Thor Energy AS

The Norwegian Thorium Initiative

April 2014

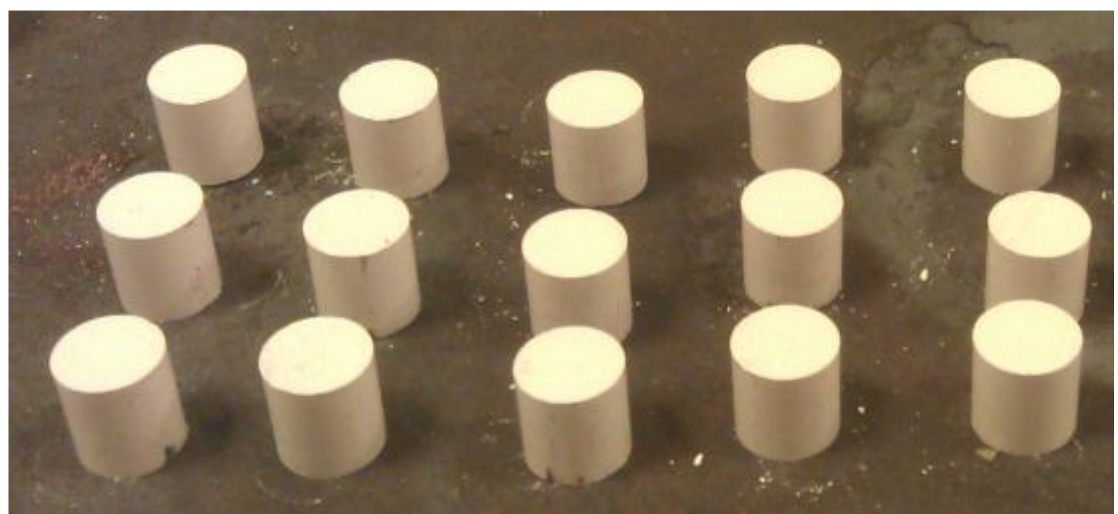
Øystein Asphjell, CEO

STRICTLY CONFIDENTIAL
This document is the exclusive property of Thor Energy AS

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

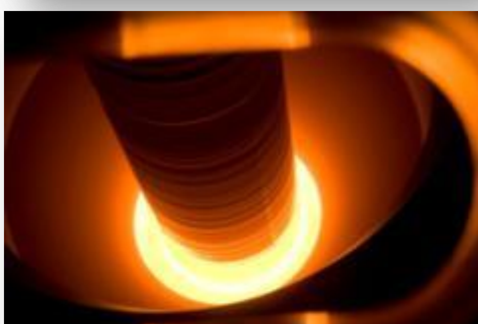
Seven-Thirty
90 +4
Thorium
232,03806



Thor Energy
Scandinavian Advanced Technology

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

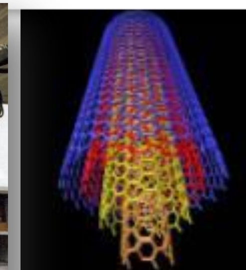
Climate neutral energy



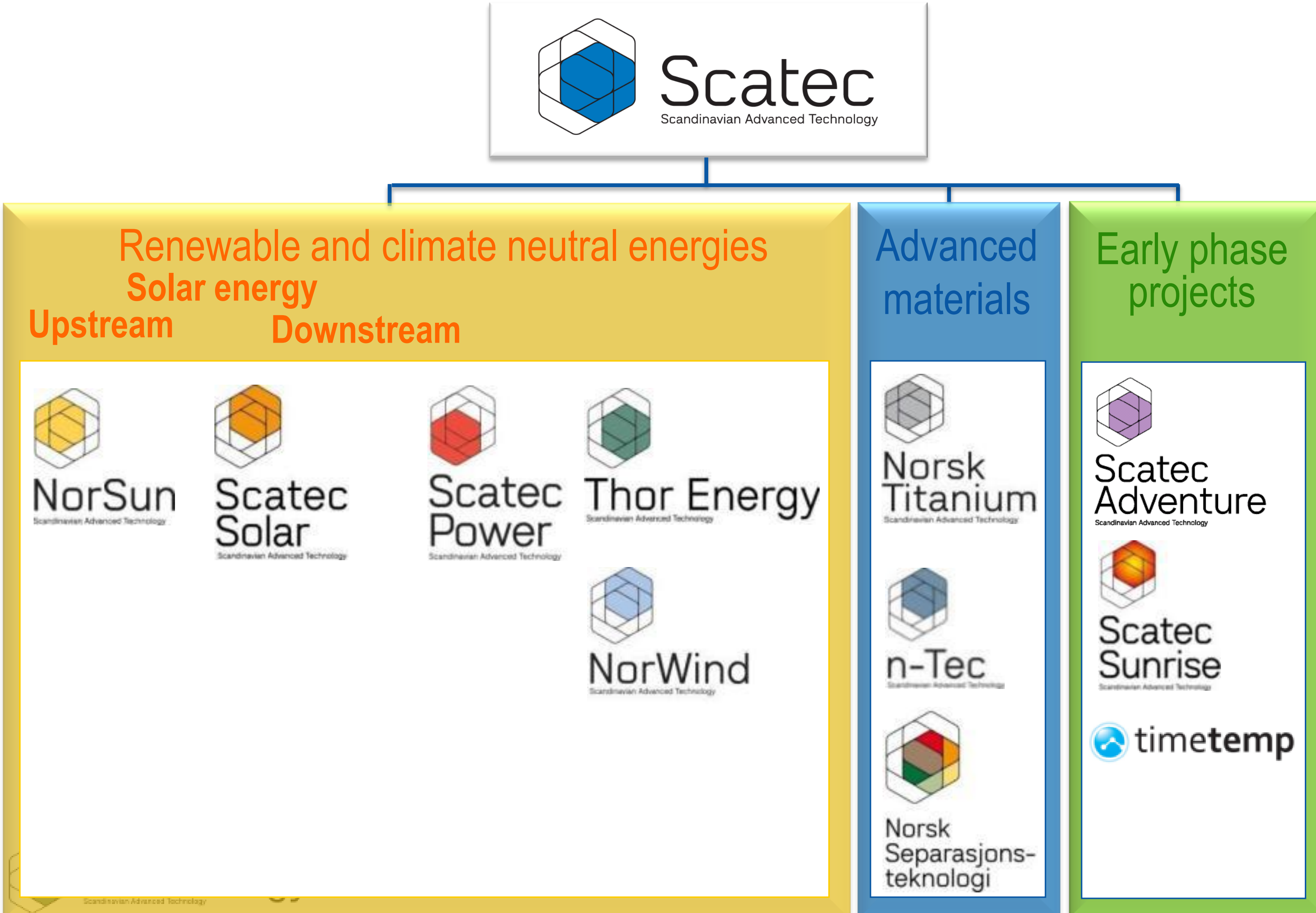
- Solar
- Thorium
- Wind

Advanced materials

- Titanium
- Nano carbon
