

MOLY PRODUCTION IN THE JULES HOROWITZ REACTOR: CAPACITY AND STATUS OF THE DEVELOPMENT

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This paper describes the capacity and the status of the development of Moly production facility in the Jules Horowitz Reactor (JHR), under construction at the CEA (Commissariat à l'Énergie Atomique et aux Énergies Alternatives)/Cadarache in France. JHR will contribute to the security of supply of medical radioisotopes, especially for the ^{99}Mo - $^{99\text{m}}\text{Tc}$.

Four locations are devoted to the ^{99}Mo production in the JHR reflector. A dedicated cooling circuit is associated to the Moly devices. In the way to perform the design, several mock-ups were manufactured since 2014. The process of industrialization began in 2015 for the execution studies and the construction of the in-pile part of the facility (movable systems, devices, safety cooling injection). The process of industrialization for the out of pile part (normal cooling circuit and I&C systems) and for the tooling will begin in 2018.

It is scheduled that JHR will start producing radioisotopes at the beginning of reactor operation (providing completion of the qualification of the irradiation process).

Keywords: Jules Horowitz Reactor, radioisotopes, nuclear medicine, ^{99}Mo , MOLY facility

1. INTRODUCTION

The MOLY (MOLYbdenum 99) device is intended to irradiate in the JHR¹ reflector, ²³⁵U enriched targets to produce ⁹⁹Mo, a fission product of ²³⁵U.

By radioactive decay, the ⁹⁹Mo (T_{1/2} ~ 66 h) produced is transformed into ^{99m}Tc (T_{1/2} ~ 6 h, γ 140 keV). ^{99m}Tc is the most widely used tracer in nuclear medicine (80% of the scans performed in nuclear medicine departments are made from ^{99m}Tc).

JHR will contribute to the security of supply of medical radioisotopes, especially for the ⁹⁹Mo-^{99m}Tc.

This paper describes first the capacity of the Moly production facility in the JHR, then the two main parts of this facility (in pile part and out of pile part). The main operating principles are explained as well as the mock-ups made in order to perform the design and to consolidate these operating principles. The major stages and milestones of the development of this project are listed at the end of this paper.

It is scheduled that JHR will start producing radioisotopes at the beginning of reactor operation (providing completion of the qualification of the irradiation process).

1.1. JHR PROJECT

The Jules Horowitz Reactor (JHR) is a Material Testing Reactor currently under construction at the CEA Cadarache. The reactor will perform Research and Development programs for the optimization of the present generation of Nuclear Power Plants (NPPs), support the development of the next generation of NPPs and also offer irradiation possibilities for future reactors. JHR will offer irradiation experimental capacities to study material and fuel behaviour under irradiation [R3], [R6], [R7] and [R9]. The reactor will also be devoted to medical radioisotope production [R1], [R2], [R4], [R5] and [R8].

1.2. MOLY PROJECT OBJECTIVES

The basic objectives of the MOLY project are to be able to produce an annual volume of 25% of European needs on an average basis and up to 50% of European needs in peak production. For it, production must be flexible according to customer's needs.

As announced in the OECD-NEA High Level Group on the Security of Supply of Medical Radioisotopes (HLG-MR) [R10], JHR will operate 220 days/year. Irradiation capacity for Moly production will be flexible according to customer's orders and may extended for limited periods as following:

Weekly maximum capacity²: Up to 4 800 ⁹⁹Mo 6-days Ci/week

Yearly maximum capacity²: Up to 115 200 ⁹⁹Mo 6-days Ci/year

The Moly facility has been designed in this way, while integrating safety and operational constraints. The Moly devices will accommodate Low Enriched Uranium (LEU) targets in accordance with the fourth principle of the OECD-NEA HLG-MR.

¹ *The Jules Horowitz Reactor (JHR) is under construction at the CEA (Commissariat à l'Energie Atomique et aux Energies Alternatives)/Cadarache in France.*

² *With the use of the outage reserve capacity (ORC)*

2. DESCRIPTION OF MOLY FACILITY

2.1. IMPLANTATION OF THE FACILITY

The Moly facility is composed of two main parts:

- the in pile part in the reactor pool, which includes the four Moly device vessels with the target holder, the movable system (see § 2.2.1), the underwater lines up to the piping penetrations and the two safety pumps;
- the out of pile part composed of the piping penetrations allowing the junction between the in pile cooling circuit and the cubicle cooling circuit, equipment for instrumentation and control system (I & C) and power supply (see § 2.3).

