2.97</td>
<td>0.01</td>
<td>&lt;0.07</td>
<td>0.15</td>
<td>&lt;0.002</td>
<td>&lt;0.005</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>29/08/07</td>
<td>1-A</td>
<td>31</td>
<td>5.52</td>
<td>0.41</td>
<td>&lt;0.06</td>
<td>0.40</td>
<td>0.02</td>
<td>&lt;0.004</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2-A</td>
<td>43</td>
<td>4.88</td>
<td>0.13</td>
<td>&lt;0.06</td>
<td>&lt;0.43</td>
<td>0.02</td>
<td>&lt;0.004</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1-B</td>
<td>60</td>
<td>4.39</td>
<td>0.11</td>
<td>&lt;0.06</td>
<td>&lt;0.12</td>
<td>0.02</td>
<td>&lt;0.004</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>05/09/07</td>
<td>1-A</td>
<td>31</td>
<td>5.01</td>
<td>0.49</td>
<td>&lt;0.06</td>
<td>1.02</td>
<td>&lt;0.002</td>
<td>0.02</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2-A</td>
<td>44</td>
<td>4.53</td>
<td>0.16</td>
<td>&lt;0.06</td>
<td>0.80</td>
<td>&lt;0.002</td>
<td>0.02</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1-B</td>
<td>60</td>
<td>3.84</td>
<td>0.06</td>
<td>&lt;0.06</td>
<td>&lt;0.80</td>
<td>&lt;0.002</td>
<td>&lt;0.001</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

5. – CONCLUSIONS

Foil targets of 50 mm x 100 mm and 130 microns of thickness and 13 grams of LEU (19.75% of $^{235}$U) irradiated by a thermal neutron flux of $6.6 \times 10^{13}$ n/cm$^2$s during 48 hours produce an activity of 127 Ci of $^{99}$Mo at the end of irradiation, and after 24 hours – beginning of the production of generators – the initial theoretical activity of $^{99}$Mo is 98.8 Ci.

The maximum wall temperature for a uniform heat distribution was 384 ºK (111 ºC) and located on the inner surface of the target showing a margin of 12 ºC respect to the onset of nucleate boiling. The wall temperature will be greater in the real case of non uniform heat distribution, under this condition the flow in the irradiation position has to be
increased. Otherwise, the target has to be moved to position of lower thermal flux. The last option will decrease the production of \(^{99}\text{Mo}\) for the same time of irradiation.

The three machines to use for the target assembly are constructed and operative, and the methodology of target assembly is known, and also one of the quality controls by industrial X-ray.

The irradiated targets cutting machine with remote control to use in the high activity hot cell was designed and constructed; it is in the stage of tests.

14 experiences were done simulating the conditions and equipment following the modified Cintichem process, obtaining values of molybdenum recovery of up to 80.8 %. New experiences will be done using the actual uranium and nickel foils of the definitive dimensions.

6.- REFERENCES


[4] “Draft Instructions for Assembling 8 g or 16 g Ni Foil Wrapped LEU Metal Foil Annular Targets”, presented at Workshop in BATAN, Indonesia, March 2006