- Rare Earth Elements



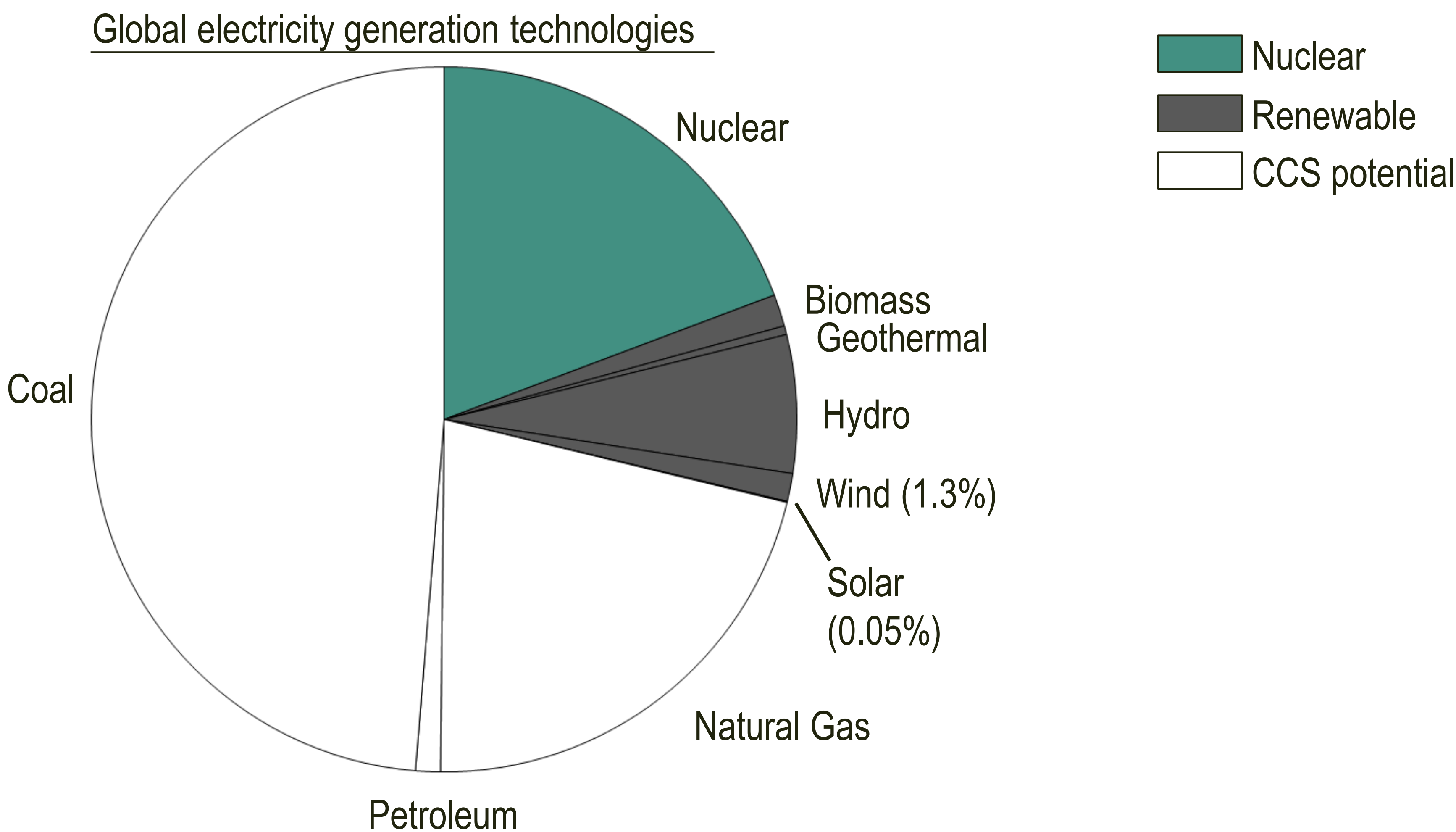
Thor Energy
Scandinavian Advanced Technology



Scatec
Scandinavian Advanced Technology
Renewable and climate neutral energies
Solar energy
Upstream
Downstream
NorSun
Scatec Solar
Scatec Power
Thor Energy
NorWind
Advanced materials
Norsk Titanium
n-Tec
Norsk Separasjons-teknologi
Early phase projects
Scatec Adventure
Scandinavian Advanced Technology
Scatec Sunrise
timetemp


Scatec Solar
Improving our future™
Kalkbult PV Park 50km

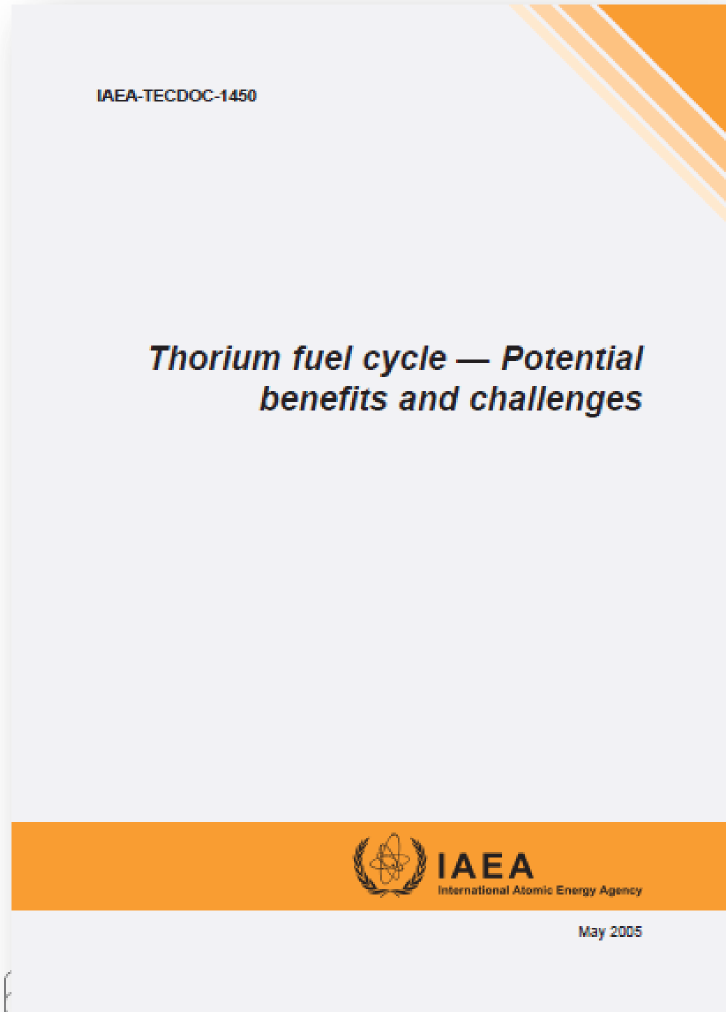
There is no single winner in the «clean energy race» – we need all economical options, incl nuclear



