ISSUES ON APPLICATION OF COMMERCIAL LWR CORE AREAS FOR IRRADIATION AND FOR TESTING OF ADVANCED FUELS

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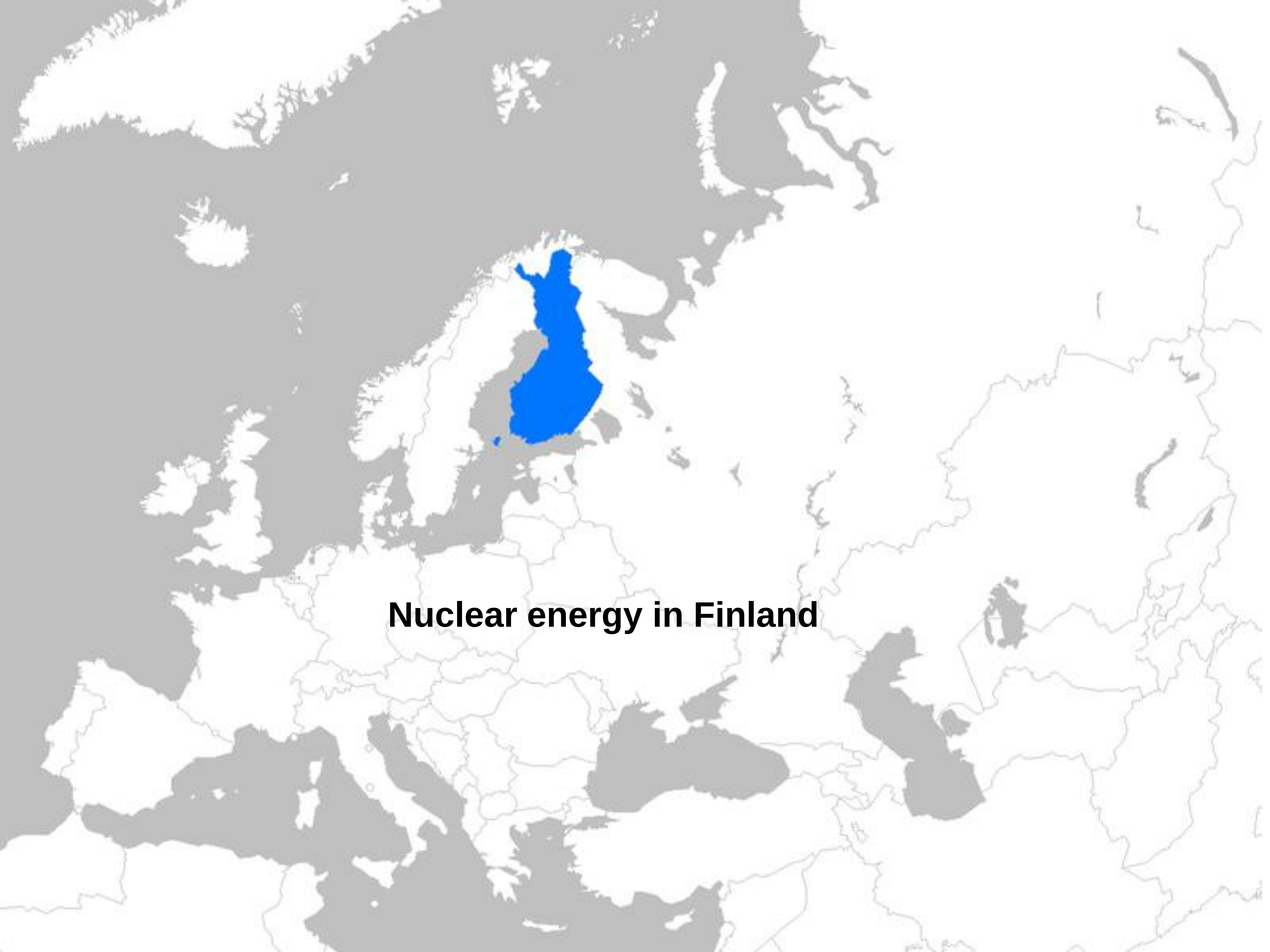
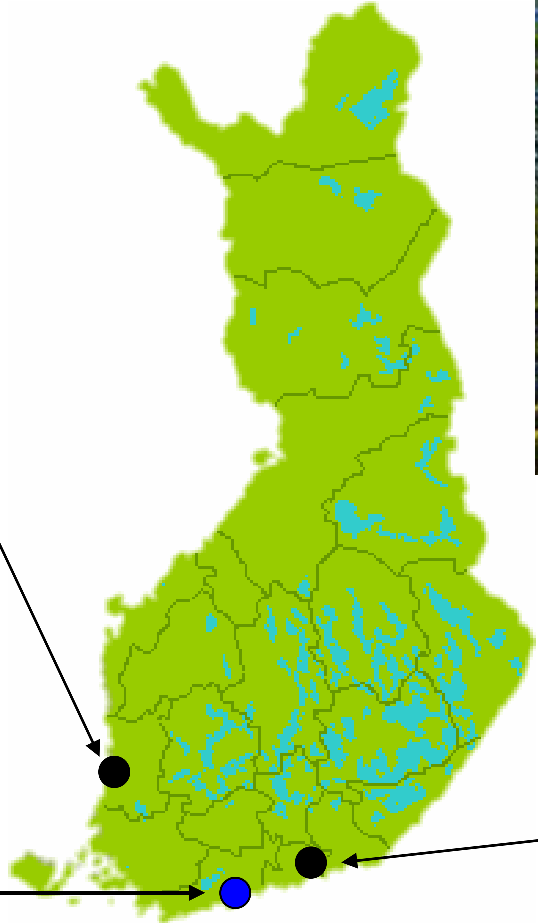


