Development of an Electromechanical Press for Hot Cell Nuclear Fuel Fabrication

J-Ph. Bayle[1], V. Reynaud[2], M. Bataille[1], M. Gennisson[3], P. Coste[1], P. Baptiste[2], C. Brenneis[3], S. Pillon[1], E. Tronche[3]

[1]CEA/Marcoule/DEN/DTEC/SECA/LFC, BP17171 30207 Bagnols sur Cèze cedex-France

[2]Champalle ALCEN Group, 151 rue Ampère, ZI les Bruyères 01960 Peronnas- France

[3]CEA/Marcoule/DEN/DTEC/SDTC/LTAP, BP17171 30207 Bagnols sur Cèze cedex-France

Abstract:

Thanks to the fruitful collaboration between CEA and CHAMPALLE (ALCEN group), an innovative electromechanical press has been developed for the manufacturing of high radioactive nuclear fuel pellets in hot cell. In this paper, the main steps of the press development are presented.

This press has been designed to be modular, uni-axial, automatic, mono-punch, single effect with a displacement-piloted die and to operate without any oil at all. Its capacity is 10 tons, the maximum height is limited to 1200 mm and the production rate is 1 to 5 cylindrical annular or full pellets per minute.

A challenge has been to compact the equipment enough to allow its implementation in an hot cell of reduced volume without making harder the necessary operations of assembly, maintenance and dismantling. It's the reason why simulation studies have been made at different steps of the project to assist the press design. The first simulation studies were carried out by using the Studio Max 3D software to optimize press size, press location and accessibility in the cell. The second ones have consisted in virtual reality simulation with the PRESAGE platform to assess the inter-connectability of the different units and the feasibility of assembling, maintening and dismantling the press.

The modularity of the press has been finally demonstrated with a full-scale test in a cell mokup built in the CEA/Marcoule HERA facility technological platform and equipped with Lacalhène MT120 motorised arm for remote handling. The thirty individual units of the press have been successfully introduced in the hot cell through a 240 mm diameter air-lock and assembled and disassembled by remote handling. The presentation will describe the remote handling operations and present comparison between operations and simulations. Currently, press instrumentation is being upgraded in order to develop powder compaction models for the prediction of press parameter setting. This press is patented.

Introduction:

One of the missions of the Fuel Fabrication Laboratory (LFC), located in Atalante facility, is to improve and develop manufacturing process of nuclear fuel containing radioactive elements as uranium, plutonium and/or americium. The conventional nuclear fuel manufacturing process is based on powder metallurgy: actinide-bearing powders are prepared by mixing or blending, then shaped in press dies under the form of full or annular pellets and sintered at high temperature. In this presentation, a focus is given on the studies related to the development of a press operating in a hot cell to shape pellets containing large quantities of americium.

Fuel pellet manufacturing in a hot cell requires simple, effective operations and robust technologies. For many reasons such as criticality issue, nuclear waste minimization, radiolytic degradation of organic liquids under irradiation, a major design criterion was to suppress oil and hydraulic systems. The compaction cycle must be fully mastered to minimize scraps and pellet grinding. For the future fuel fabrication facilities, process automation is inevitable. To minimize the powder holdup, a mono-punch uniaxial technology is preferred to a rotary one. Furthermore, the hot cell volume dedicated to the pellet production being limited, the press must be compact and modular and each press module must be small enough to be introduced in the cell by airlock entrance of narrow diameter.

To reach such challenging specification, a methodological approach has been applied to design the press, based on different steps and tools as illustrated in **Fig 1**. Furthermore, a partnership between CEA and CHAMPALLE has been built to combine the press manufacturing experience and know-how of CHAMPALLE, and the nuclear fuel compaction and equipment nuclearization knowledge of CEA **[1]**.

