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Designing a Thorium Fuel Irradiation Experiment

November 2009

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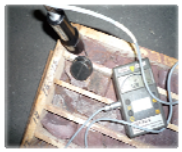
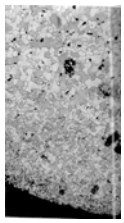
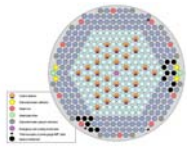
A Design Story







First some FAQ:

1. Why a Private Norwegian Company?
2. How does it fit with near-future Fuel Cycles

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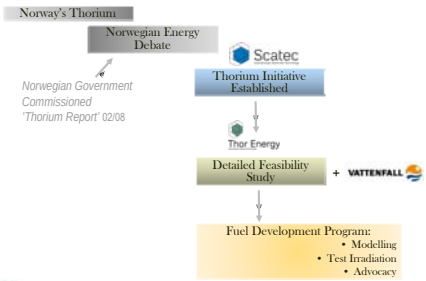
FAQ1: Thor Energy Background



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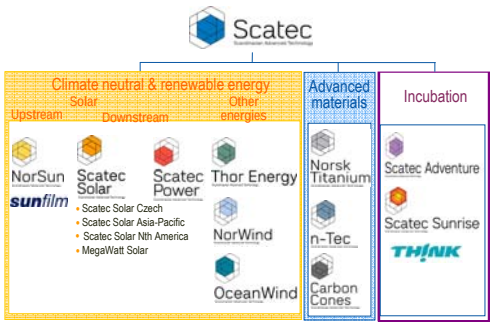

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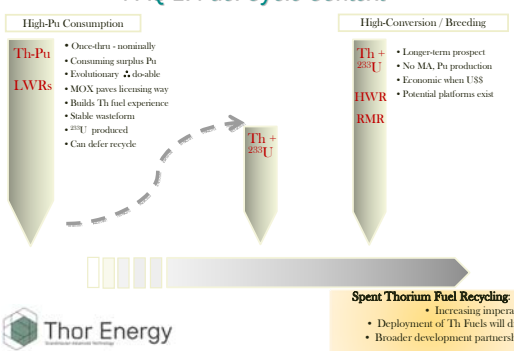
FAQ 2: Fuel Cycle Context



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Fuel Development Activities

Thorium-Plutonium Fuel Irradiation

- Test irradiation of candidate Th-Pu fuel in Halden – collecting data to demonstrate safety & performance

Building Computational Tools

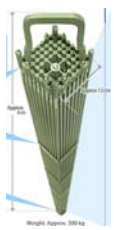
- Los Alamos National Labs – fuel model development
- In-House – adapting irradiation performance code for Th-Pu fuels
- University of Tokoyo / CRIEPI – atomistic simulations of $(Th,Pu)O_2$
- EU Benchmarking Project – compute depletion for an irrad Th-Pu pin

Thorium Fuel Assembly Design

- Specific Th-Pu fuel bundle design for a BWR

Future closed cycles

- MIT & Chalmers University – high ^{233}U conversion in "RBWR"



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& so to Experiment Planning

The decision to undertake an irradiation experiment set in place a planning process with five elements:

- Defining Experiment Objective/s
- Identifying Fuel Behaviours to Characterize
- Selecting Measurables
- Defining Test Pellet (& rodlet) Properties
- Setting an Experiment Execution Plan

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Experiment Objective

... to yield data that can be used to demonstrate the safe, long term performance of thorium-plutonium ceramic fuels, and that this information can directly suport the planning and approval of an LTA irradiation for such a fuel...

eg, ⇨ Statens strålevern

& not purely academic

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Behaviours to Characterize

Pellet properties evolve as fuel burns – the most important changes to know about are:

- Temperature & Thermal Property Changes
  - —temperature, conductivity decrease, expansion, heat capacity
- Fission Gas Release
  - —amount, onset and composition

expect later onset for ThO_2, more I?

