Thor Energy
Scandinavian Advanced Technology

Thor Energy AS

The Norwegian Thorium Initiative

October 2013

Øystein Asphjell, CEO

STRICTLY CONFIDENTIAL
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Thor Energy AS is a nuclear fuel technology company

- Advanced, Thorium-based oxide fuel for use in today's and tomorrow's Light Water Reactors
- Near-term benefits to nuclear utilities
- Long-term benefits for the good of society
- Established in 2005 in Oslo, Norway
- Established the «International Thorium Consortium», Dec 2011.
- Loaded Thorium-oxide into the Halden Reactor on April 25 2013

Seven-Thirty

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Thorium
232,03806

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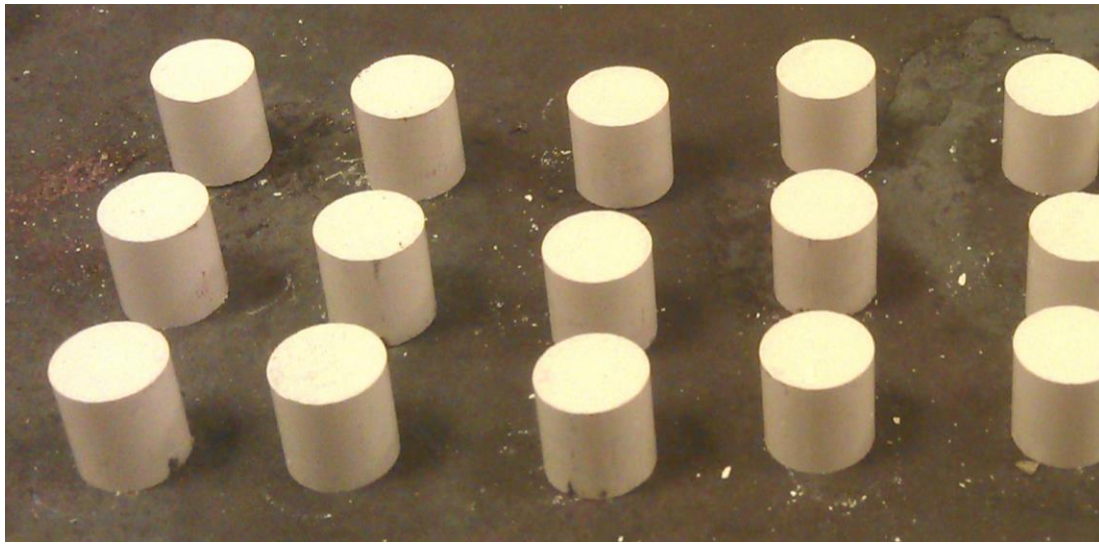
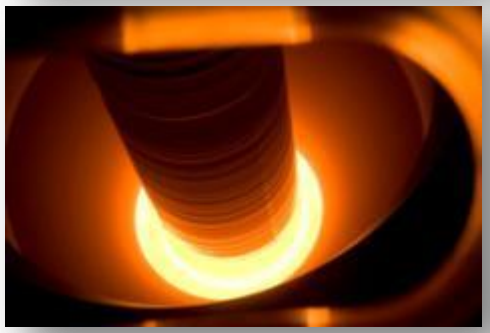


Thor Energy AS is a part of the SCATEC-group:

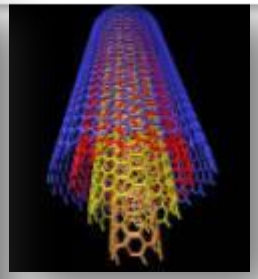
Climate neutral energy



- Solar
- Thorium
- Wind

Advanced materials

- Titanium
- Nano carbon
- Rare Earth Elements



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Renewable and climate neutral energies

Solar energy

Upstream **Downstream**

NorSun
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Scatec Solar
Scandinavian Advanced Technology

Scatec Power
Scandinavian Advanced Technology

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NorWind
Scandinavian Advanced Technology

Advanced materials

Norsk Titanium
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n-Tec
Scandinavian Advanced Technology

Norsk Separasjons-teknologi

Early phase projects

Scatec Adventure
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Scatec Sunrise
Scandinavian Advanced Technology

timetemp

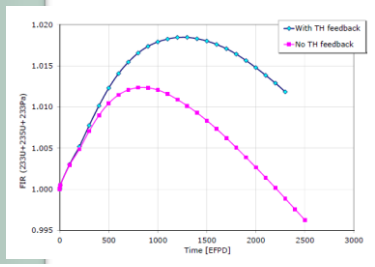
The evolution of Thorium; a 2-step phase-in

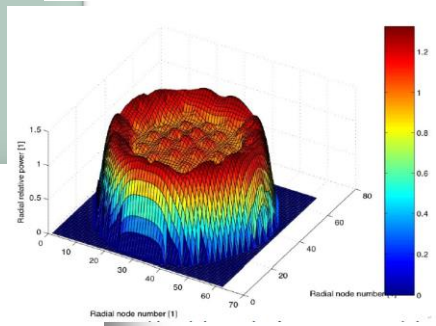
Step 1:
ThPu-oxide - once through
(Today's LWRs)

- To burn exisiting waste- stockpiles
- To produce less waste with no new Plutonium
- Increased safety margins / Superior material properties
- Longer cycles / economy
- Building a U233-"mine"
- "Benifical transition" to nuclear sustainability
- 5-10 years

Step 2:
Positive conversion – closed cycle
(Advanced LWRs / "RBWR" / RMWR)

- No feedstock limitations / "closed cycle"
- ZERO long lived waste produced (<700yrs)
- Waste volume reduced by 95%
- Extremely proliferation resistant
- 20-25 years





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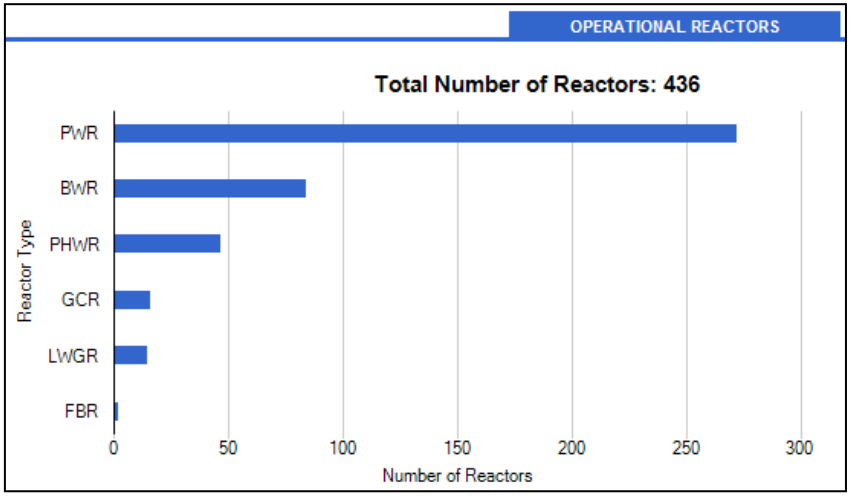
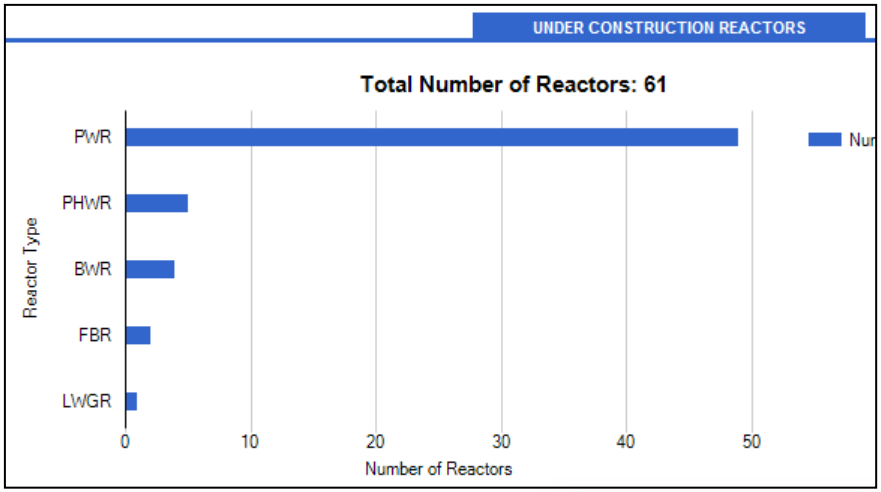
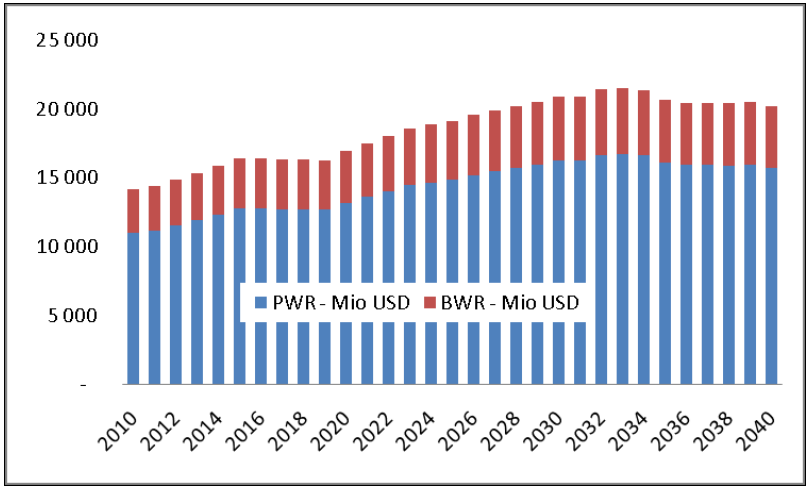
Light Water Reactors are, and will be, the backbone of nuclear power generation







World Nuclear Association

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Thorium-Pu Oxide Fuel in LWRs……why?