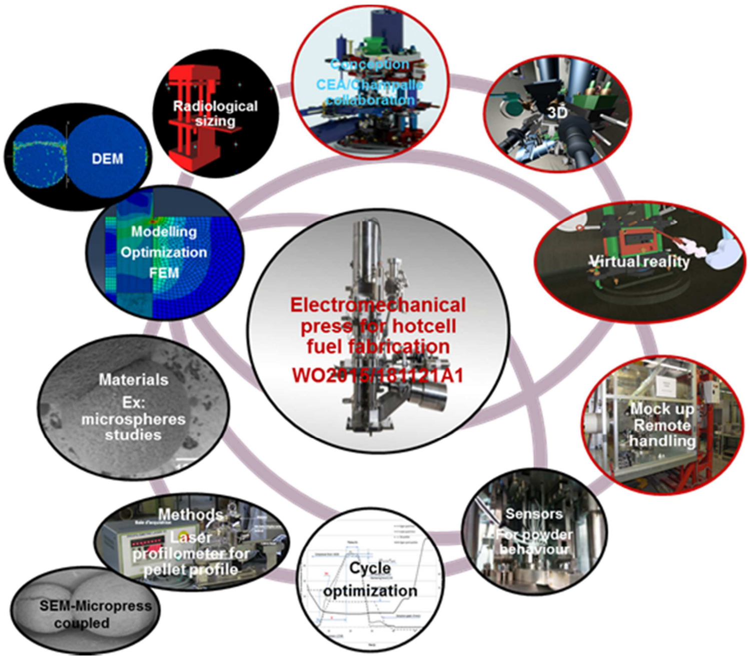

Fig 1: Main research studies

In this presentation, a focus will be given on the effort devoted to the mounting or unmounting press in hot cell with remote handling. All the operations will be described and shown in order to highlight the press robustness and modularity.

Road map:

The reduction of criticality risks at each stage of the process is an important goal for the development of any nuclear fuel manufacturing equipment. It is the main reason why the press has been designed to operate without oil and is fully electromechanical.

It is a uniaxial automatic mono-punch simple effect press, with a die displacement which can be piloted or not. Pellets can be produced by force or displacement piloting. The upper punch and die are mobile at different velocities, while the lower punch is fixed. The die is used for the ejection step with an upper punch support pressure. To produce annular pellets, a needle goes through the lower punch and follows the die displacements.

An electric motor with a minimum gap in the transmission system, combining rotary and translatory mechanisms activates the upper punch and the die. To put the apparatus in a hot cell of limited height, the die motorization was placed on the lateral side of the press. The lateral effort is transformed into a longitudinal one via a toggle joint located under the die plate.

The press capacity is 10 tons, the maximum height is limited to 1200 mm and the production rate is 1 to 5 cylindrical full or annular pellets per minute. It weighs 400 kg. The press, adapted for nuclear operations, was patented by CEA and CHAMPALLE **[2]**.

The implementation of the apparatus in a hot cell for nuclear fuel production required a modular design. Simulation studies have been carried out using 3D software to assist the press design and control that all the press modules can pass through a narrow cell airlock and to validate the modular units ability to be assembled, dismantled and maintained by remote handling.

Virtual reality simulation studies were also conducted to simulate the remote handling operations, the inter-connectability of the different units, by taking into account the force feedback of the virtual arm to prepare the experimental demonstration and train the operators.

To demonstrate finally the performance of the selected design options, the press was set up in a mock-up in the HERA facility technological platform at CEA/Marcoule for full-scale trials of disassembly and mounting operations with MT120 remote handling arm. The thirty individual units of the press passed through a 240 mm diameter air-lock to be assembled by remote handling in hot cell. The change of press tool and the accurate centring of the upper punch and the die (with or without needle) were found quite easy and so validated **[3]**.

Cad simulation:

The 3D simulation was realized by the CEA team using the 3DS Max Autocad software **[3]**. The hot cell environment was first recreated with the input-output air-lock unit, the overhead traveling crane, the remote handling arm, as well as the press set up in the cell. Then, the virtual entry and exit of the press units through the airlock and the operating method of assembly, maintenance and dismantling were controlled. Finally, press accessibility in the cell has been checked, tools necessary for the assembly operations (gripping tools, for example) improved and modular decomposition validated. **Fig 2** gives some illustrations of this simulation study **[3]**.