Source: World Outlook 2008 (Energy Information Agency)

Thor Energy
Scandinavian Advanced Technology

Thorium has been addressed and tested for 40 years, but not commercialized due to “stagnation of new builds”, investments in the Uranium value chain and expectations of continued low cost U



IAEA-TECDOC-1450

Thorium fuel cycle — Potential benefits and challenges

IAEA
International Atomic Energy Agency

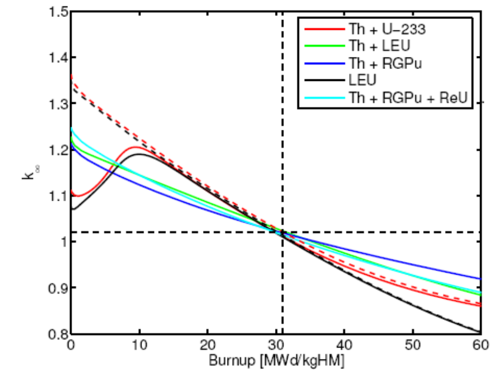
May 2005

Conclusions of IAEA Report

- Thorium 3-4 times more abundant than Uranium, and all of it is useable, as opposed to only 0,71%
- Th produces low radio-toxicity waste
- Th is a better ‘fertile’ material than ^{238}U in thermal reactors
- ThO_2 is chemically more stable and has higher radiation resistance than UO_2
- long term interim storage and permanent disposal in repository of spent Th–based fuel are simpler than for U
- Th–based fuels and fuel cycles have intrinsic proliferation-resistance
- The Th cycle can be used for incineration of WPu or civilian Pu in ‘once-through’ cycle

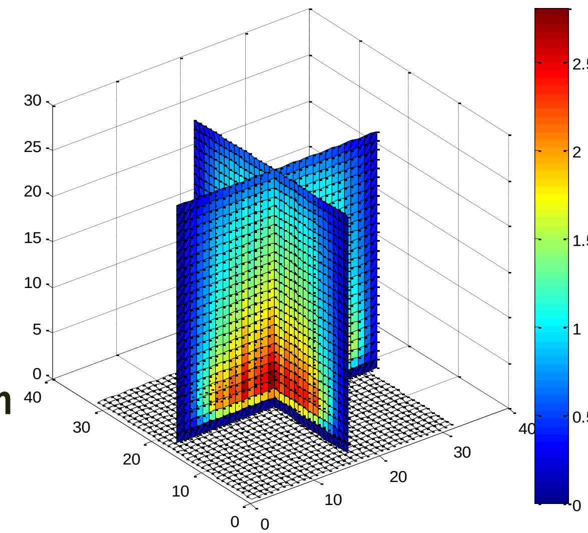
Thorium Fuel Cycle Feasibility Study Completed

15 man-years, multi-MUSD, cooperation w utility VATTENFALL



Topics:

1. Th mining, fuel fabrication and commercial market
2. Proliferation and safeguards (Dr. Bruno Pellaud)
3. Th-history & selection of technologies & fuel design
4. Th-fuel in the reactor
5. Spent fuel management and economy
6. Licensing & approval (Dr. Raj Shegal)
7. Environmental & life cycle assessment



Conclusions:

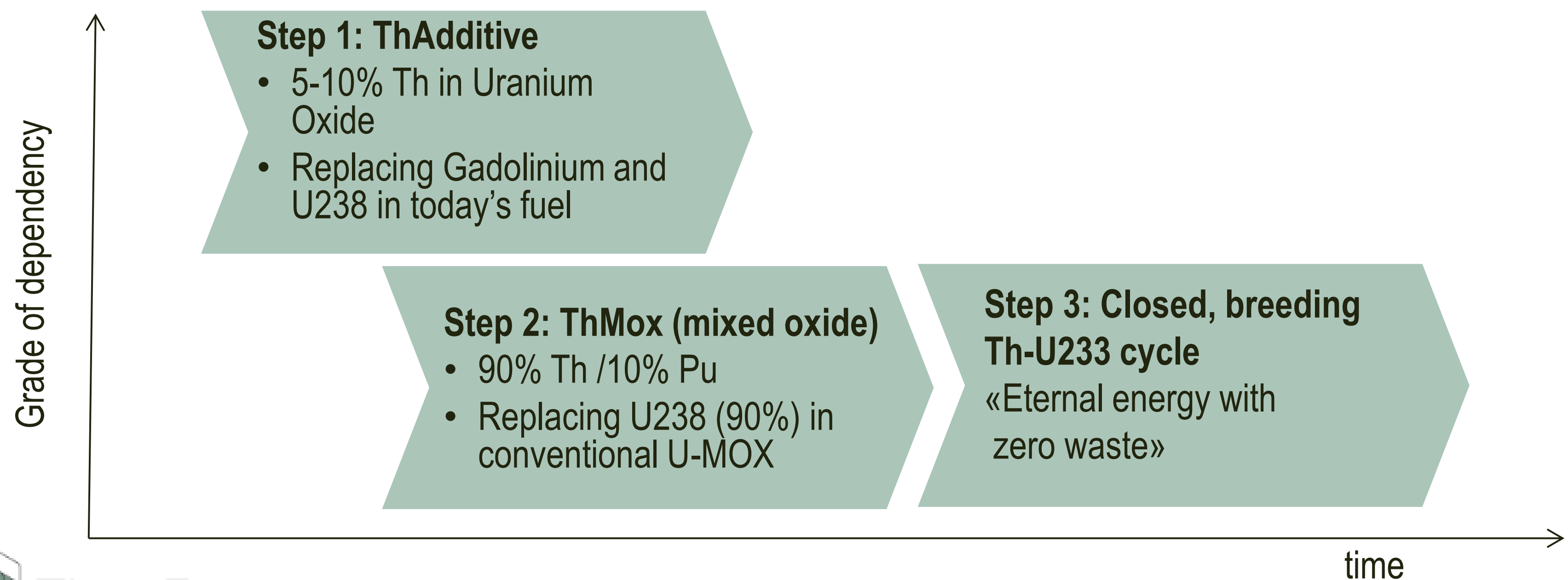
- No technical showstoppers identified
- Can be introduced in exisiting licensing framework
- Potential for higher burn-ups, improved economics
- Will stabilize fuel prices by introducing alternative to Uranium
- Will enable significant reduction of Plutonium inventories
- Higher proliferation resistance than the Uranium cycle
- More stabile waste-form