2.2. IN PILE PART

In the JHR Beryllium reflector, a reflector sector (FIG. 1) has been designed to accommodate the four Moly devices and their movable system, in order to provide a large production capacity with the greatest flexibility.

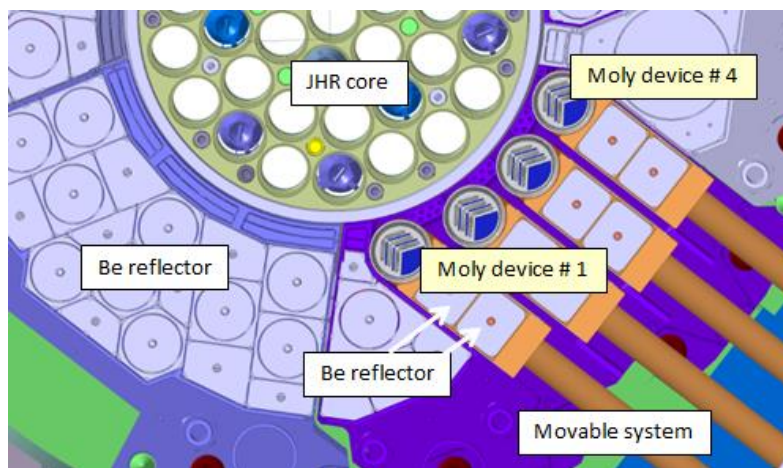


Figure 1 : Implantation of the Moly devices in the JHR reflector

In order to close the JHR reflector, two blocks of Beryllium are loaded on the movable system at the back of each Moly device (FIG. 1 and 2).

2.2.1. Movable system

Four movable systems allow the radial displacement of the four Moly devices in order to achieve loading and unloading Moly targets while JHR is at power state. The movable systems allow also the adjustment of the irradiation positions of the Moly devices as a function of the reactor power (70 MW or 100 MW) in order to optimize the production of ⁹⁹Mo while respecting the cooling capacities of the circuit and the customer's needs.

The FIG.2 view shows the different parts of the in pile part of the Moly facility.

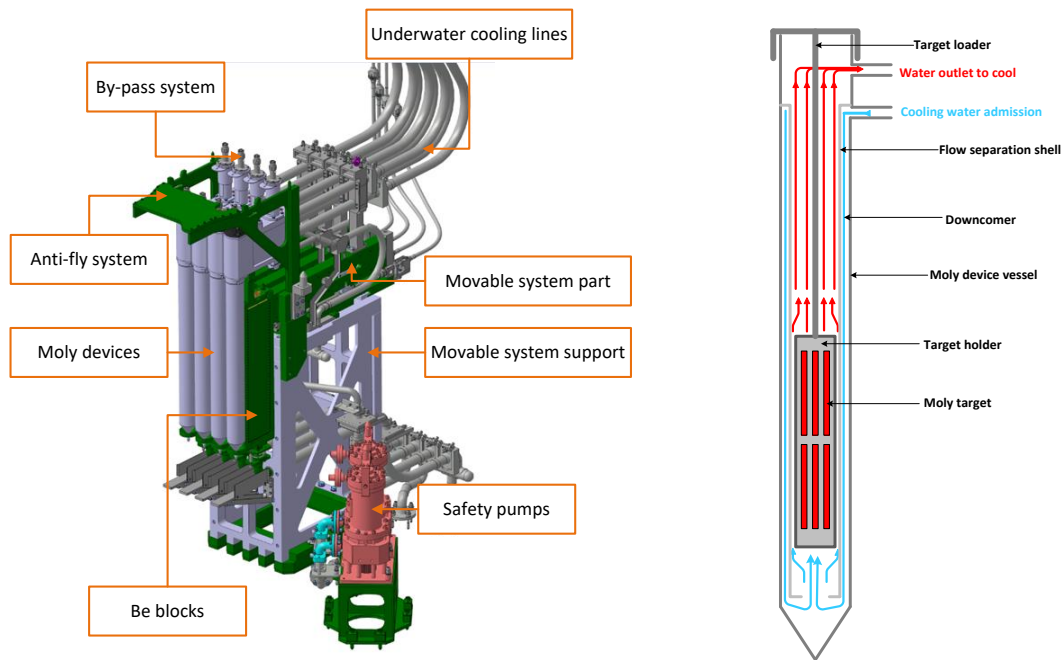


Figure 2 : CAD view of the Moly facility in the reactor pool: "in pile part" and schema of the target cooling principle