- **Utilizes a new and abundant natural resource;**

  Large above-ground & eternal under-ground…
- Higher conversion ratio in thermal / intermediate spectrum
- **Increased safety margins**;
  - Higher heat conductivity
  - Higher melting point
  - Less fission gas release
  - Non-soluble in water
- **Increased Plutonium destruction** (up to 60% more than with U-MOX)
- Building a U-233 «mine» - with reprocessing it is multiple recycleable in LWRs
- **Zero <u>new</u> long lived waste (MA or Pu) produced**
- Less dependency on Uranium resources
- **Evolutionary step towards closed, breeding Th232-U233-cycle in Advanced-LWRs**
- Fuel can be fabricated in conventional MOX-facilities with very little modification
- Fuel can be licensed and used as present day MOX-fuel in reactors

Country	Tonnes	% of total
Australia	489,000	19
USA	400,000	15
Turkey	344,000	13
India	319,000	12
Venezuela	300,000	12
Brazil	302,000	12
Norway	132,000	5
Egypt	100,000	4
Russia	75,000	3
Greenland	54,000	2
Canada	44,000	2
South Africa	18,000	1
Other countries	33,000	1
World total	**2,610,000**	

Conclusions in the EU / SNETP-report of 2011;

Development of a thorium fuel cycle today would probably begin with mixed thorium-plutonium fuel assemblies in light water reactors. This is expected to be necessary to gain experience of thorium related technologies e.g. in fuel manufacturing and reprocessing. It is also a way of "phasing in" thorium in the commercial fuel cycle, as light water reactors could provide ^{233}U during a transition period.

Directly introducing both a new reactor and a new fuel is associated with huge risks and is unlikely to be attractive to utilities. It should be noted though for the purpose of achieving breeding with thorium fuels, it is likely that the light water reactor would not prove adequate.

In the short term, thorium may find limited use in LWRs to jump-start the development of fuel cycle technologies required for the closed fuel cycle envisaged at a later stage.

An R&D-programme on thorium-fuels and fuel cycle options, in synergy with U/Pu-cycle, is welcome and this rather independent of specific choices of reactor technology. R&D on Th-oxide fuels including the reprocessing of these fuels and the recycling of the U, Pu and Th-vector from the used fuels is to be envisaged allowing to assess the various development paths for such Th-bearing fuels. Th-fuel irradiation experiments both in furthering the understanding of such fuels with various U and Pu compositions as well as the reprocessability of these is to be envisaged as important and necessary R&D-steps in the nearby-future allowing to map the available options for a, whenever needed, use of such Th-bearing fuels in both LWRs as transition step towards use on future reactor types.

http://www.snetp.eu/www/snetp/images/stories/Docs-SRA2009/sraannex3final.pdf

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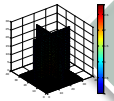
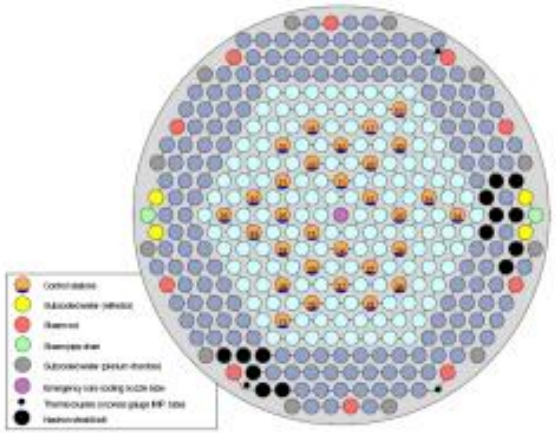
Thor Energy's key fuel development activities:



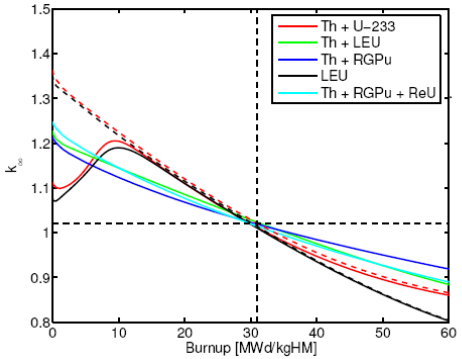
Thorium-Pu Fuel Irradiation Campaign

Feasibility study → Fuel design → **Irradiation** → Test rods → Fuel bundle



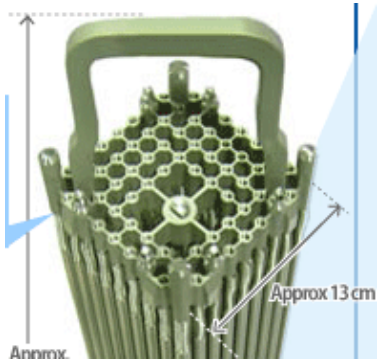
Validated computation tools

- **Neutronics, materials & fuel performance (Frapcon)**
- **Unique, patentable software tools, unique for Th**
- **Benchmarking with the irradiation campaign**



Advanced bundle and core designs

- **Patent pending: Pellet geometry**
- **Patent pending: SiC cladding with ThPu pellets**
- **2 patents in progress**



Advanced pellet design

- **Thor Energy laboratory at IFE, Norway**
- **Patent pending: Pellet comp. & mfg. (w. LANL)**
- **1 patent in progress**

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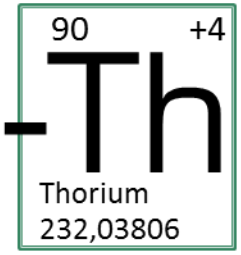

The Thorium Irradiation Campaign in the Halden Reactor

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Irradiation experiment objective

…. to yield data that can be used to demonstrate the safe, long-term performance of thorium-plutonium oxide fuels for Light Water Reactors, and that this information can support the planning and approval of a commercial a fuel…..

Regulator and Operator requirements in focus

...and not purely academic

The International Thorium Consortium:

Fortum

- Nuclear utility
- Reactor operations
- Regulatory experience
- Future fuel user?
- Finland / Sweden

Westinghouse

- Global fuel vendor
- Fuel mfg competence
- Regulatory experience
- Future fuel mfg?
- USA / Sweden

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- Fuel & test designer
- Developing fuel technology
- Project coordinator
- Norway

Partners:

IFE The OECD Halden Reactor Project
Institutt for energiteknikk

- Campaign execution
- Rig design
- Irradiation
- PIE
- Norway

NATIONAL NUCLEAR LABORATORY

- Test fuel manufacturing
- Material provider
- Nuclear competence
- England

European Commission Joint Research Centre
Institute for Transuranium Elements

- Provider of pellets, phase 1
- Th-experience

Statoil

The Research Council of Norway

- Financing

Rhodia
Member of the Solvay group

Steenkampskraal Thorium Limited

Associated member

- Provider of Thorium
- Fuel chemical comp.
- France

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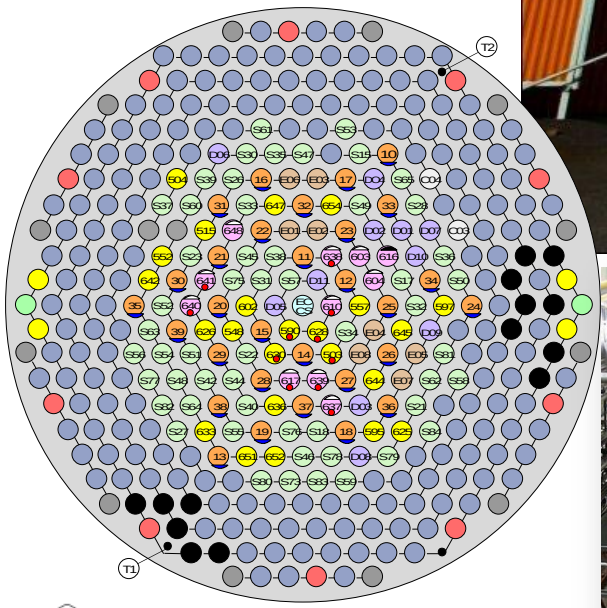
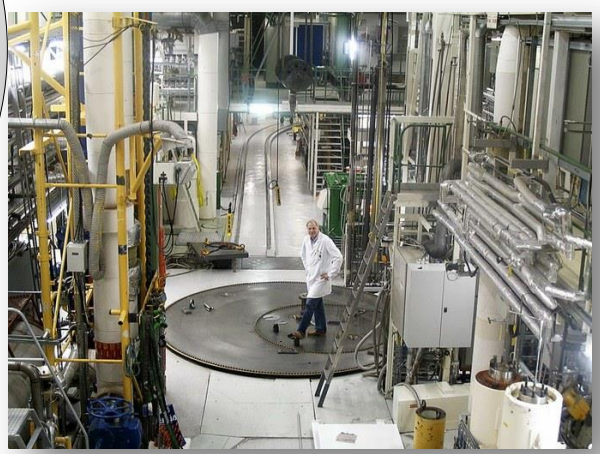
Institutt for energiteknikk
OECD HALDEN REACTOR PROJECT
50 1958 - 2008





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The Thorium Irradiation Campaign in the Halden Reactor

FUEL FABRICATION PROGRAM

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Options for Th-oxide deployment in LWRs:

Th-additive:
-5-10%Th in UOX
-core power flattening
-material property benefits
-minimize Gd-use / cost
-neutronic benefits
-All LWRs

Th-MOX, minPu:
-8-12% Pu / Th
-Maximise value of fissile material
-Core loading schemes
-U233 for future use
-All MOX-nations, old & new

Th-MOX, maxPu:
-15-22% Pu / Th
-Maximise destruction of Pu stockpile
-Superior capacity (60%) over U-MOX
-UK & USA (?)

High burnup:
~20% Pu/Th in SiC
-100 Gwd burn up
-Much higher value from the Th
-Utilising U233
-All LWRs (15+ years)

Th-MOX2:
-For Gen2 RgPu
-Higher wt-loading of Pu possible

-Existing MOX-nations

Th-U233:
-Future closed cycle
-RBWR-platform
-Repro tech required
-U233 disposition?