Nuclear energy in Finland

25,4% of electricity by nuclear (2008)

Olkiluoto 1&2
BWR 880&860MW
1979, 1982
2008: 14.4TWh, 95%



Triga MkII
1962, Espoo

Loviisa 1&2
PWR 2×488MW
1977, 1981
2008: 7,7TWh, 90%

The 5th unit under construction
Commercial start in 2013

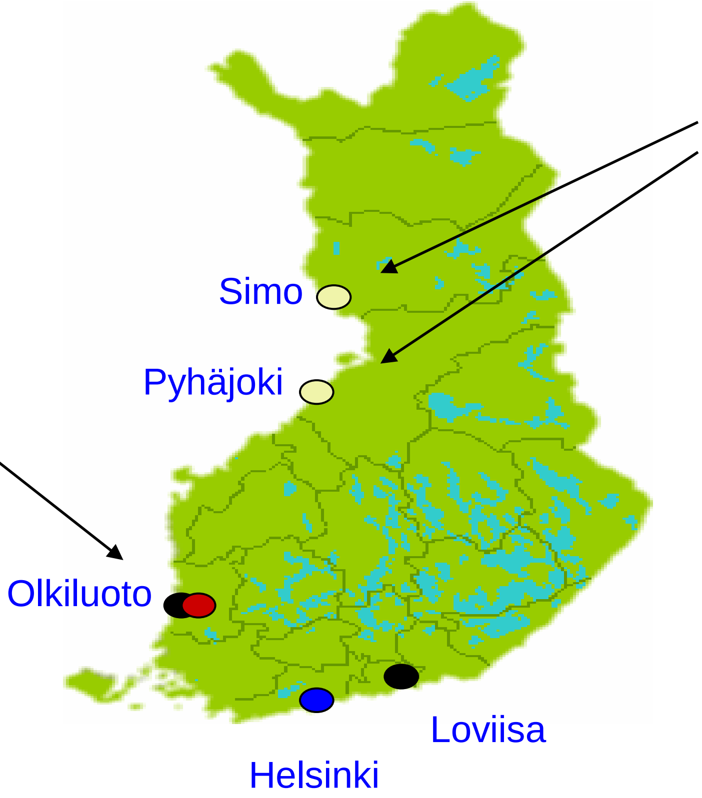
Environmental Impact Assessments and Applications for Decision in Principle accepted for two further units

TVO, Olkiluoto 4

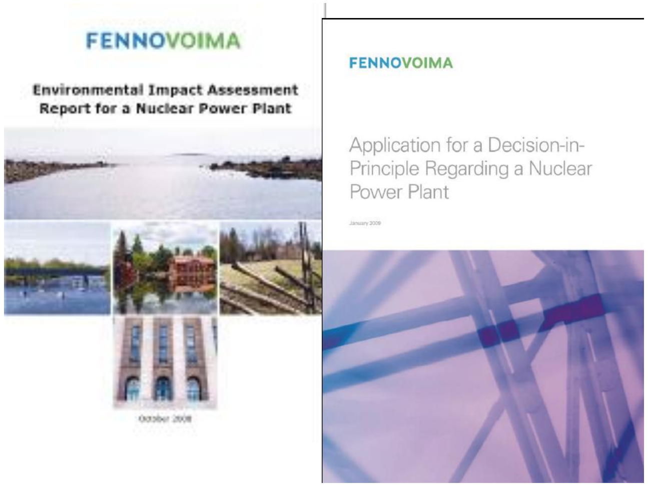
Environmental Impact Assessment Programme Summary