Thor Energy
Scandinavian Advanced Technology

VATTENFALL

The transition to a Thorium cycle
- Step-wise and evolutionary approach

- **Thorium (Th 232) instead of Uranium (U238):**
  - Higher conversion in thermal spectrum
  - Higher thermal conductivity
  - Chemical and physical material benefits
  - Less creation of Minor Actinides
  - Higher proliferation resistance



Thor Energy
Scandinavian Advanced Technology

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

Step 1:

ThPu-oxide - once through

(Today's LWRs)

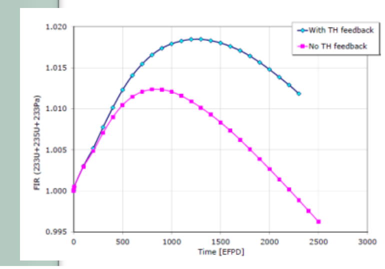
- To burn exisiting waste- stockpiles
- To produce less waste with no new Plutonium
- Increased safety margins / Superior material properties
- Longer cycles / economy
- Building a U233-"mine"
- "Benifical transition" to nuclear sustainability
- 5-10 years

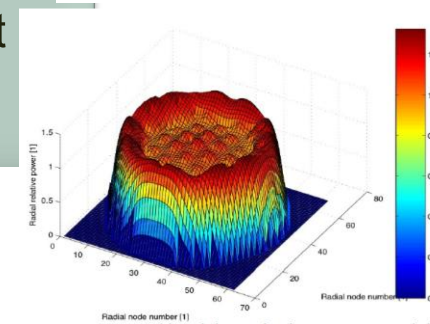
Step 2:

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





Thor Energy
Scandinavian Advanced Technology

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**	

Thor Energy

Scandinavian Advanced Technology

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

Thor Energy
Scandinavian Advanced Technology

U.S.NRC

United States Nuclear Regulatory Commission

Protecting People and the Environment

NUREG/CR-7176
ORNL/TM-2013/543

Safety and Regulatory Issues of the Thorium Fuel Cycle

Thor Energy
Scandinavian Advanced Technology

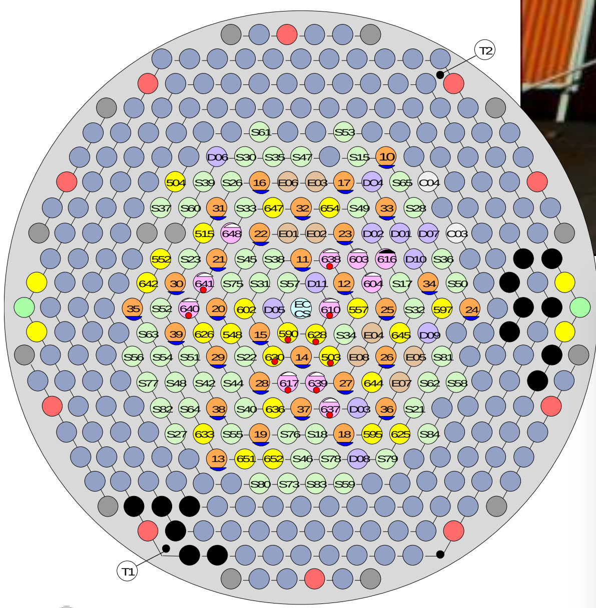
Seven-Thirty

90 +4
Th
Thorium
232,03806

The Thorium Irradiation Campaign in the Halden Reactor

Thor Energy
Scandinavian Advanced Technology

Institutt for energiteknikk
OECD HALDEN REACTOR PROJECT
50 1958 - 2008



Thor Energy
Scandinavian Advanced Technology

IFE Institutt for energiteknikk

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

Thor Energy
Scandinavian Advanced Technology

- 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

itu
European Commission
Joint Research Centre
Institute for Transuranium Elements

- Provider of pellets, phase 1
- Th-experience

The Research Council of Norway

- Financing

Statoil

Steenkampskraal Thorium Limited

Thor Energy
Scandinavian Advanced Technology

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

U.S.NRC

Statens strålevern
Norwegian Radiation Protection Authority

...and not purely academic

Seven-Thirty

90 +4 Thorium 232,03806

The Thorium Irradiation Campaign in the Halden Reactor

FUEL FABRICATION PROGRAM

Thor Energy

Scandinavian Advanced Technology

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
-Destruction of Pu
-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

Th-Ce-oxide fuel pellets by Thor Energy:

Los Alamos NATIONAL LABORATORY

2009: *Th-Ce-pellets*
Patent pending

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

IFE Institutt for energiteknikk

ThO_2

$15\%CeO_2ThO_2$

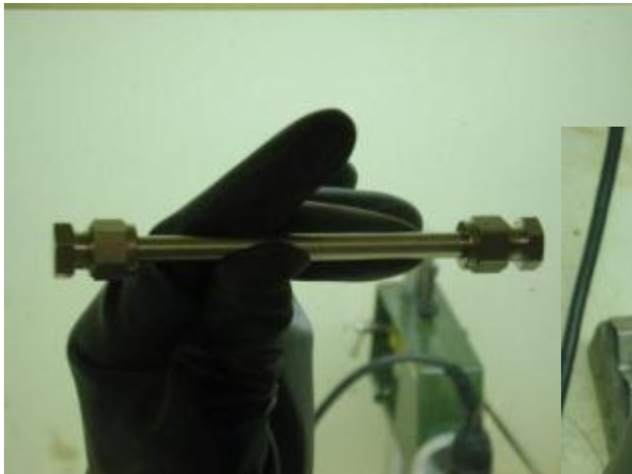
$0.5\%Nb_2O_3 15\%CeO_2ThO_2$

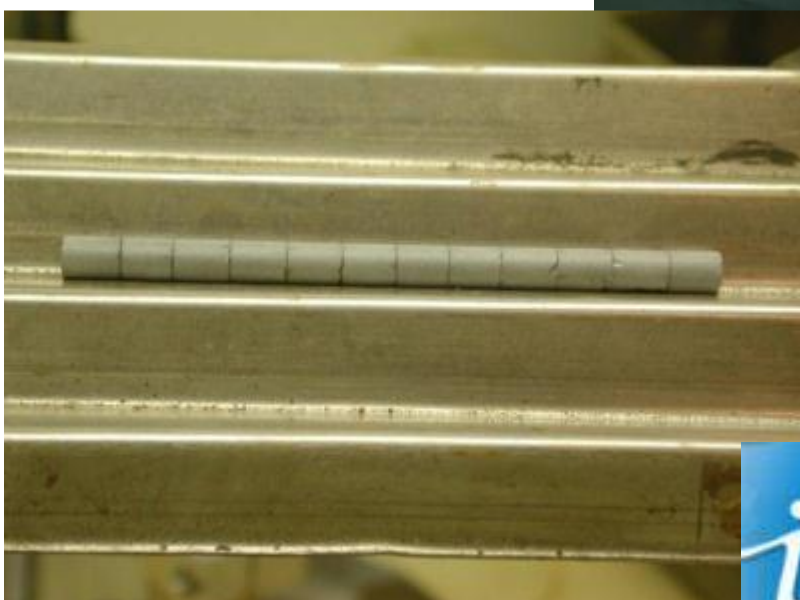
Thor Energy
Scandinavian Advanced Technology