-Feasible alternative to FBR

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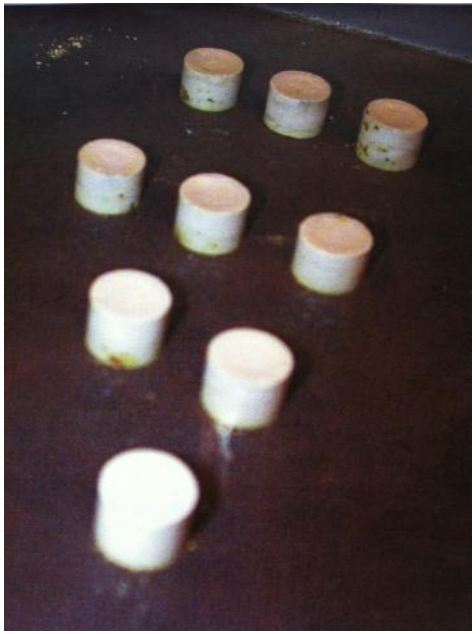
Th-Ce-oxide fuel pellets by Thor Energy:

Los Alamos NATIONAL LABORATORY

2009: *Th-Ce-pellets*
Patent pending



2012: *Th-Ce-pellets w. Ni*

ThO_2

$15\%CeO_2ThO_2$

$0.5\%Nb_2O_3 15\%CeO_2ThO_2$

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485.4g
UO2 med 7% Thorium
Thorium/UO2
42% Th.

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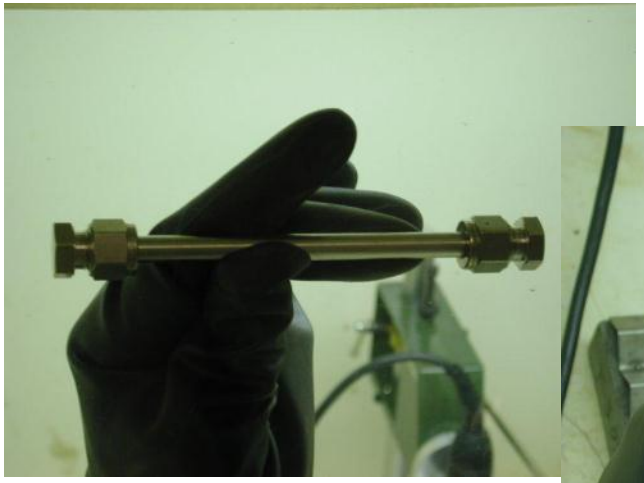

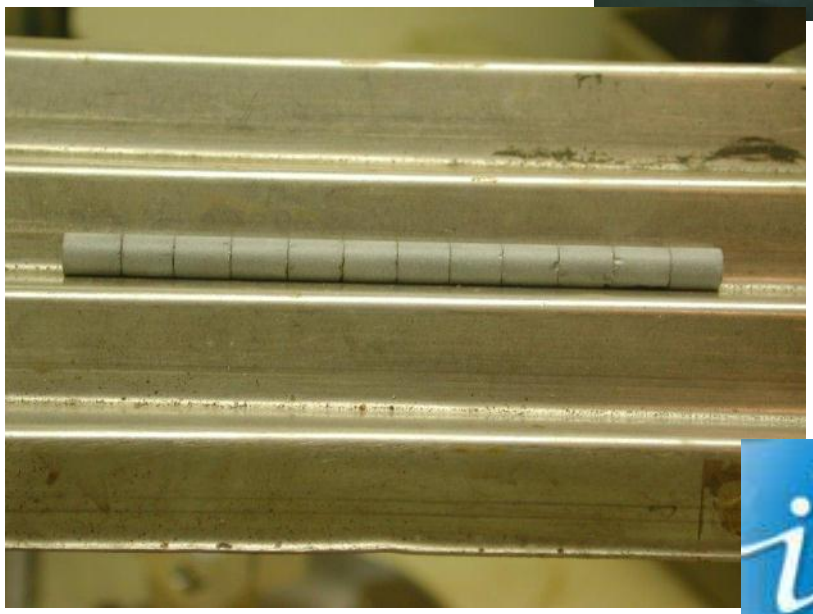

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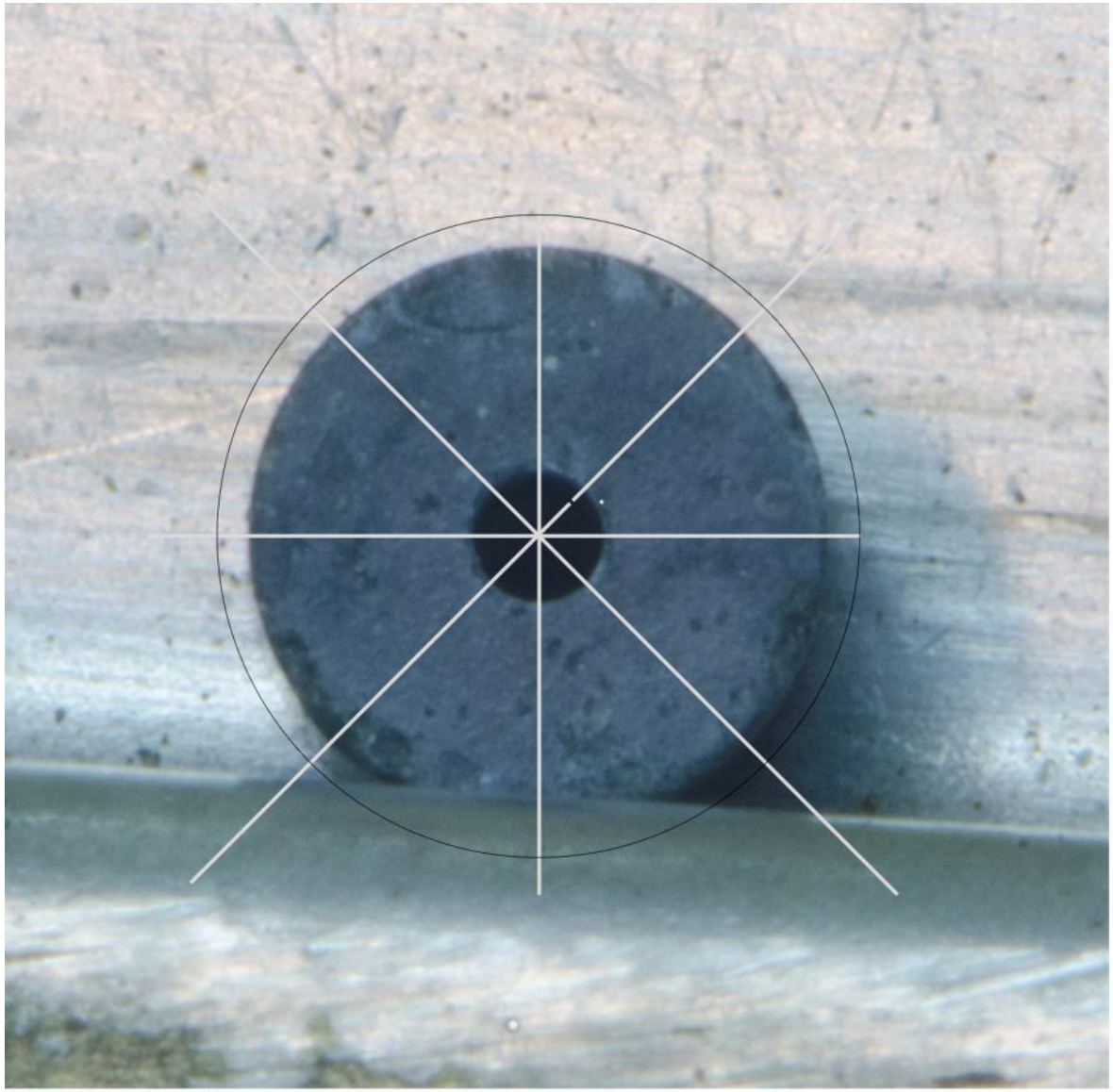

