

NEW ALPHA-LAB AT KJELLER NORWAY FOR MANUFACTURE OF PELLETS AND INSTRUMENTED EXPERIMENTAL FUEL. DESIGN AND CAPABILITIES.

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ABSTRACT

For over two decades IFE Kjeller has operated an alpha laboratory with glove-boxes with the capability to produce MOX-containing instrumented, experimental fuel rods for further testing under controlled conditions in fuel experiments in the HBWR research reactor at Halden. As a result of a requirement for testing Th-MOX in the Halden reactor, the alpha fuel lab at IFE Kjeller was extended by a new line of five interconnected glove boxes for pellet manufacture from limited amounts of powders with a Pu content of up to 20%. The paper describes the new alpha (glove-box) laboratory at the IFE Kjeller lab and gives a perspective on the capabilities and limitations of MOX work allowed.

1 Introduction

1.1 Regulations, demands, and laboratory design.

Manufacture of Pu-containing Th-MOX fuels (alpha emitters), e.g. ThO₂-PuO₂ must be done in an alpha laboratory or MOX laboratory. Such a lab is defined in Norway by the authorities as a type "A-laboratory" and has to follow a range of national and international regulations, recommendations, and procedures. That includes a laboratory in a controlled zone designed with gas-tight glove boxes with underpressure and controlled atmosphere (e.g. nitrogen enriched air), a system for alpha-tight handling and transports between the glove boxes, complex ventilation, air-filtering and monitoring systems and back-ups. Further, the alpha-laboratory needs to have a safety case with risk assessments, and has to meet safety and security requirements, e.g. radiological monitoring and shielding, safeguarding, fire protection, and issues concerning waste, criticality and physical protection, intrusion, etc.

2 Experimental

This chapter describes the laboratory, glove-boxes, equipment, and processes.

2.1 Laboratory

The glove box lab is designed to follow ASTM: «C852-93 Plutonium gloveboxes»¹⁾. The new alpha lab with its new line of glove-boxes for pellet manufacture has about double the area of the previous alpha lab. The laboratory has an operation limit of 20% PuO₂ enriched fuels in limited amounts, namely several hundred grams of ThO₂-PuO₂.

Safety and security in glove box laboratory. The new alpha laboratory houses additionally a new line of 5 interconnected glove boxes for pellet manufacture from powders. The new laboratory is a separate fire compartment with no windows. The entrance to the laboratory is through a sluice (air-lock) and it has emergency exits. In the laboratory the air pressure is lower than in the building and is even lower in the glove boxes. The lab has its own, separate ventilation system (out-air) with air filters and shutters in ventilation ducts. The ventilation

system is connected to emergency and UPS back up electricity supply with alarms. The fire protection system in the laboratory is an automatic water vapour sprinkler system and the glove-boxes are equipped with a manually operated halotron fire extinguisher. Further, the lab has a radiation / airborne contamination monitoring system with alarms. The lab is a separate criticality zone.



Fig 1. New alpha-lab at Kjeller Norway for MOX pellet produksjon

2.2 MOX-pellet modifications and instrumented fuel rod manufacture

The original alpha laboratory for manufacture of instrumented MOX containing fuel rods is equipped with four, stainless steel, vacuum glove-boxes. Three of them are designated and equipped for pellet modification and one for fabrication of MOX-containing instrumented, experimental fuel rods for further testing under controlled conditions in fuel experiments in the HBWR research reactor at Halden. MOX-pellet modifications include operations such as

- Drilling
- Cutting
- Grinding/polishing & ultrasonic cleaning
- Quality control of pellet height, diameter and weight

The glove-boxes are equipped with power-tools for cutting, drilling a centre hole in pellets necessary for instrumented experimental fuel, pellet grinding, a balance, dimension measurement (measure gage), and an ultrasonic cleaner. One large glove-box, the so called “factory” glove-box, is equipped for operations necessary in the production steps of instrumented experimental fuel rods:

- Pellet drying, fuel stack alignment & fuel rod assembling
- Mounting of instrumented end-plugs
- TIG-welding of end-plugs including seal welding
- Pressurisation
- Free volume measurement
- Quality control of instrumented fuel rod by He-leak testing

2.3 Line for MOX pellet manufacture from powders

The new line of interconnected glove boxes is equipped for fuel storage, pressing, sintering of Th-MOX fuel pellets from powder, quality control, and microstructural characterization.