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

Thor Energy
Scandinavian Advanced Technology

90 +4
Seven-Thirty
Thorium
232,03806



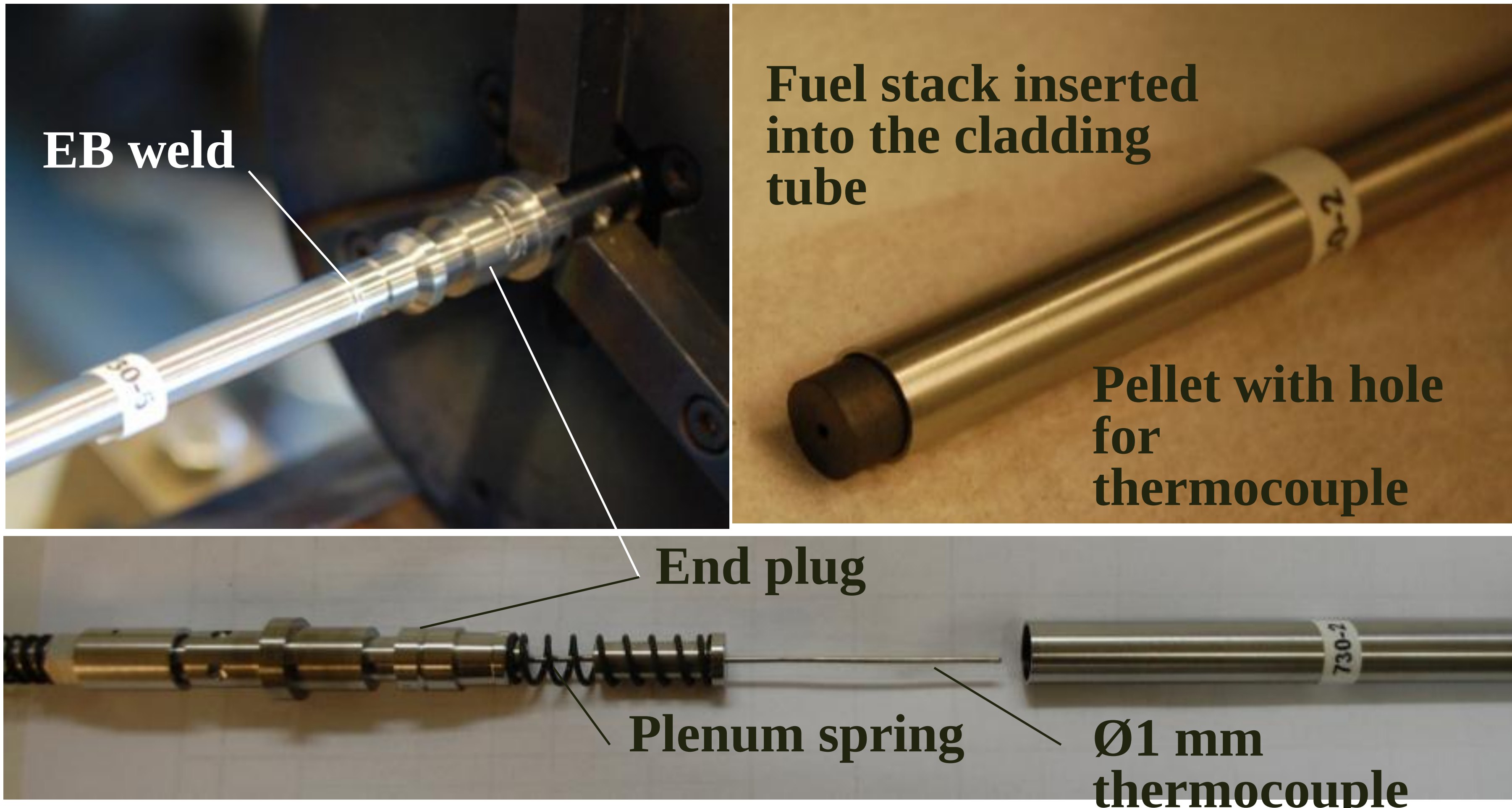

Thor Energy
Scandinavian Advanced Technology

itu

The IFA-730 Fuel Test Rig Completion

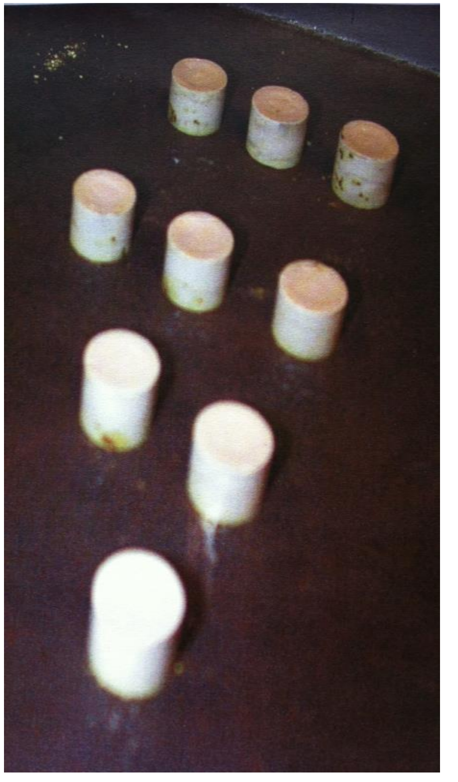
Thor Energy
Scandinavian Advanced Technology

The IFA-730 Fuel Test Rod



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, Sept 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