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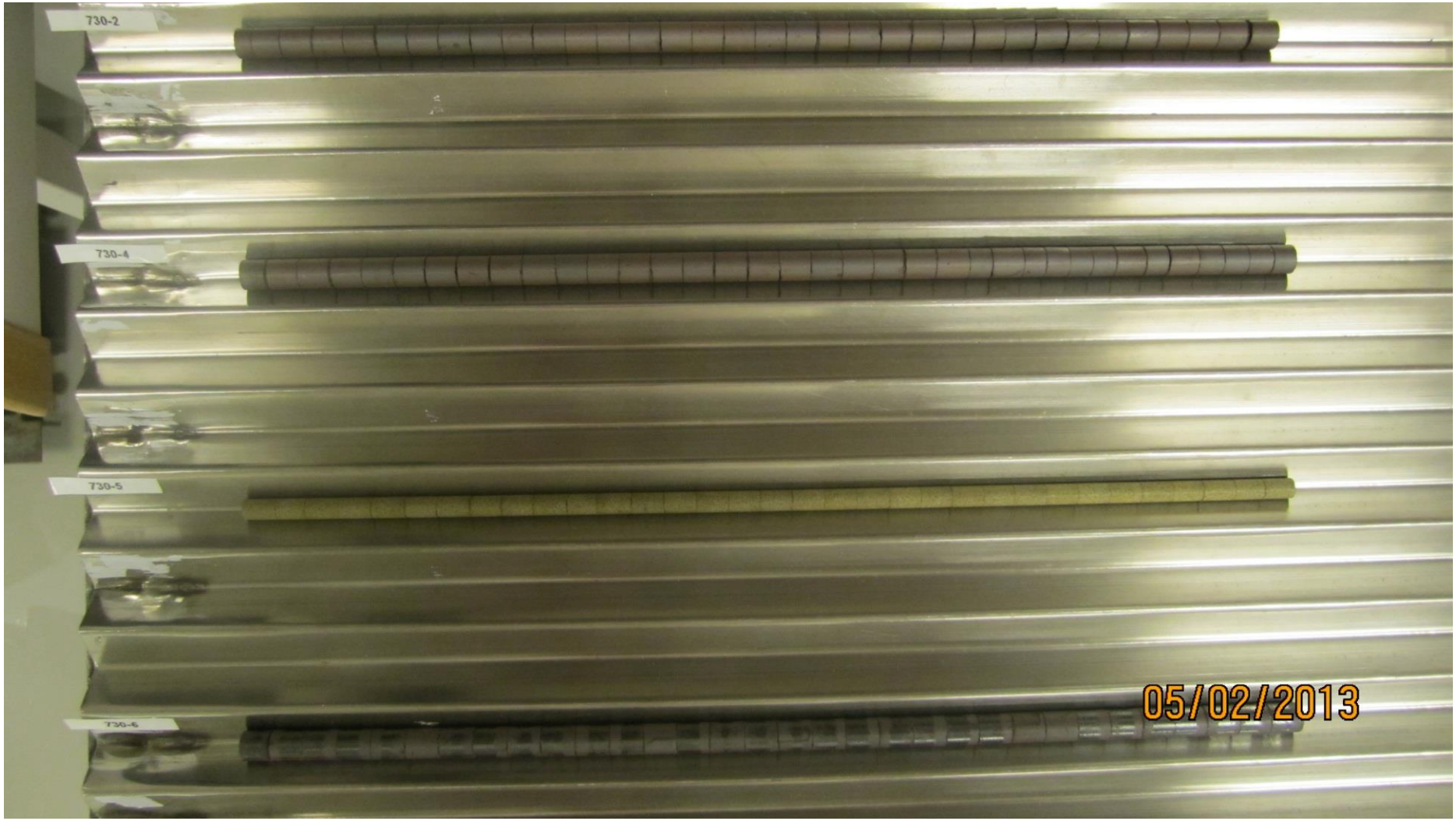
The IFA-730 Fuel Test Rig Completion



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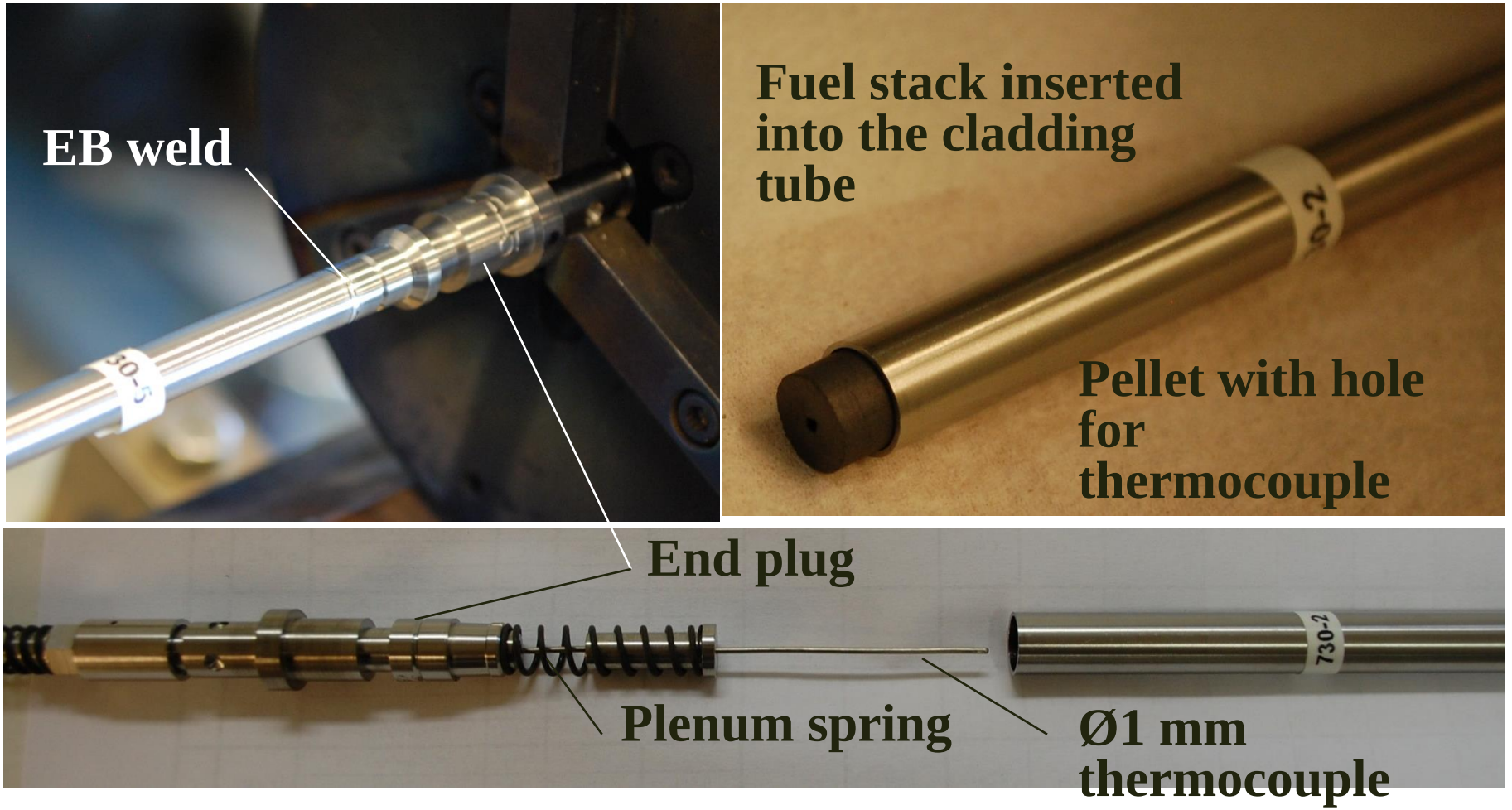
The IFA-730 Fuel Test Rod



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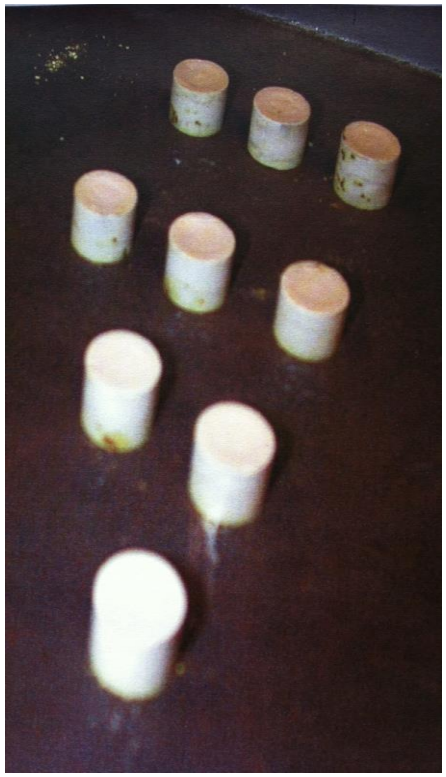
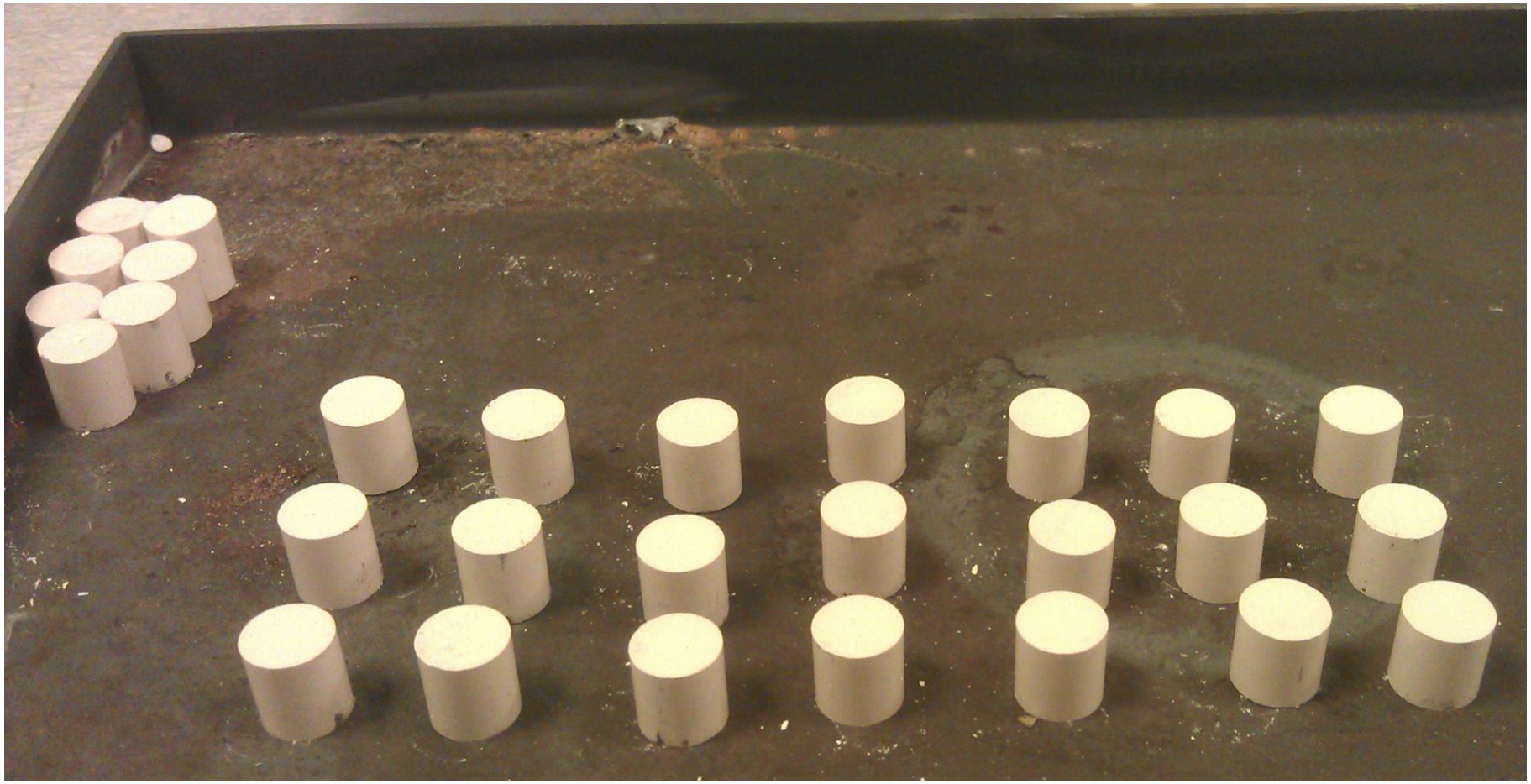
Experiment execution;