Extension of the Olkiluoto nuclear power plant by a fourth unit

Application for a Decision-in-Principle concerning the Construction of a Nuclear Power Plant Unit – Olkiluoto 4



Fennovoima 1



FENNOVOIMA

Environmental Impact Assessment Report for a Nuclear Power Plant

October 2008

FENNOVOIMA

Application for a Decision-in-Principle Regarding a Nuclear Power Plant

January 2009

Commercial operation by 2020
Fennovoima site selection
Waste management of Fe1
Five reactor candidates in DiP
Consequences of EU stress tests
DiP assumes sufficient know-how

www.tem.fi
Ministry of Employment and the Economy

Nuclear waste management in Finland

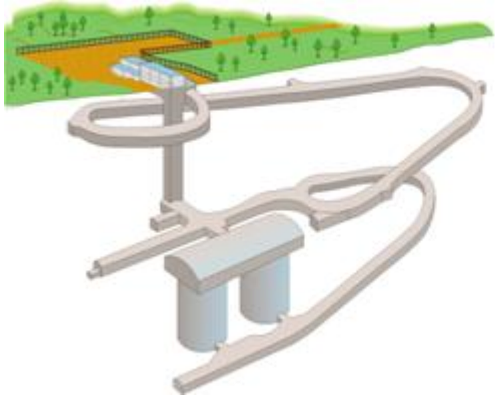
Olkiluoto Power Plant

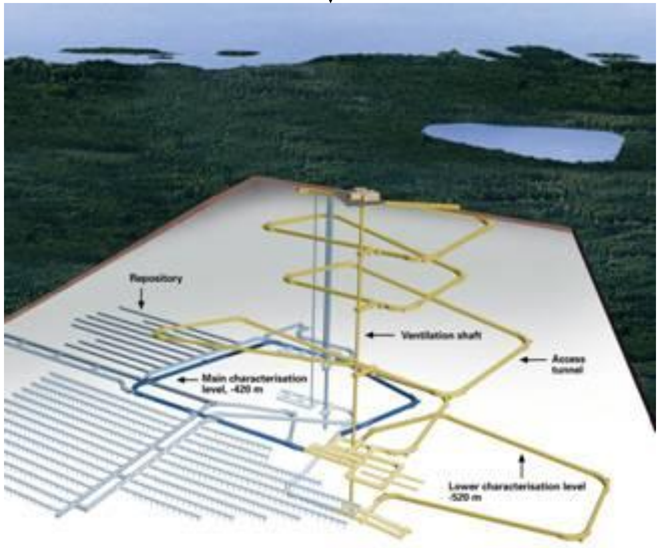
Loviisa Power Plant

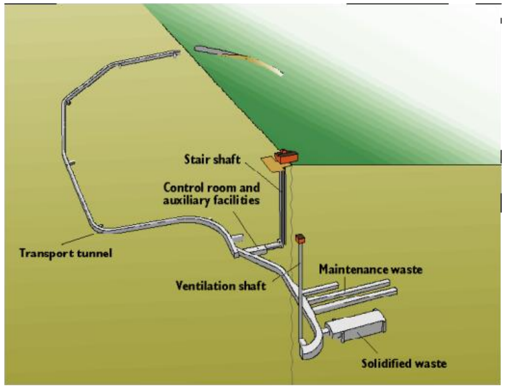
Spent fuel
Posiva

Operational waste
TVO

Operational waste
Fortum





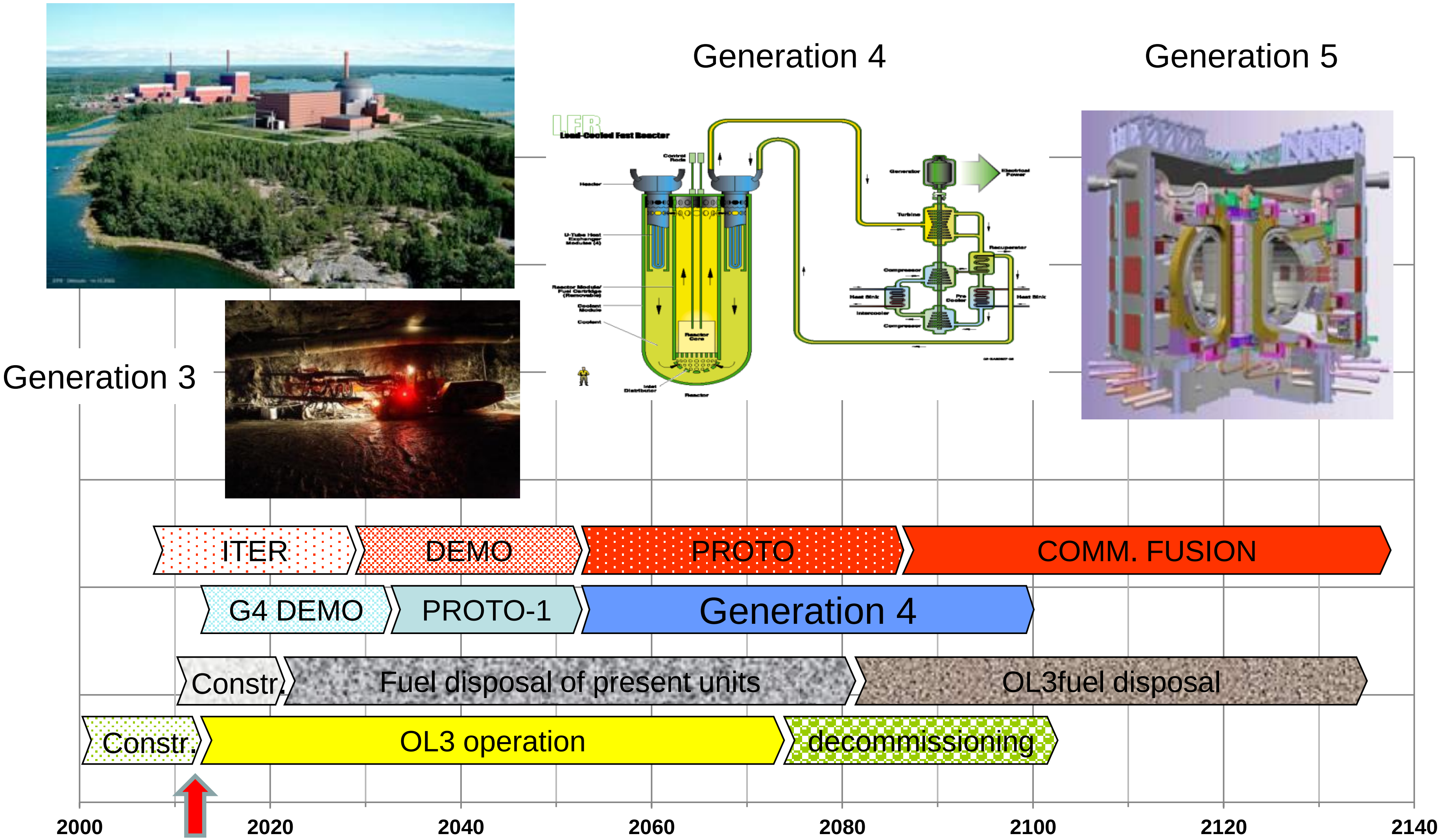


www.posiva.fi

Construction license in 2012, disposal start in 2020

Posiva Oy/ Jussi Partanen

Energy R&D involves long-time commitment – there is time for emerging systems



Generation 3

Generation 4

Generation 5

ITER

DEMO

PROTO

COMM. FUSION

G4 DEMO

PROTO-1

Generation 4

Constr.

Fuel disposal of present units

OL3fuel disposal

Constr.