The glove-boxes are commercial vacuum glove boxes of stainless steel modified at IFE to have the required interconnectivity of the boxes, and necessary attachment points to electricity, electrical contacts, USB ports, gas-supply, fire extinguisher, ventilation and filtering. The boxes are interconnected by tunnels and separated by ports.



Fig.2. New line of five interconnected, separate glove boxes for Th-MOX pellet manufacture from powders equipped for powder storage, powder mixing & milling & sifting, pressing, quality control sintering.

2.4 Processes

The functionality of the laboratory, glove-boxes, experimental equipment in boxes and experimental parameters has been tested by manufacture of Thoria-Ceria fuel pellets, where Ceria was used as surrogate for Plutonia. Test pellet manufacture follows the ASTM standard for UO_2 pellet production as close as possible ³⁾.

- *Blending of fuel powders.* In the commissioning tests fuel powders were mechanically blended to desired proportions and lubricant/binder was added. Fuel powder preparations include equipment and process-parameters for following steps:
 - Blending of fuel powders to desired $ThO_2 : PuO_2$ content (Parameters: Spooning of powders, precision of balance /weighing)
 - Sifting (Parameter: mesh size)
 - *Co-milling / Ball milling.* The powders were co-milled in a laboratory planetary ball-mill in a Zirconia container with Zirconia balls. (Laboratory planetary ball mill parameters: rpm, time ,material and size of container and balls)
 - Sifting (Parameter: mesh)
 - Addition of lubricant/binder (Parameters: Quantity and Spooning of Zn-stearate additive/lubricant)
 - Ball milling (Parameters: see above)
 - Sifting (Parameter: mesh)
- *Compacting powder to green pellets.* *Compacting* was done in a modified laboratory press, one pellet at a time with critical parameters
 - Pressure (300-400 MPa)
 - Loading / Unloading
 - Press tools – die & piston (diameter / hardness / surface quality)

- Lubricant (volume fraction, added during pressing, separate lubrication of press tools)
- *Sintering of green pellets* on a Mo tray in the temperature-stable 10 cm zone in a horizontal vacuum tube furnace with critical sintering parameters
 - Sinter Temperature: (≤ 1600 °C) / Time at Sinter Temperature (≤ 4 hours)
 - Sinter-cycle length: (ca. 25 hours: heating – holding (Zn-stearate) – heating – holding at sinter temperature – cooling)
 - Atmosphere: (controlled / air)
- *Quality control follows the ASTM standard for UO₂ fuels as close as possible*⁴³⁾
 - Weight Sintered 4,9 - 5 g
 - Geometry
 - Height: ca. Green 9.2 mm Sintered 8.2 mm
 - Diameter: ca. Green 10.4 mm Sintered 9.2 mm
 - Density (geometrical) Green 67% of T.D. Sintered 93.5% of T.D.
 - Pellet appearance/surface quality checked for
 - Chips
 - Cracks
- Wet grinding of sintered pellets to required diameter was done.

2.5 Safety and experimental process data

During the commissioning test runs, studies were undertaken with the goal to establish data on:

- Powder loss / contamination of boxes during a pellet production run
- Lubrication method for pellet pressing
- Values for shrinkage and standard deviation of pellet quality within one batch

The powder loss during pellet production is in this case the value of the calculated difference from the measured fuel powder weight at start-up and the sum of the total pellet weight and the spilled powder collected after the process. Lost fuel powder is to be regarded as contamination in glove-boxes and support systems and is therefore important for risk assessments.

Lubrication during pressing is provided by Zinc-stearate addition either directly to the fuel powder or by wetting the press tools with Zinc stearate prior to pressing. Pellet shrinkage data from green to sintered pellets (including standard deviation data based on diameter measurements) are important for press tool (die and piston) material selection (Parameters: hardness (hardened steel/ hard metal), surface finish (roughness) and press-tool dimensions (die and piston). Too little lubricant leads to damages on the press tool and damaged fuel pellets.