- **Phase 1a:**
  - 2 pins with 85%Th - 15%Pu pellets made by ITU, Germany
  - 2 pins with 7%Th – 93%UOX made by IFE, Norway
  - 1 pin with 65%Th – 35%UOX made by IFE, Norway
  - 1 UOX reference pin
  - Test rig #1
  - Loaded into Halden Reactor, April 2013 !
- **Phase 1b:**
  - 2 pins with 86%Th – 14%Pu made by IFE, Norway
  - Replacing Th-U pins in Test rig #1
  - Loading into Halden Reactor, April 2014
- **Phase 2:**
  - 8 pins with 86%Th – 14%Pu made by NNL, UK
  - 2 pins UOX reference
  - 2 pins MOX reference
  - Test rig #2
  - Loading into Halden Reactor, Oct 2015



Phase 1B Pellet Mfg commencing in Q1 2014

Recent «dry-runs» with Th-Ce; (67% TD after pressing / 96%(?) post-sint.);



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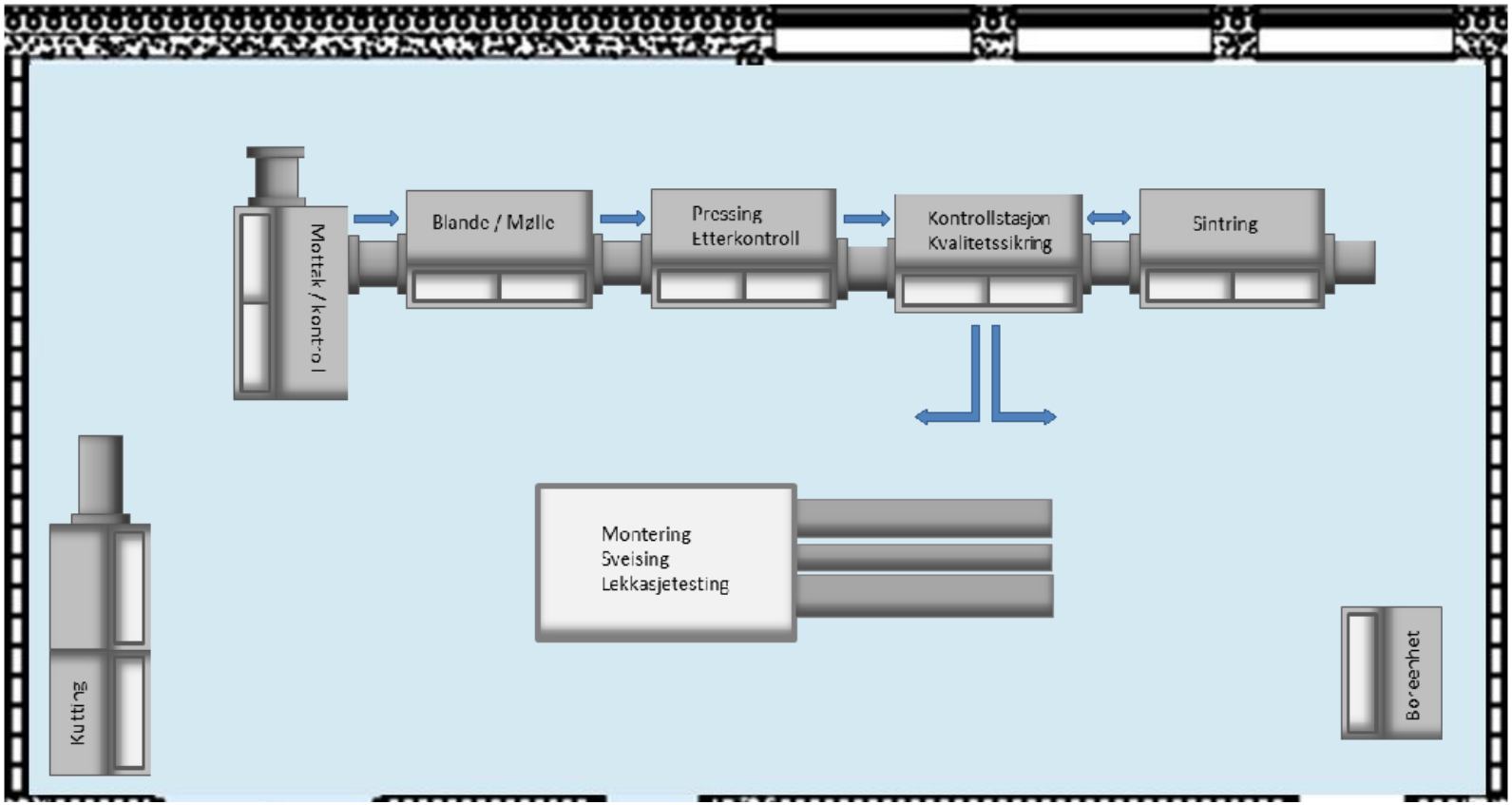
The Thor Energy Alpha Lab (Comissioning Dec. 2013): Pellet Manufacturing Phase 1b PuO_2ThO_2 Pellets



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Thor Energy Alpha Fuel Manufacturing Lab

Replicates industrial MIMAS type mfg line

Comissioning Dec 2013, Mfg in Q1 2014

Plans for advanced pellet work for 2015 onwards

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The Thorium Irradiation Campaign in the Halden Reactor

IRRADIATION CAMPAIGN

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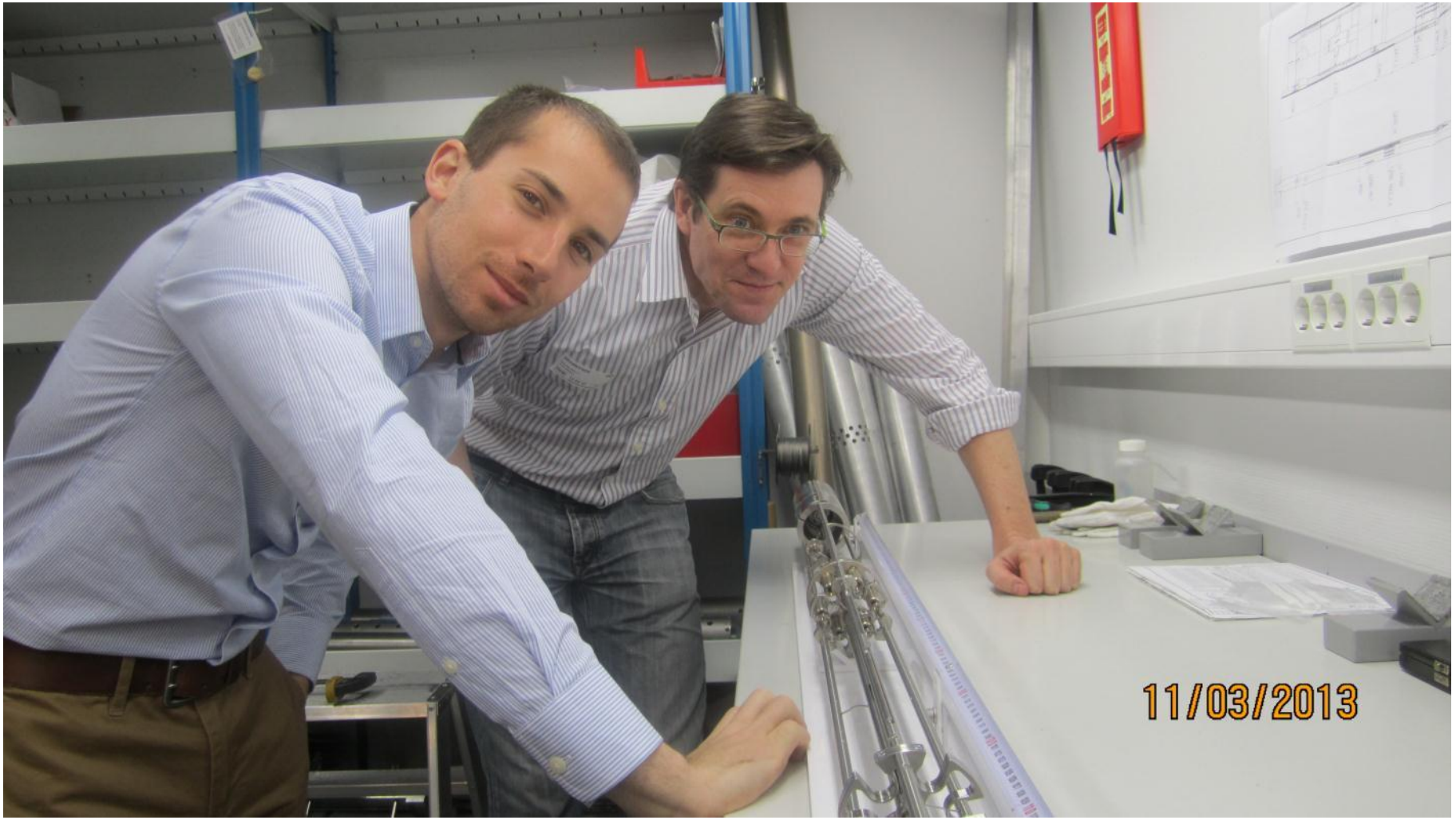