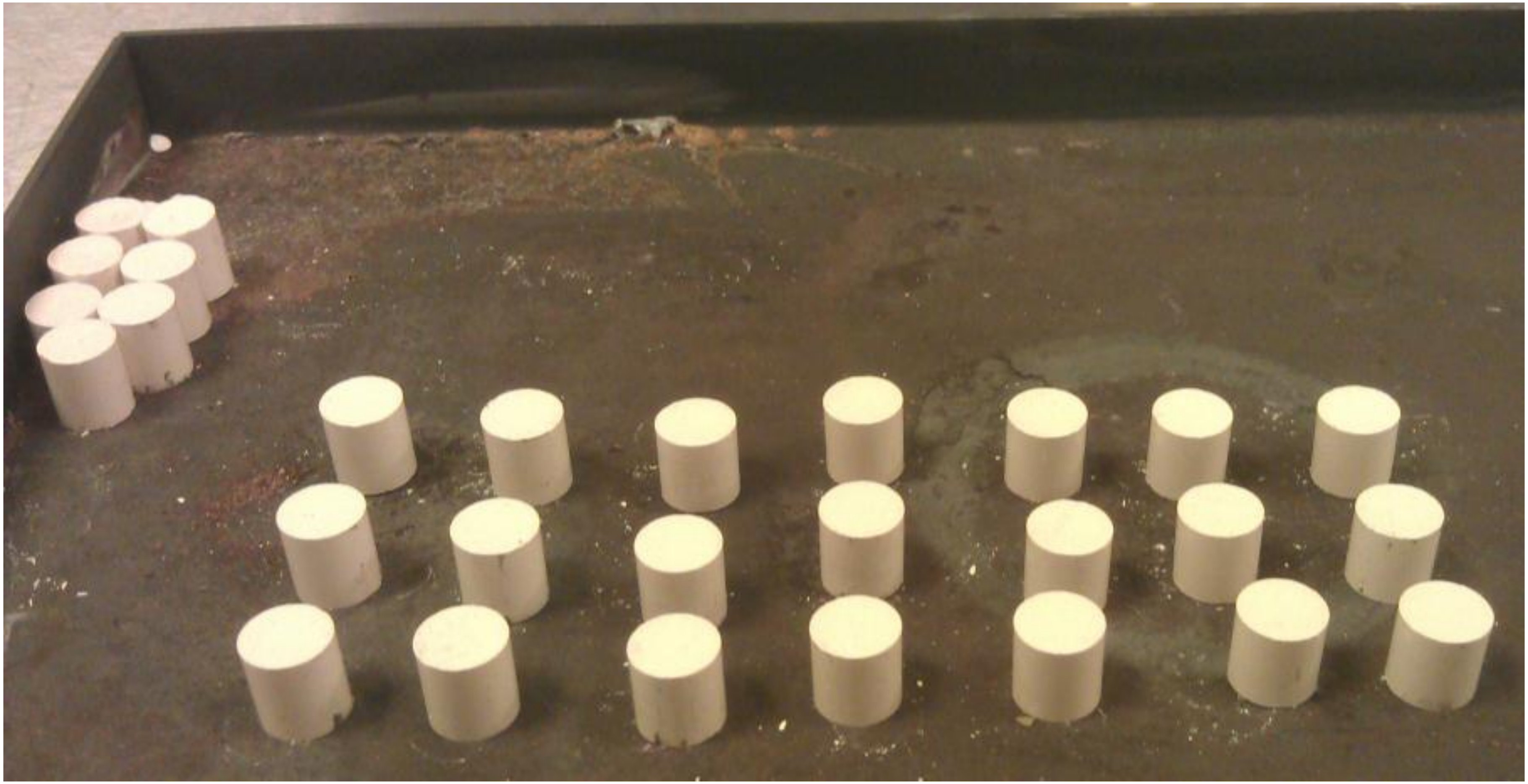
Thor Energy Alpha Fuel Manufacturing Lab

Replicates industrial MIMAS type mfg line
Enables production of advanced, Pu-based fuels
Plans for advanced pellet work for 2015 onwards

Thor Energy
Scandinavian Advanced Technology

Phase 1B Pellet Mfg (Pu-Th) Campaign:

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



Thor Energy
Scandinavian Advanced Technology

Seven-Thirty

90 +4 Thorium 232,03806

The Thorium Irradiation Campaign in the Halden Reactor

IRRADIATION CAMPAIGN

Thor Energy

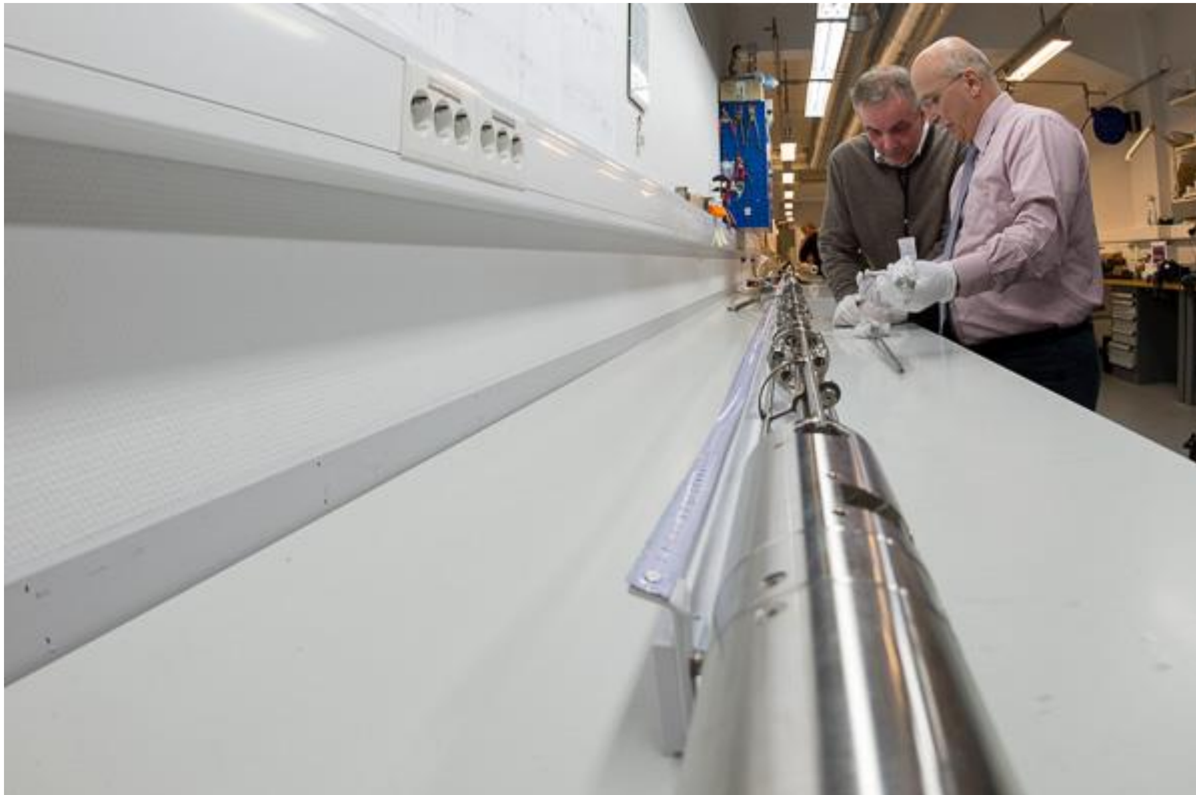
Scandinavian Advanced Technology

Thor Energy

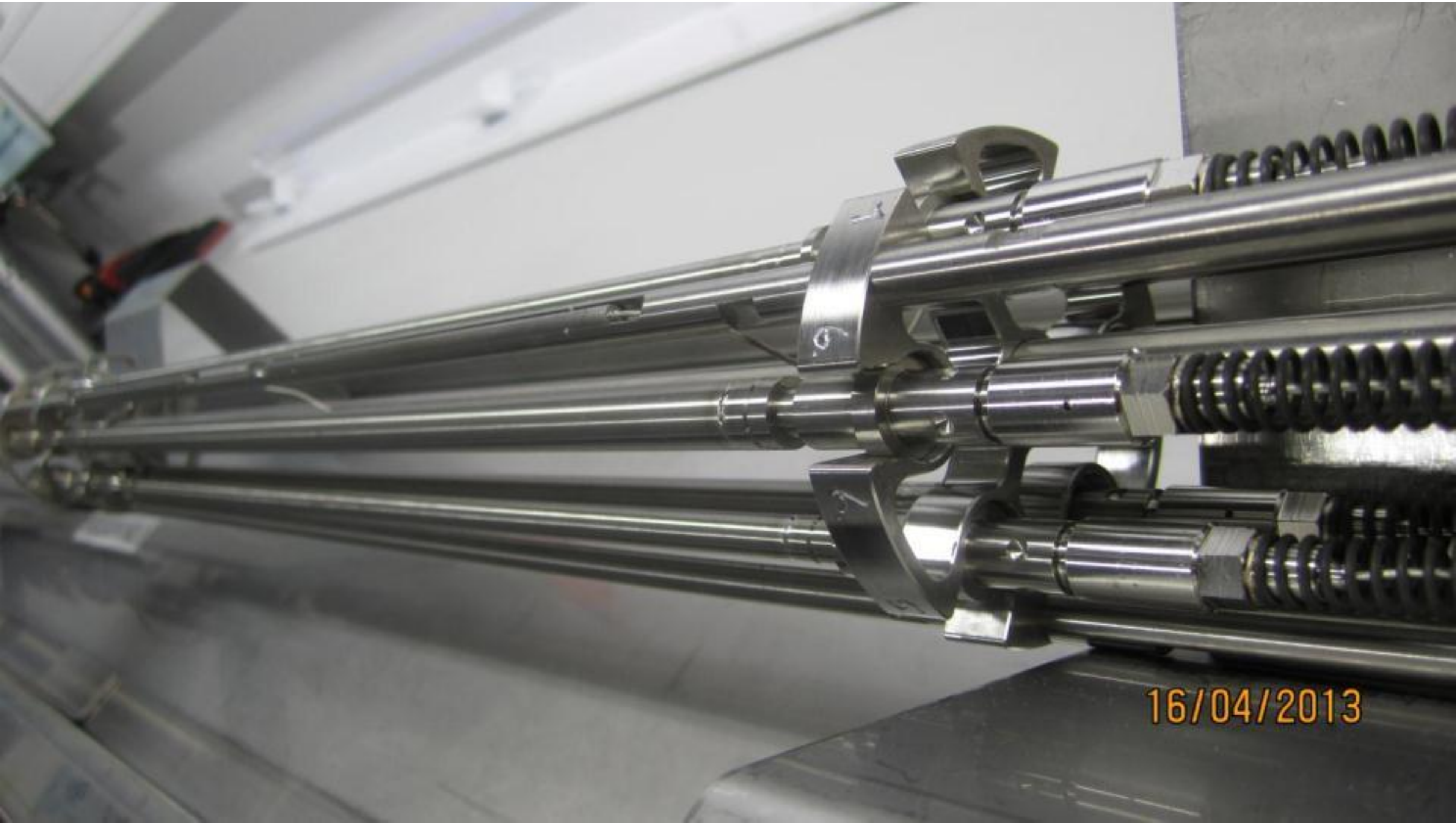
Scandinavian Advanced Technology

Seven-Thirty

90 +4 Thorium 232,03806



Thor Energy
Scandinavian Advanced Technology

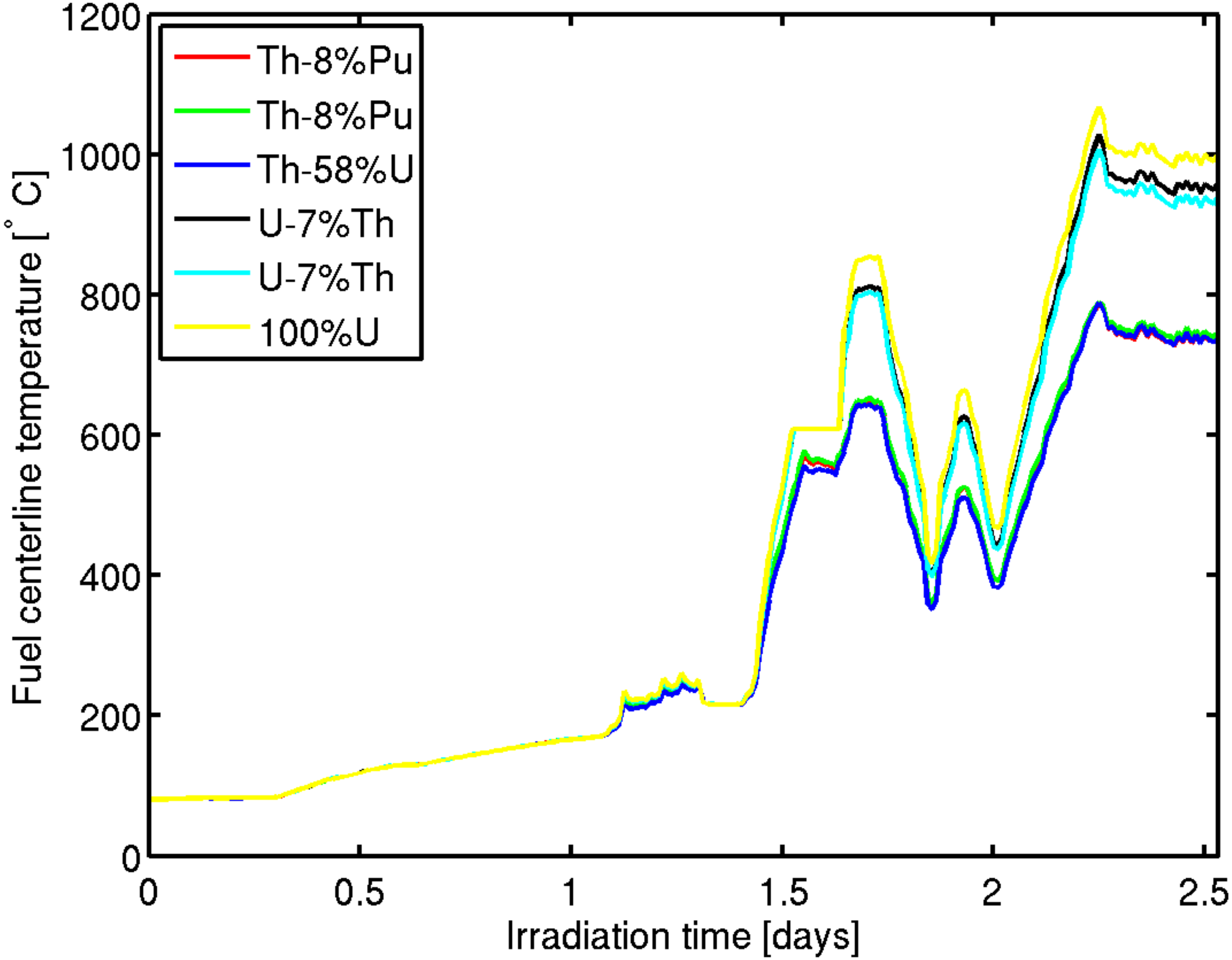


Thor Energy
Scandinavian Advanced Technology

Seven-Thirty
90 +4
Thorium
232,03806

Thor Energy
Scandinavian Advanced Technology

25. April 2013
Thorium fuel loaded into the Halden Reactor



Thor Energy
Scandinavian Advanced Technology

The Telegraph

Friday 06 September 2013

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

Print this article

Share 884

Facebook 753

Twitter 131

Email

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.

Financial Guides & Reports »

Professional Secrets: How to Profit from Oil Download FREE Report

3 Stocks set to soar in September 2013 Download Free Report