2.2.2. By-pass system

A dedicated system allowing both the by-pass of the cooling circuit and the natural convection of the device is integrated closer to the device. This by-pass system, operated with a pole by the operator when the device is in the back position, makes it possible to carry out the operations of unloading / loading the target holder without disturbing the cooling of the other irradiation devices.

2.2.3. Safety cooling flow injection

The safety circuit composed with two safety pumps, non-return valves and safety pipes is located in the reactor pool. This localisation allows a safety injection flow close to the devices and also avoid a common mode in the cubicle (i.e. to avoid the lose of main pumps and safety pumps at the same time).

The two safety pumps allow the safety cooling injection for the four Moly devices in accidental or seismic situations. In order to ensure that the safety pumps can operate during and after an earthquake, the pumps and their electrical supply will be qualified to the earthquake by tests on vibrating table.

2.2.4. Internal layout of the device

The Moly device is designed to accommodate Low Enriched Uranium (LEU) targets. The Moly device consists of a cylindrical outer vessel. The part located between the device vessel and the flow separation shell constitutes the downcomer (FIG. 2). The downcomer allows the downward movement of the cooling water in the device and thus the cooling of the external vessel of the device.

The target holder accommodates two levels of six targets (i.e. 12 targets / each Moly device) centered on the Maximum Flow Plan of the reactor core. The number of targets to be irradiated in each device is depending on customer needs. Thus, in the case where the loading of targets of a device is partial, the free spaces will be replaced by dummy targets, in order to balance the losses of pressure in the channels and thus the flow in all the irradiation devices.

The internal arrangement of the targets inside the target holder is optimized, on the one hand to guarantee the required neutron performance (target spacing and width water zone) and on the other hand to ensure good refrigeration (width of the cooling channel). Cooling of the targets is done by upward movement of the water in the channels situated on either side of the targets.

The target holder is coupled with a target loader that will allow both its handling and the closing of the device (non-sealed closure with mechanical bayonet lock). The upper part of the target loader allows the coupling of the Moly handling pole for the steps of transfers under water from the Moly device vessel to the radioisotope table for its loading / unloading.

2.2.5. Radioisotope table

This table, located in the intermediate storage pool, next to the reactor pool, is dedicated to the following operations:

- Loading of new targets in the target holder using a dedicated tool (loading tool).
- Coupling / uncoupling the target loader with the target holder and with the handling pole.
- Unloading the irradiated targets from the target loader into the transfer basket.
- Underwater cooling stage of the irradiated targets, stored in the transfer basket (5 hours minimum before reaching the hot cell).
- Storing short handling poles.

2.3. OUT OF PILE PART

The piping penetrations allow the junction between the in pile cooling circuit part and the cubicle cooling circuit part. A simplified schema of the cubicle cooling circuit part is represented on the FIG. 3 below.