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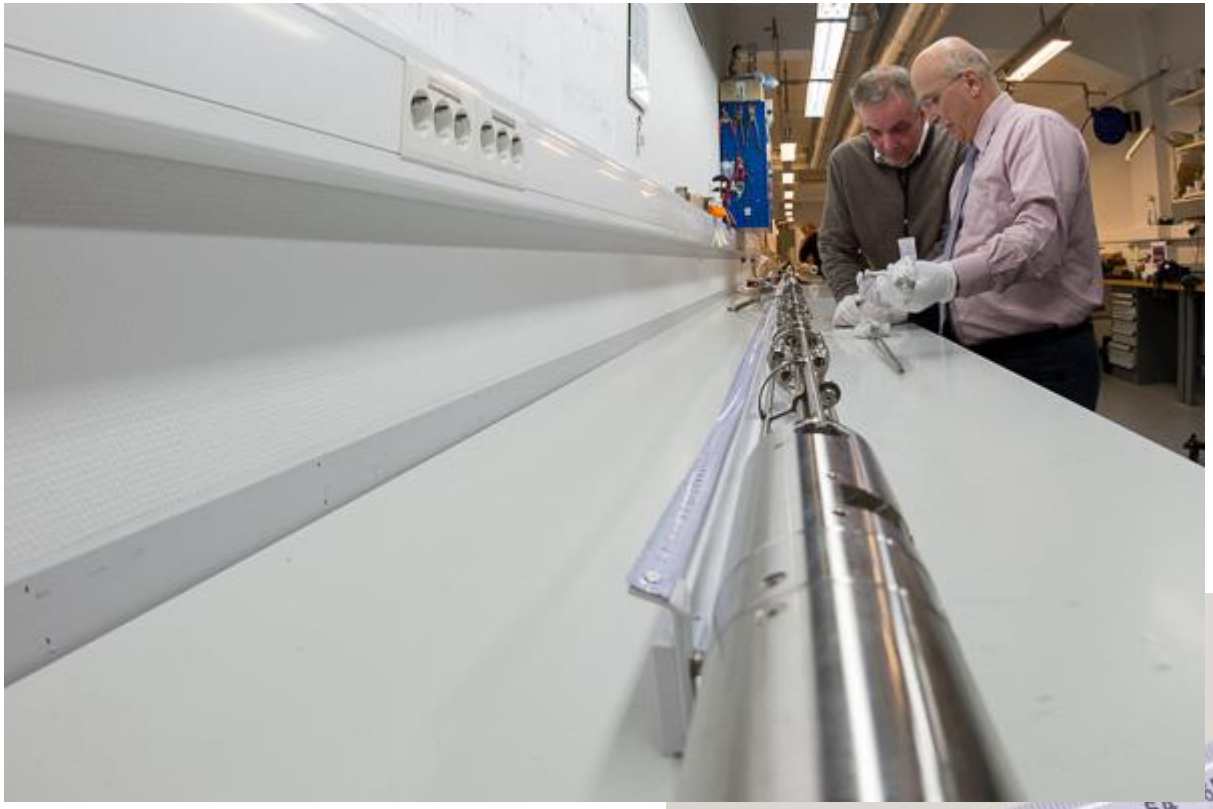

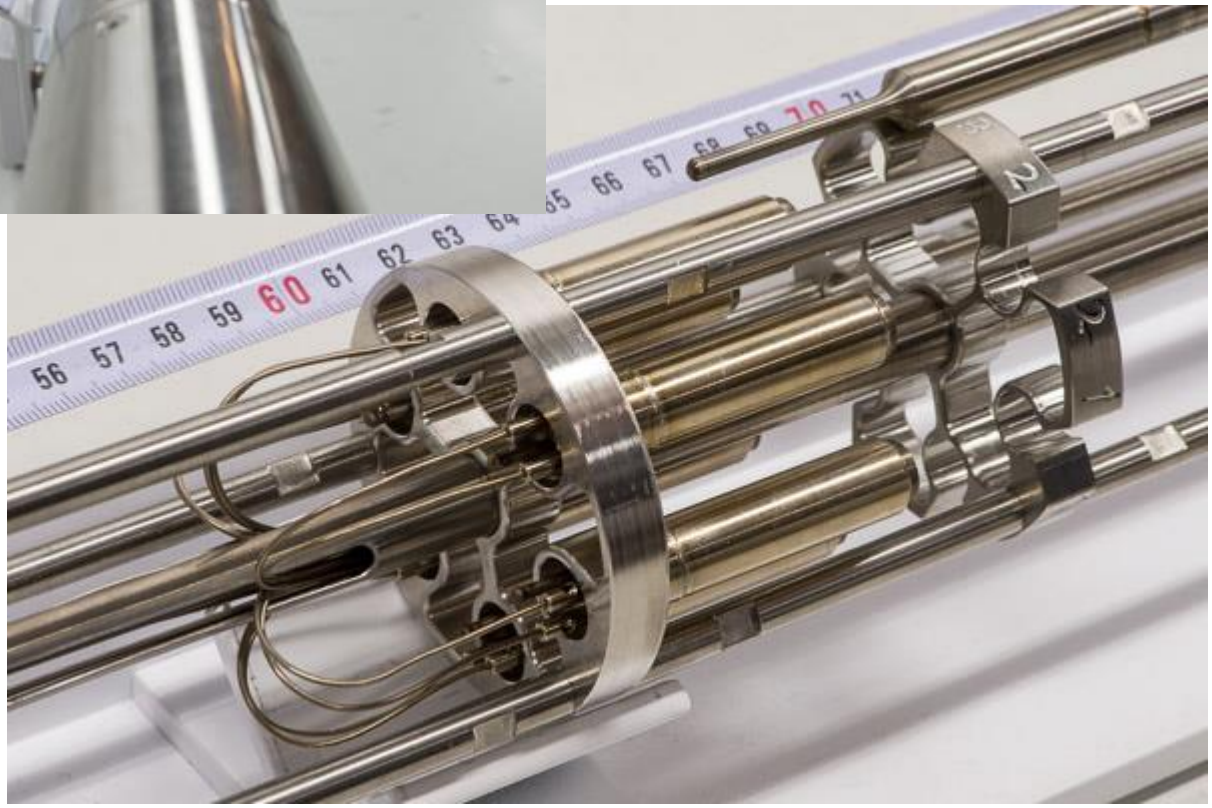

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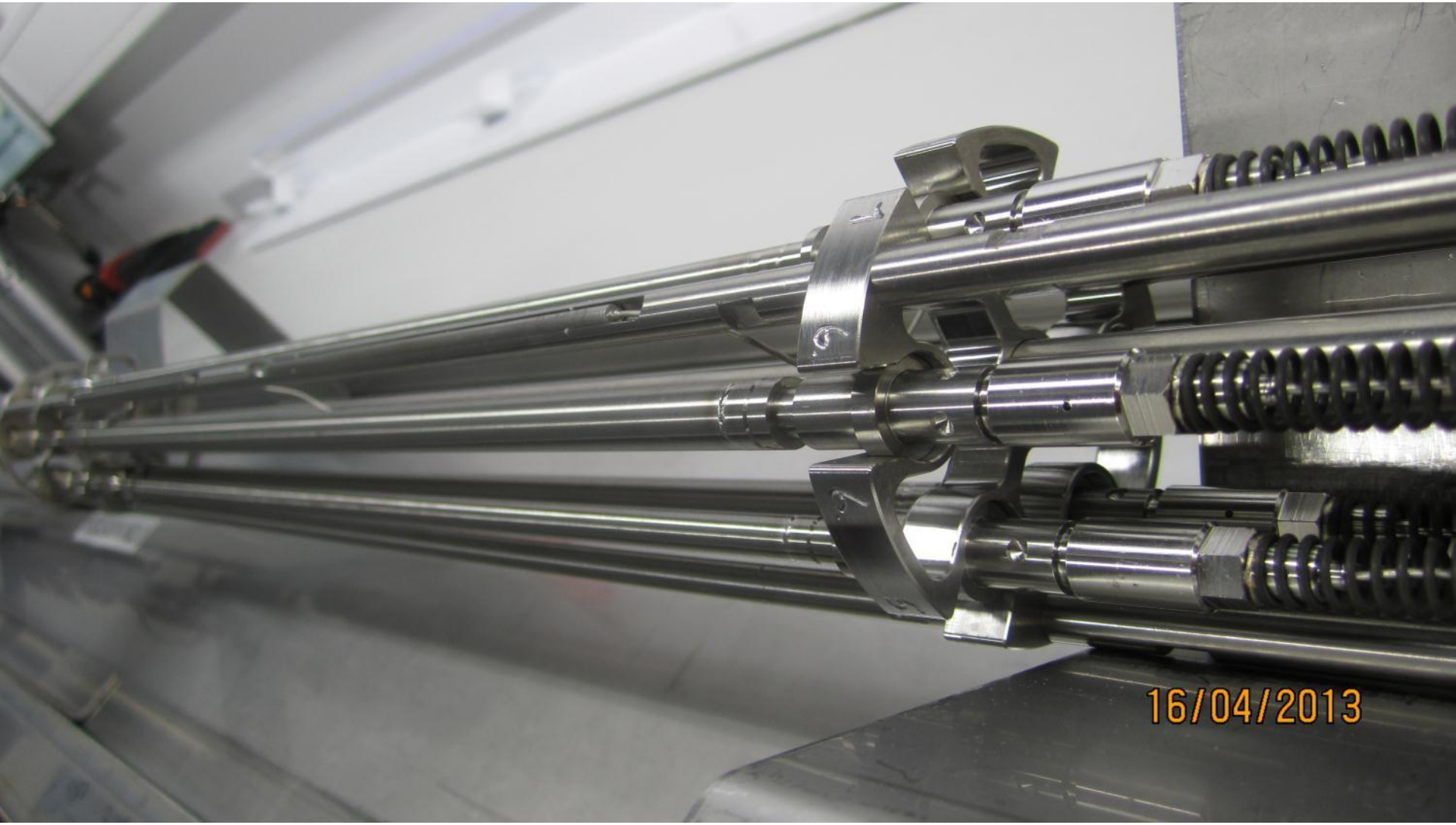