Top 10 Trading Mistakes with CFDs - Free 5 page guide Download Free Guide

How you can benefit and what to look for in a SIPP provider Free SIPP guide >>

Why Royal Mail Shares Could be a Bargain Buy Download FREE Report

Sign up to our weekly Money newsletter

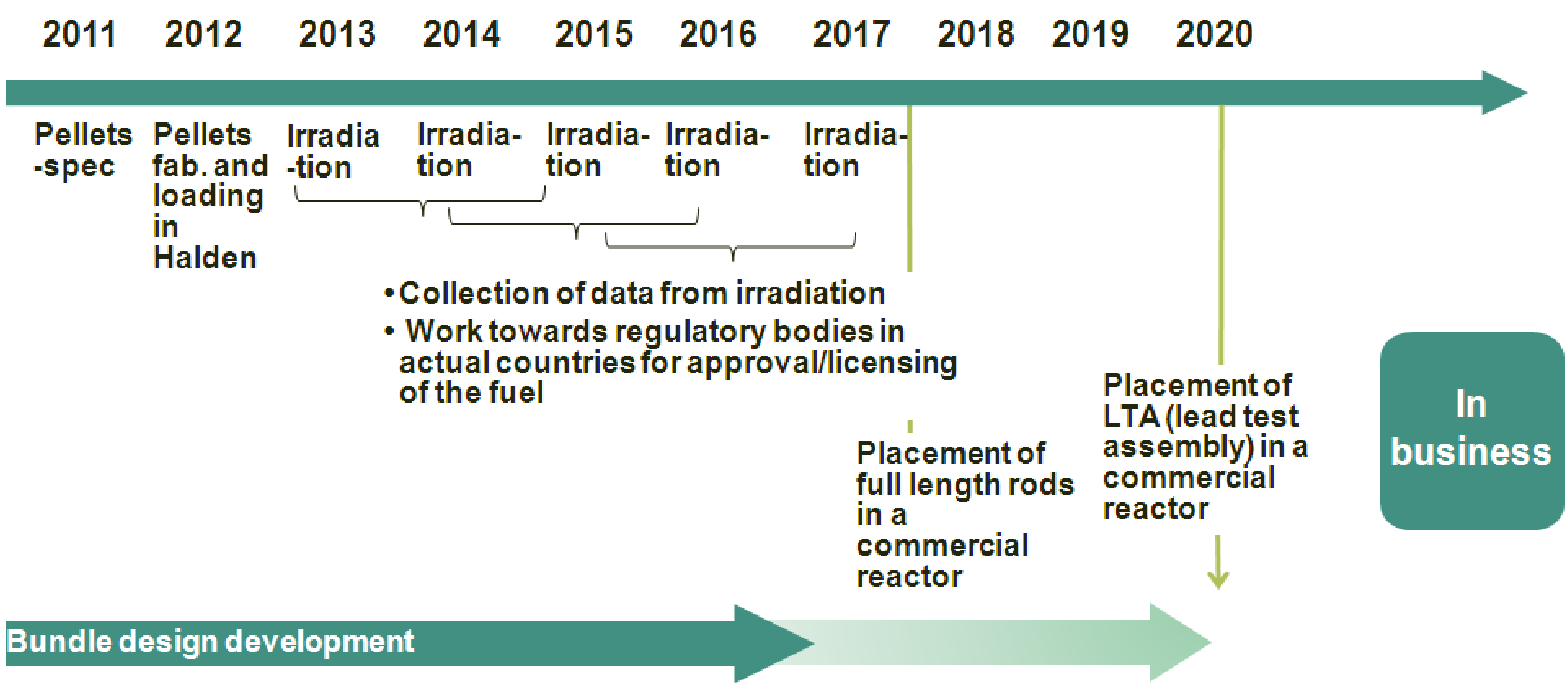
More From The Web

NRK

BBC WORLD NEWS

Thor Energy
Scandinavian Advanced Technology

Timeline for bringing Th fuel to the market



Thor Energy
Scandinavian Advanced Technology

Seven-Thirty
90 +4
Thorium
232,03806

Seeking new Consortium members

- In order to expand knowledgebase and broaden the footprint of Th in LWR
- Japanese participation is of special interest:
  - MOX experience
  - Infrastructure for closed cycle
  - Consciousness of «sustainable nuclear»
- Full membership includes:
  - Participation in Steering Committee
  - Access to all irradiation data (online and PIE)
  - Co-authorship on published papers

Seven-Thirty

90 +4
Thorium
232,03806

The Thorium Irradiation Campaign in the Halden Reactor

…the Thorium evolution…..

Thor Energy
Scandinavian Advanced Technology