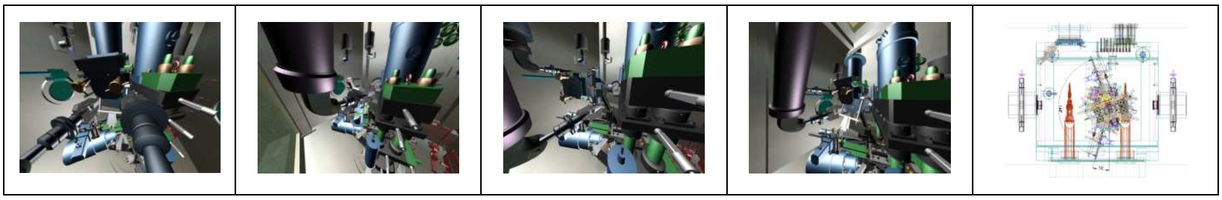

Fig 2: 3D simulation step

Virtual reality before remote handling trials:

The objectives of the virtual reality 3D simulation studies **[3]** were to simulate the assembly, dismantling, maintenance and all the press functionalities within the hot cell. In addition to the previous 3D simulation, a virtual hot cell has been created, with force feedback remote handling arm allowing the detection of collisions between the arm and the press units. It was also possible to change the arm kinematics parameters (movement angles and freedom degrees).

Thus, the virtual simulation offers a better representativity and precision of the press unit compared to 3D simulation: size gap between the modules are taken into account so that the assembling operations are more realistic, **Fig 3**.

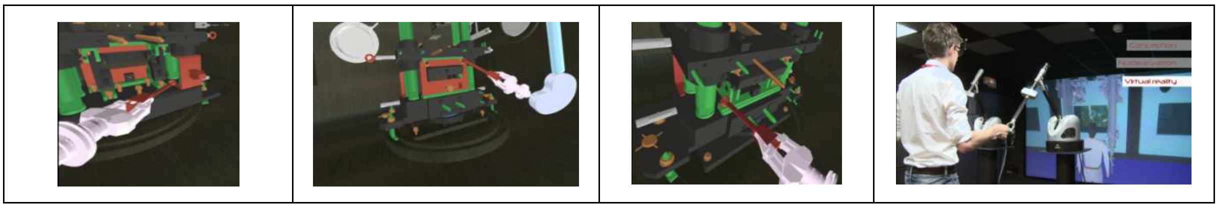

Fig 3: Virtual reality step

Remote handling trials:

The remote handling trials were carried out in an inactive cell mock-up, **Fig 4**. The mock-up was composed of a box with windows. Walls have been adjusted to adapt the box volume to the equipment size. The mock-up is equipped with MT120 remote handling arm, **Fig 4**.

Fig 4: Press in the mock-up with remote handling

The 3D picture, **Fig** 5, shows the press description.