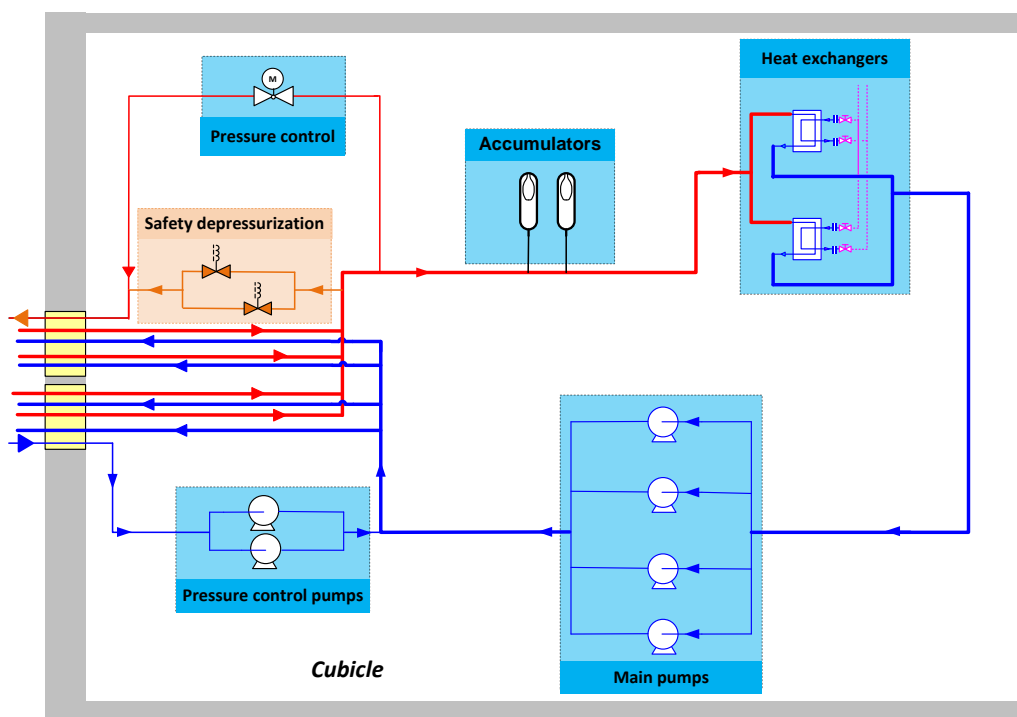


Figure 3 : Schematic diagram of the cubicle cooling circuit part of the Moly facility

2.3.1. Main circuit

The main cooling circuit consists of the main cooling lines common to the four Moly devices, which supply from the secondary lines devices, two heat exchangers and the four main pumps. Along the main refrigeration circuit the various equipment or lines are pitted to ensure that all the functions required for operation and safety of the circuit are ensured.

The main and secondary lines are equipped with pressure, flow and temperature sensors, allowing the monitoring of the operating parameters of the circuit and the initiation of preventive and safety actions if necessary.

The water circulation system of the MOLY circuit consists of 4 main pumps, arranged in parallel, operating at a nominal fixed flow rate (about 32 m³/h each). The water of the Moly circuit passes through 2 heat exchangers (P = 1 MW each) connected in parallel and supplied to the secondary side via an auxiliary reactor pool circuit. Two accumulators are mounted in parallel on the main line upstream of the exchangers. These accumulators allow real time smoothing of the circuit pressure during the forward / reverse operations of a device and the connection / disconnection of a device to the cooling circuit (via the by-pass system).

To renew the water of the Moly circuit and thus to free of a check on its chemical quality, two pressure pumps allow injection of water directly from the pool towards the main line. In addition to this water injection, a water discharge line to the pool equipped with a motorized valve is present. The functionality of these two lines (injection and discharge water) allows continuously regulation of the circuit pressure.

2.3.2. Safety part of the circuit

A depressurization of the circuit is needed in accidental situation or seismic event to allows the efficiency of the safety injection system to the devices (see § 2.2.3). For this depressurization, two solenoid valves are mounted in parallel (redundancy) on a line connected to the pool discharge line (see "safety depressurization" in FIG. 3). The opening of these solenoid valves is made by cutting off their electrical supply by the Moly safety control or by manual opening from the accidental console.

3. MOCK-UP IN SUPPORT TO THE DESIGN

In support to the design and to the safety demonstration, several mock-ups were realized during studies stages. Some of them were described hereafter.

3.1. DEVICE AND TOOLS MOCK-UP

Tests facilities were made to mock up the hydraulic behavior in the Moly device and the handling in representative JHR conditions.

3.1.1. Manufacturing process and Hydraulic test

In order to validate the design, the manufacturing process and the hydraulic of the Moly devices, a scale 1 mock-up was realized. This mock-up consists of the Moly device vessel, the target holder and the target loader (FIG. 4).



Figure 4 : Photos of Moly device mock-up and of handling tests

Hydraulic measurements were done in representative pressure drop in nominal operation of the Moly devices and with same range of nominal flow. Target holder was loaded with 12 dummy targets. Three different bottom shapes were realized to test their hydraulic influence for the total pressure drop of the Moly device.