- Mechanical Interactions
  - —densification, swelling

may be less creep & swelling for ThO_2

- Chemical Interactions
  - —SCC, oxygen movement

O behaviour very different in ThO_2
I yield higher (released?)

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to be Measured

Experiment design involves compromises & risk assessment. Online measurables defined early.

- On-Line Measurables
  - – *temperature*: centerline & rod wall
  - – pellet stack elongation
  - – clad elongation
  - – rod internal pressure

PCMI
FGR
swelling
densification

- Post-Irradiation Examination
  - – FG analysis
  - – *microscopy*: optical, SEM, TEM, EPMA
  - – conductivity
  - – radiography

microstructure
nuclide composition
FP distribution
structural dimension

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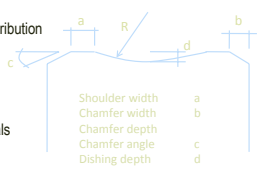
Pellet Properties

Test-fuel ceramic must represent that which can be deployed commercially. Pu content effects things wrt UOX:

- Microstructure
  - – density / porosity & pore size distribution
  - – grain size & grain distribution
  - – Pu homogeneity
- Composition
  - – *impurities*: metals (Am), non-metals
  - – stoichiometry
- Shaping
  - – dishing, L/D



Need to characterize fresh pellets in terms of: density, grain structure, Pu distribution, chemical purity, thermal properties

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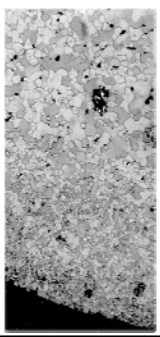
Complex Issues

A few technical points needed specific/careful resolution:

- Assurance re non-metal impurity levels
  - – sample size requirement
  - – QA processes
- Stoichiometry Control
  - – *different for thoria*: risk is hypostoichiometry
  - – thermo-gravimetric test = re-oxidation condition
- Specification of Microstructural Parameters
  - – grainsize distribution



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Lessons Learned

General wisdom was gained re ordering a two-phase (Pu) fuel:

- Importance of QA Procedures
  - QA can provide confidence on impurity limits where measurement not possible / feasible
  - 'surrogate' strategies can be considered, but have limitations
- The need for Compromise
  - when ordering a batch of Pu-containing pellets

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Experiment Execution

- Rig Layout
  - number and length of rods
- Instrumentation
  - combination of pressure, temperature & extension
- Rod Design
  - pellet-clad gap, fill gas
- Power 'Roadmap'
  - starting LHGR
- Discharge Schedule
  - intermediate B/U steps

Not all parameters to be locked-in. Early consideration beneficial for reactor operator

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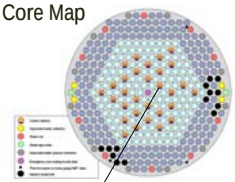
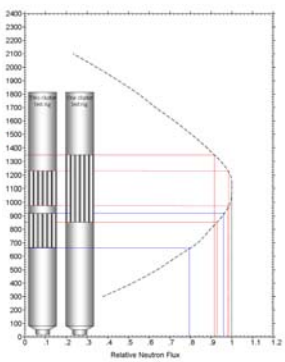
Halden Reactor Core Map



- Fuel temperature
- Rod pressure
- Dimensional changes



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Acknowledgements

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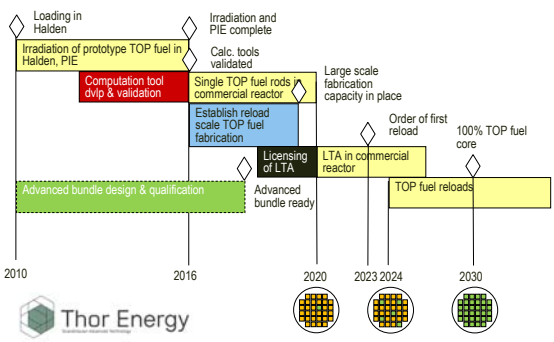
Time Schedule for Th-Pu fuel Introduction



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