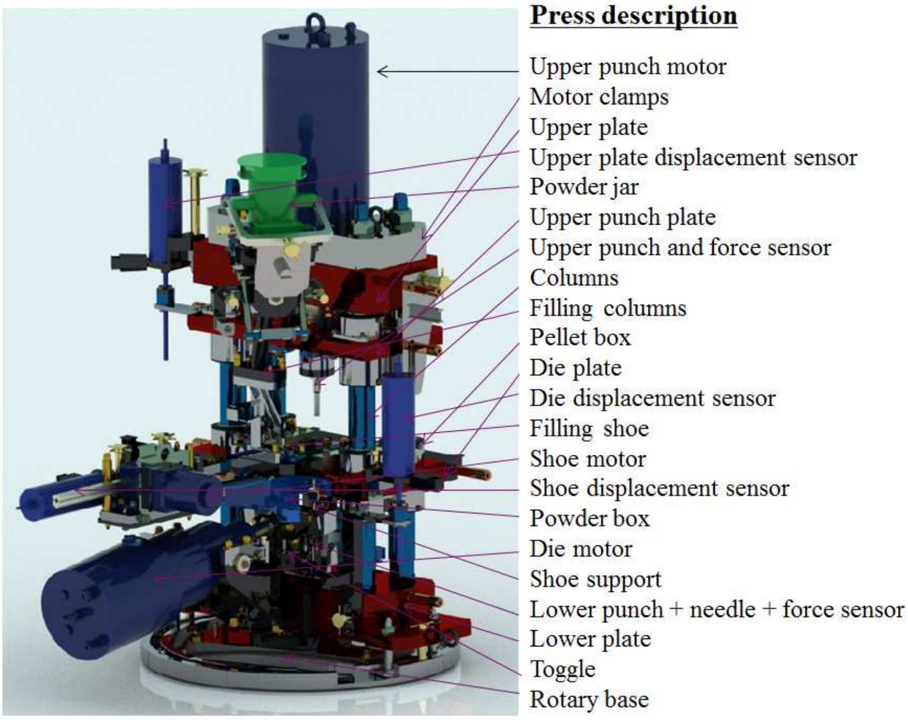

Fig 5: 3D picture and press description

The first preliminary step in the disassembly procedure is to drain away the powder into the recovery box (under the filling shoe) then withdraw the box. This draining operation is an automatic task managed by the Men Machine Interface of the press supervisor. The second preliminary step consists in withdrawing the filling powder jar (above the filling shoe), **Fig 6**. Then, the machine dismantling takes place with the following successive modules : 1)tool module (applied force sensor, upper punch, die, needle, transmitted force sensor and lower punch), 2)shoe motor, 3)shoe, 4)upper punch motor, 5)upper plate, 6)upper punch plate, 7)die plate, 8)die motor, 9)die motor support, 10)toggle, 11)columns, 12)lower plate, 13)displacement die sensor, 14)displacement shoe sensor, 15)displacement upper punch sensor, 16)lower plate and 17)rotary base.

To facilitate all these operations, the press can be easily rotated to increase the unit accessibility.

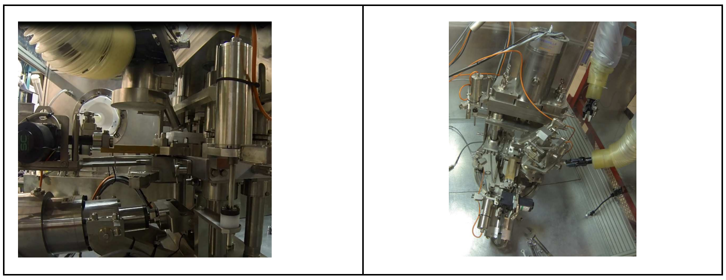

Fig 6 : Preliminary step before unmounting

For unmounting the tool module, the clamping strip is firstly removed by remote handling. Then, a specific tool has been designed, as shown in the picture bellow, to withdraw in only one step the centered upper punch, die and lower punch. The module is gripped by the lift unit with a ring, **Fig 7**. Module is finally transferred into a stainless steel container and evacuated via a 250 mm air-lock.

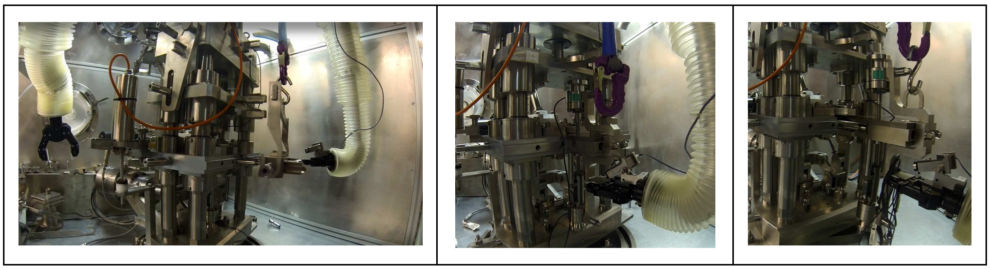

Fig 7: unmounting tools

Before withdrawing the shoe module, the filling shoe, and the displacement sensors of the die, of the upper punch and of the shoe have to be removed, **Fig 8**.