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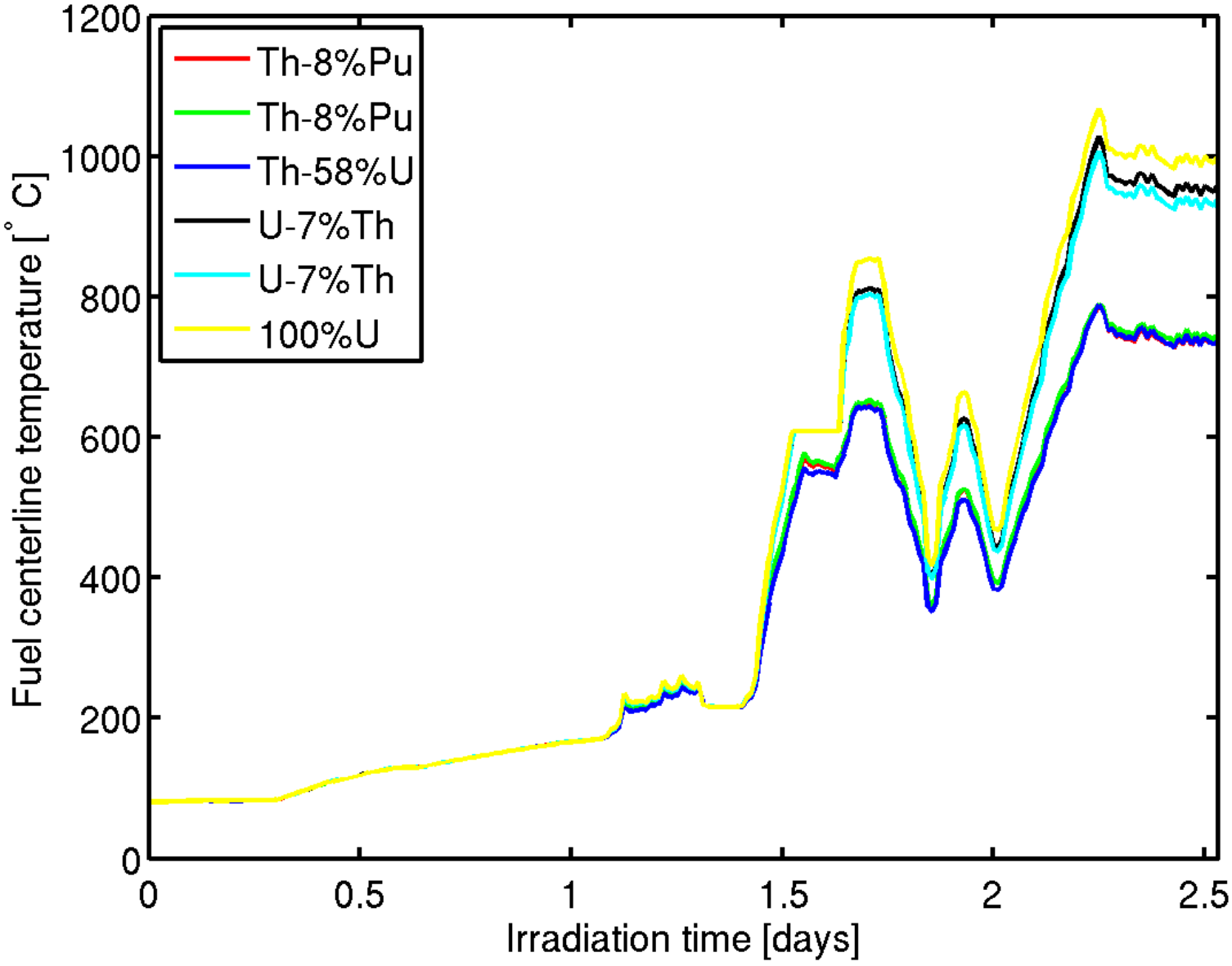
25. April 2013

Thorium fuel loaded into the Halden Reactor



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Thorium put to the test as policymakers rethink nuclear

Scientists are turning their attention to thorium, a cleaner and cheaper alternative to uranium.

Workers install a fuel pin into a test reactor in Halden, Norway.

By Szu Ping Chan

6:00AM BST 21 Aug 2013

70 Comments

Two years after the Fukushima disaster rocked the nuclear industry, the jury is still out in many countries on the role of atomic fuels.

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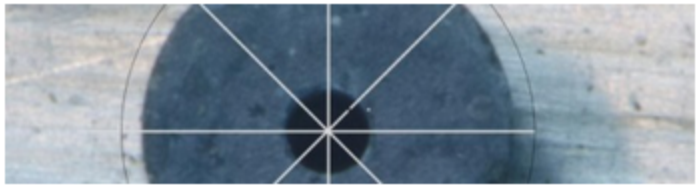
Thorium test begins

21 June 2013

Thorium fuel is now being tested in the Halden research reactor in Norway. It was loaded in the last week of April, defining the start of a physical test program that will simulate how it operates in a power reactor.

Led by Norwegian company Thor Energy, the test will provide unique information necessary for qualifying this new fuel material for commercial use in current reactors.

The thorium fuel is in the form of pellets composed of a dense thorium oxide ceramic matrix containing about 10% of finely blended plutonium oxide as a 'fissile driver'. As a mixed-oxide (MOX) fuel variant it is familiar to the nuclear industry, but thorium-MOX fuel has certain advantages compared to the uranium-MOX fuels in use at some reactors around the world. It promises higher operating safety margins due to higher thermal conductivity and melting point, and produces no new plutonium as it operates. Thor Energy pointed out that thorium-plutonium fuels therefore provide a new option for reducing civil and military plutonium stocks.



Close up with one of the test fuel pellets (Image: Thor Energy)

Company CEO Oystein Asphjell said the trial was was "the beginning of a new era - not only for our company and our partners, but as an important evolutionary step in the nuclear power industry."

The irradiation test will run for around five years after which the fuel will be studied to quantify its operational performance and gather data to support the safety case for its eventual use in commercial reactors. Areas for study include a range of chemical and physical changes in the fuel related to high temperatures, neutron flux, interations with fuel cladding and changes in ceramic structure.

WNA Links

- Thorium

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IFA-730.1 Summary

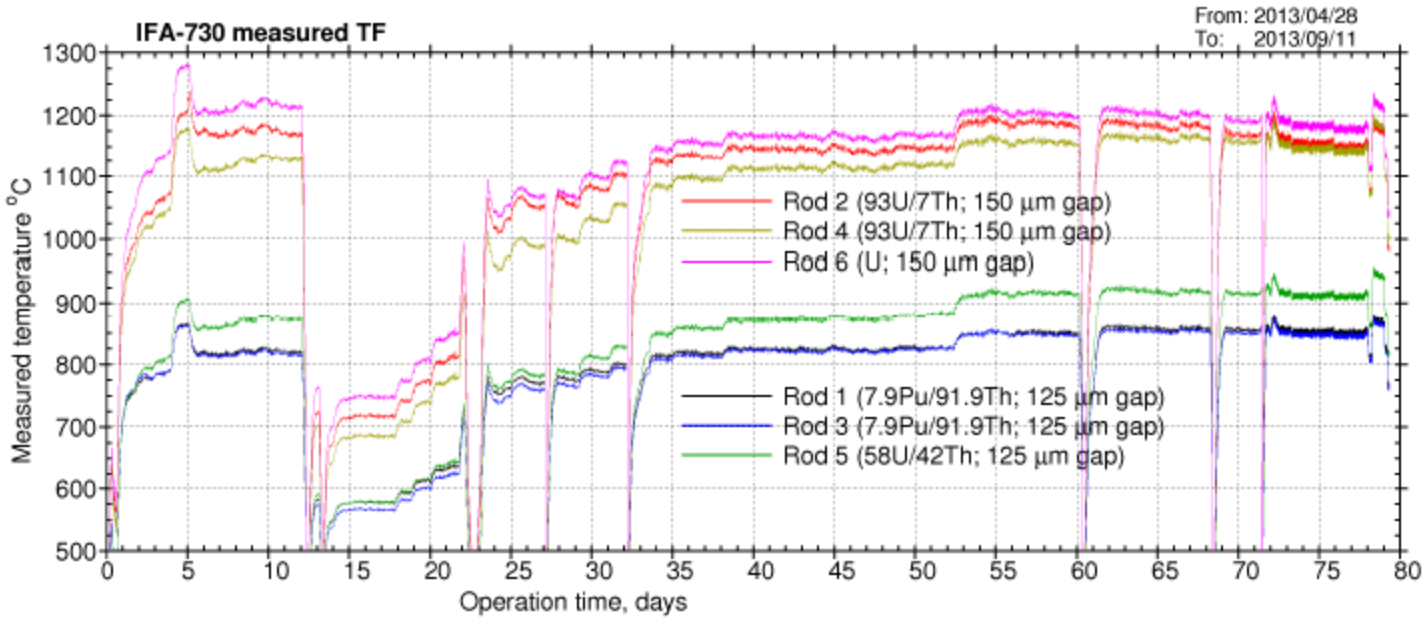
- Rig operated since 28.4.2013
  - Power kept at ~30 kW/m for large diam. rods
    ~20 kW/m for small diam. rods