3.1.2. Handling test

The handling tests were executed at a mock up pool facility. The goal of these tests was:

- to determine if loading and unloading the target holder from the mock-up Moly device is possible in representative condition of operation in the JHR (at approximately 8 to 9 meters of distance),
- to test the loading/unloading of targets in the target holder (at approximately 4 to 5 meters of distance),
- to test in fatigue strength the process bayonet coupling for the loading/unloading of the target holder from the mock-up Moly device.

An underwater camera was used to have a better view of the long distance tools for loading and unloading (FIG. 4).

These tests permit to validate parts of the design of the Moly device and also the design of tools needed to the handling operations. These tests permit also to made human and organizational recommendations in complement of the safety analysis.

3.2. SAFETY COOLING CIRCUIT MOCK-UP

A hydraulic representative mock-up of the Moly cooling circuit was realized in order to validate the operation concept of the safety injection and also to support the hydraulic studies, already performed.

The whole mock-up is instrumented with pressure sensor and flow meter to record and analyze the transient between the normal and the safety operating, in order to assess the correct behavior of the entire system. The preliminary data validates the fact that the general system operates correctly (normal pump, safety pump and non-return valve). Comparison between these experimental results and the simulating results, obtained by hydraulic modelling using the CATHARE 2 code is still ongoing.



Figure 5 : Mock-up facility for Hydraulic Tests

This mock-up is also a bench test for the individual performances of equipment (pump, non-return valve and different sensors technologies) in support of the design but also in the coming years for pre-commissioning tests. Ultimately, the mock-up will be modified in order to be able to carry out endurance tests on the metallic hoses in which the cooling water circulates and which follow the movement of advance / retreat of the movable systems.

4. PAST AND UPCOMING MILESTONES

Since 2011, beginnings of the Moly project, several milestones were achieved:

- Physical studies of performance (neutronic, thermo hydraulic) were carried out with LEU targets of one potential customer [R11] and formed the basis of technological studies.
- The manufacturing contract for the in pile part of the Moly facility was launched in October 2015.
- The pre-dimensioning studies for the out of pile part have been completed and studies on the I&C and the high-power current supply are still on going.
- Studies on tools for operational purposes have made progress in connection with input data provided by one potential customer [R11].
- Various tests on mock-ups permit to optimize the design of the equipments, throughout the design process and detailed studies.
- The safety analysis of the Moly facility was carried out by integrating progressively the design evolutions and human and organizational aspects (iterative process).

In 2018 main milestones will be monitor progress of the Moly project:

- The safety report, currently being verified, will be sent to the French safety authority in 2018 for licensing.
- Manufacturing of in pile part equipments, except safety pumps will be done in 2018.
- The blank assembly of the JHR reflector in order to verify the correct integration of the Moly equipments in interfaces with the JHR reflector will be begin end of 2018. After that important milestone, the mounting of the Moly in pile part will be done in the same slot as the mounting of the JHR reflector (end of mid-2019).
- The call for tender and the contracting of the out of pile part of the Moly facility will be done in 2018.
- The call for tender for the Moly operating tools (including the tools necessary for operations with the transport packaging) will be done in 2018.

- The studies to define the measures to be carried out for the qualification of the irradiation targets location (i.e. neutronic performances) will be carried out in 2018.

5. CONCLUSION

The Moly studies in the JHR allow the development of a facility capable to produce on basis a large part of European needs (from 25% to 50%). In case of global shortage and with specific provisions taken where appropriate, our maximum capacity could be able to reach up to about 25% of the world's annual demand in ^{99}Mo . In this configuration, ten millions of patients could benefit yearly from radio-isotopes produced on JHR. The flexibility of this production capacity will contribute to limiting future risks of shortages for five decades.

The studies, manufacturing of Moly equipment and associated logistics are still on going in order to reach the first Moly target production as soon as possible after the JHR phase of commissioning. In this way, the JHR reactor will be a major actor in the European production of $^{99\text{m}}\text{Tc}$ in order to secure the supply of this medical radioisotope.

In the same way, the CEA will also able to develop the necessary devices and tools for the production of other radioisotopes in support of nuclear medicine (diagnostic and therapy).

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