Fig 8: Filling shoe and sensors withdrawal

The shoe motor and the shoe can be successively removed, **Fig 9**,

Fig 9: shoe motor and support unmounting

then, the die motor, **Fig 10**.

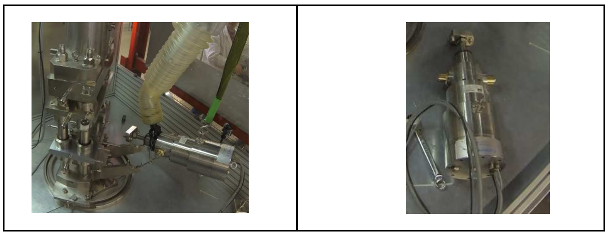

Fig 10: Die motor unmounting

The two clamps that fix the upper plate motor are dismounted by unscrewing the four nuts. The four plates are wedged before withdrawing the heavy upper punch motor with the lift unit. The evacuation of the motor in the container was quite difficult because of its weight, **Fig 11**.

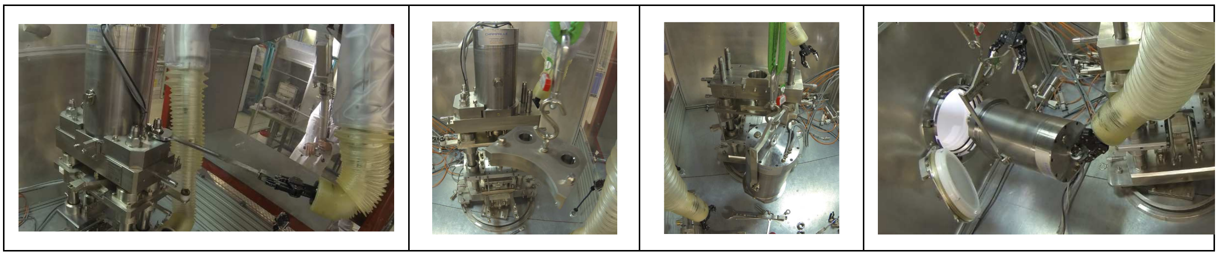

Fig 11: Clamps and upper punch motor unmounting

The upper plate, the upper punch plate, the die plate, the four columns and the lower plate dismantling takes place, **Fig 12**,

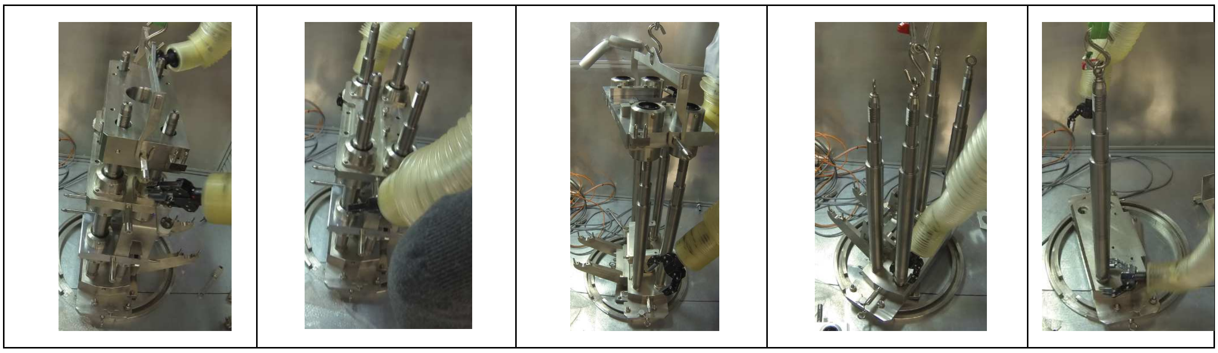

Fig 12: Upper plate, upper punch plate, die plate, lower plate withdrawal

and the toggle module , the die motor support, **Fig 13**.