- Collection of irradiation data on
  - **Fuel centre temperature** **Fuel thermal conductivity**
  - Rod pressure Fuel dimensional stability and fission gas release
  - Cladding elongation Pellet-cladding mechanical interaction (fuel dimensional stability)

- Continued operation planned at current power levels

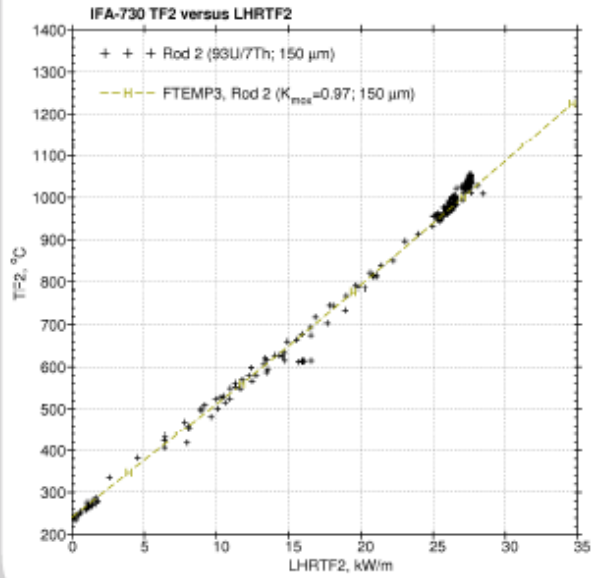
IFA-730 Fuel temperature

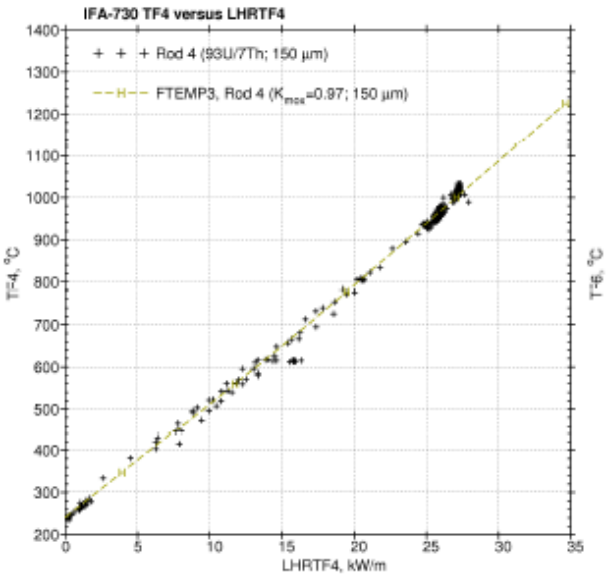
- Expectation:
  - Temperature in ThU rods lower or similar to reference UO_2 → confirmed
  - Temperature in PuTh pellets lower than in reference ThU → confirmed
- Further irradiation will provide information on long term behaviour

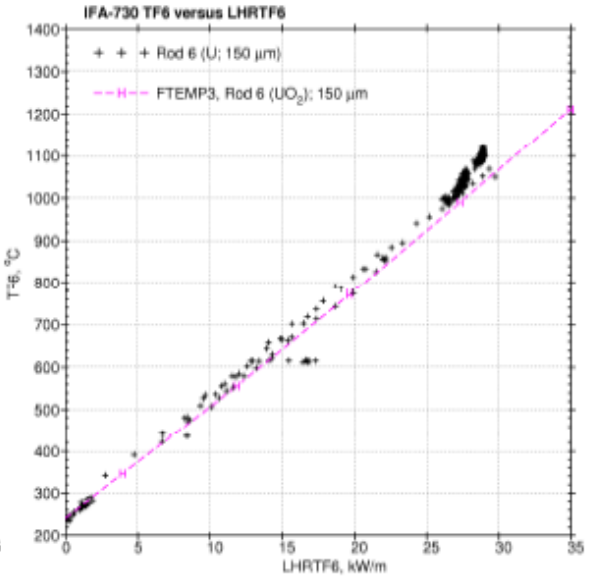


IFA-730 Results: Fuel temperature

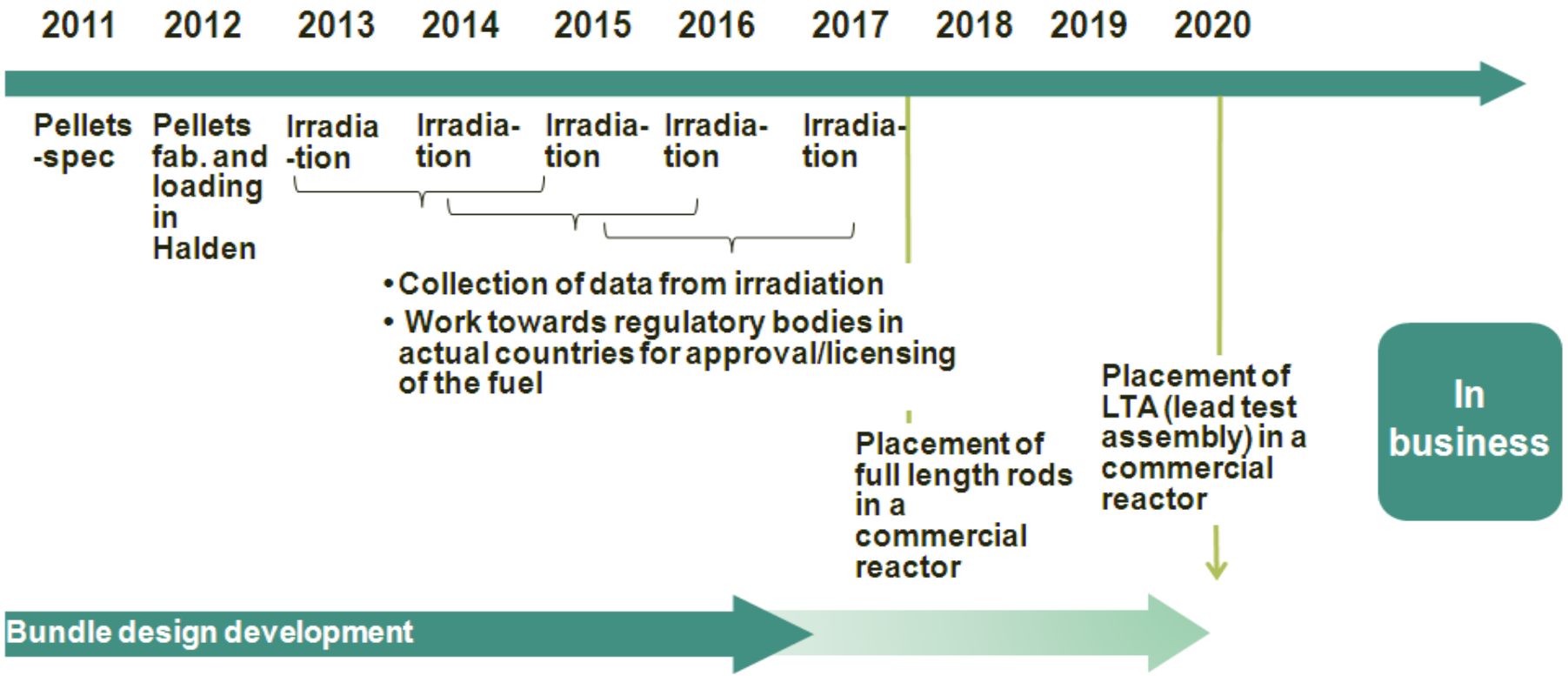
- Comparison with temperature calculations, start-up data: large diameter rods
  - In general good agreement between measured temperature and calculations
  - Temperature in Th fuel slightly lower than reference UO_2 fuel







Timeline for bringing Th fuel to the market



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Norway election: Conservative Erna Solberg triumphs

Erna Solberg: "Today you've helped make history"

Politisk plattform

for en regjering utgått av Høyre og Fremskrittspartiet

13 – Miljø og klima

Miljø- og klimautfordringene er omfattende både nasjonalt og internasjonalt. Regjeringen vil bygge sin politikk på forvalteransvaret og føre-var-prinsippet. Den kloden vi skal overlate til våre barn skal være i minst like god stand som vi overtok den fra våre forfedre. Regjeringen vil føre en offensiv klimapolitikk og forsterke klimaforliket, jf samarbeidsavtalen. Utbyggingen av fornybar energi må økes (kapittel 14).

- Opprette et FME-senter for Thorium.
- Utvikle NORFUNDs investeringer i fornybar energi globalt.
- Heve innslagspunktet for grunnrenteskatt for småkraftverk fra 5 MVA til 10 MVA.
- Gjennomgå ENOVAs rolle for å målrette arbeidet bedre, slik at selskapet beholder en sterk rolle innen ENØK i industrien, offentlig sektor og i varmemarkedet.
- Endre energimerkeordningen slik at den optimaliserer energiforvaltningen i alle nybygg og større ombygninger basert på krav til levert energi.
- Innføre et skattefradrag for ENØK-investeringer i hjemmet.

Thor Energy

Scandinavian Advanced Technology

Thor Energy – Status Sept 2013:

- Fuel in reactor -> producing energy from Thorium!
- International Thorium Consortium operating very well
- Developing & protecting fuel-IPR (pellet- and bundle-design) & modelling tools to commercialise Th-based fuel product for LWRs
- **2 patents filed, 2 pending, 2 pre-applied, 2 in progress++**
- Approx 15 scientific papers published
- Monitoring & influencing national policies on Thorium
- **Seeking 1-2 more members of the Consortium**
- Seeking investors / industrial partners / owners in order to expand technology development program.

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The Thorium Irradiation Campaign in the Halden Reactor

…the Thorium evolution…..

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