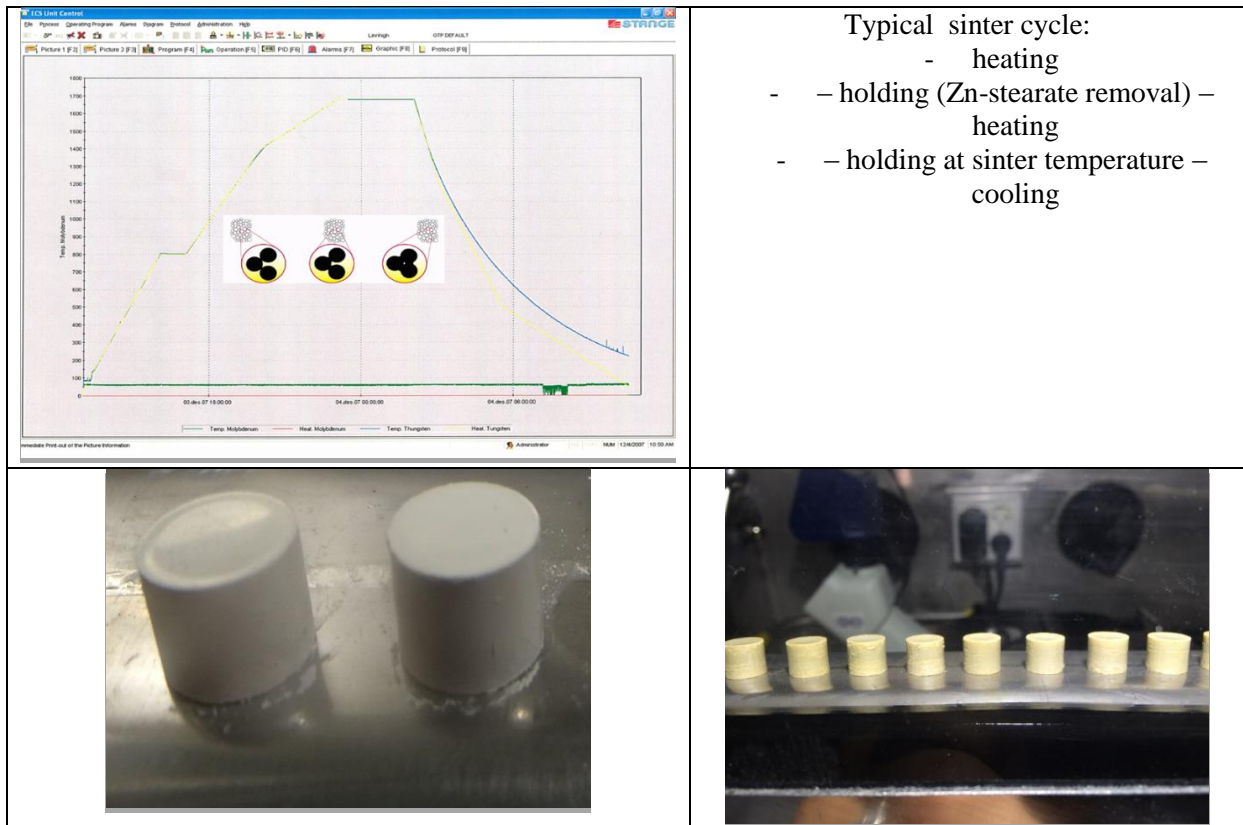


Fig.3. Typical sinter-cycle for ThO₂-CeO₂ – appearance of green pellets and sintered pellets

3 Results from test runs of laboratory installations – quality, reproducibility – shrinkage and powder loss

Commissioning runs showed that all equipment in the glove boxes is functioning. Batches of sintered pellets with no wrecks and good reproducible quality were manufactured. No visible chipping or cracks are observed in the pellets.

Observed shrinkage values as calculated from measured green to sintered pellet diameter reductions are found to be for ThO₂-CeO₂ pellets low, namely 10-12 %, compared to UO₂, where a usual shrinkage from green diameter to sinter diameter is 20 %.

Test runs showed that about 1% powder is lost in pressing/sintering processes as contamination, most of it can be cleaned up with paper and in total 0.01 % is assumed to end as contamination in the filters ²⁾

4 Conclusion

IFE Kjeller has from before capabilities in its alpha laboratory to produce MOX containing instrumented, experimental fuel rods for further testing under controlled conditions in fuel experiments in the HBWR research reactor at Halden. IFE Kjeller has now commissioned an extension to the laboratory allowing production of Th-MOX fuel pellets by the powder metallurgical route via mixing, milling, sifting, pressing and sinter processes. In the new line of five interconnected and fully equipped glove boxes, IFE can directly manufacture pellets from powders where the Pu content can be as high as 20%. In further steps in the laboratory such pellets can be modified and assembled to instrumented experimental fuel rods for testing in the HBWR with the purpose to gather in-pile fuel rod instrumentation data allowing

the user to learn more about the development of in-pile fuel centre temperatures, clad elongation, rod pressure etc..

5 References

1) ASTM: «C852-93 Plutonium gloveboxes».