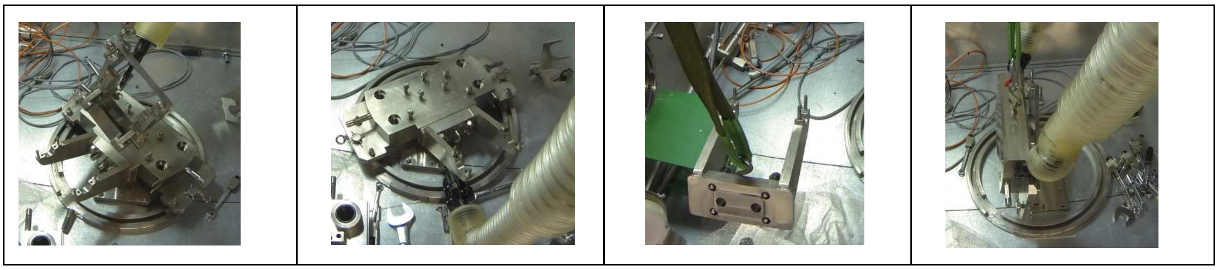

Fig 13: Toggle and die motor support unmounting

The ultimate step is the separation of the lower plate from the rotary base to allow the base withdrawal. The circular track being fixed to the mockup remains permanently, **Fig 14**.

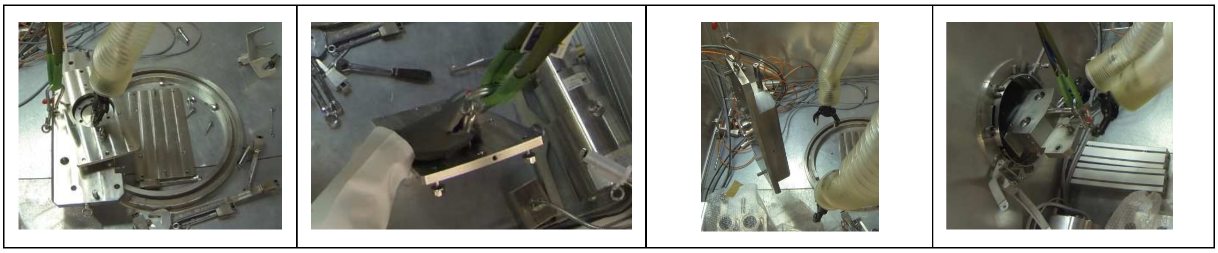

Fig 14: Lower plate and rotary plate separation

The same operations have been carried out in reverse to validate the mounting modus operandi.

Conclusion and perspectives:

The press mounting or dismantling feasibility with remote handling in hot cell has been successfully demonstrated without significant difficulties. Some tools have had to be modified or created and some points in the procedure have been improved. The complete operations (except all the evacuation operations) lasted about two weeks and required three operators, trained to remote handling. 22 modules have been dismantled, around thirty screws and nuts have been withdrawn and 12 dedicated tools have been used. A few heavy modules have been handled with the lift unit. The rotation of the press has significantly improved the accessibility of the modules in the cell.

This study highlighted the press unmounting or mounting remote handling feasibility in inactive cell. The demonstration has required two years of development and three main stages: 3D simulation, virtual reality and full-size trials in mock-up. 3D simulation and virtual reality have significantly reduced the difficulties during the trial thanks to the press design optimization and the operator preparation.

The press has been recently upgraded by the implementation of a new sensor located in the die, in order to measure the radial stresses during compaction when the die movements are fixed. The radial stress measurement is an important data used for the flow index calculation and the compaction modelling for density gradient minimization, **[4]**, **[5]**, **[6]** and **[7]**. We are studying the role of the lubricant and the lubricant behavior depending on temperature and radiations.

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