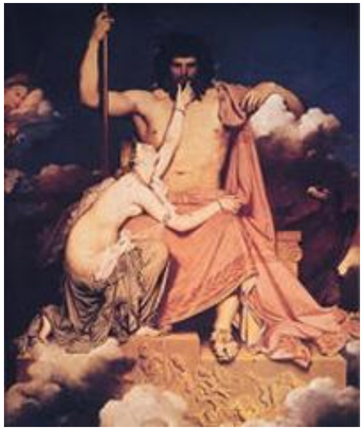
OL3 operation

decommissioning

Why and how thorium in Finland

Thor from Norse mythology
Iceland,, 10th century

Thorium as nuclear fuel – pros and cons



- **Sustainability**: Th adds significantly to U resources; abundant for breeders. Optimization between ^{239}Pu and ^{233}U cycles.
- **Safety** 1: Fuel – neutronics, thermal and chemical properties, burnup 100 MWd/kg, cladding performance, reactivity changes (^{233}Pa → ^{233}U accumulation, burnable poison, B-shim)
- **Safety** 2: Reactor dynamics (thermal or fast, heat transport), full Th-usage with cycle different stages from ^{239}Pu to ^{233}U (life-cycle assessment). Decay heat for both shut-down and for intermediate fuel disposal.
- **Nuclear waste**: fission products vs. actinides. Is P&T practicable?
- **Safeguarding**: ^{232}U a radiation barrier, ^{232}Pu production, seed enrichment LEU
- **Thorium technology**: fuel, reprocessing, reactor, O&M. A new NPP design is needed. Small nuclear countries have to rely on international markets.
- **Economic viability**: price of ^{235}U? BOC and EOC views
  Very different opinions.

For the near future Th is not a bargain?

Th-fuel: Motivation and challenges regarding Finland

- Th-U –fuel in **present LWRs**. A small nuclear country cannot afford prototypes.
- **Once-thru cycle**: wasting fissile material?
- **Reprocessing** in an international facility; transport of active fuel assemblies.
- Modifications of **waste management** concepts, vitrified waste
- Licensing of Th fuel in LWRs
- **Cost** structure of nuclear energy in Finland; viability of Th, competition against MOX and price of Pu. Comparisons between OL3 and a AHWR. Th almost free, U about 45% of the fuel costs
- **Short-term benefits** arise from spin-offs, education, code-validation in new parameter ranges, etc

A.Gallen –Kallela, Forging of the Sampo, 1893

A.Gallen –Kallela, Defence of the Sampo, 1896

Sampo, a magical artifact that produced good fortune to its holder

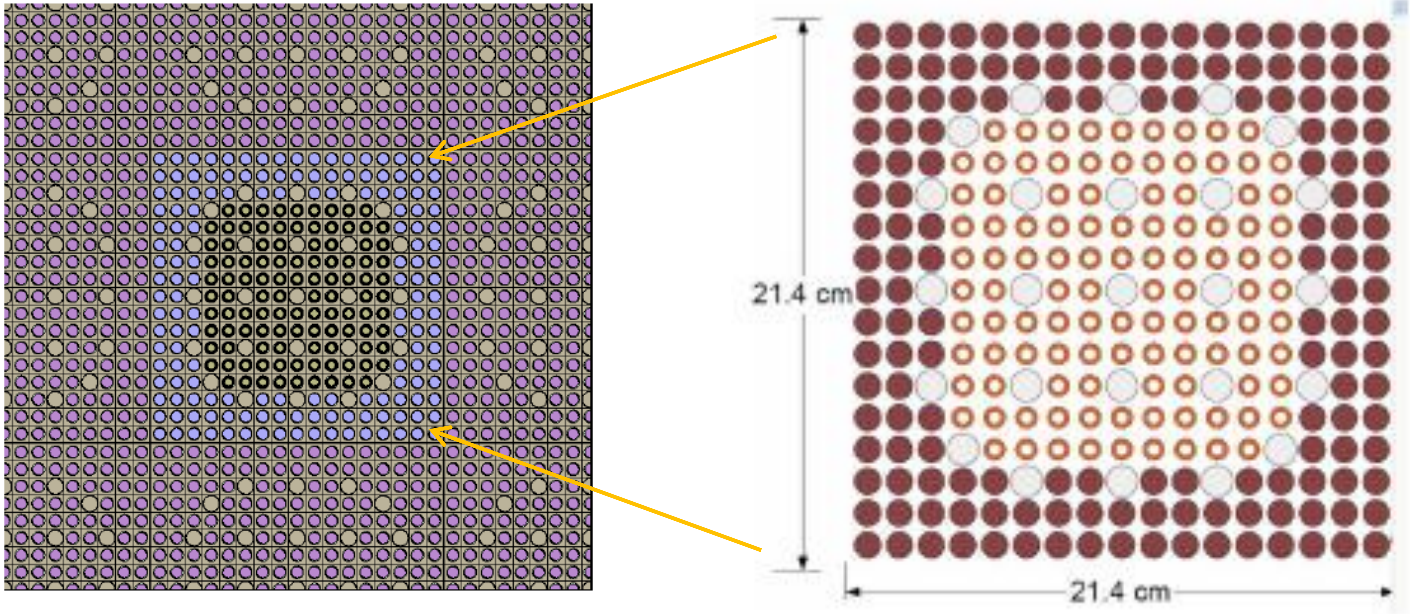
Thorium assemblies in present LWRs

Code calculations

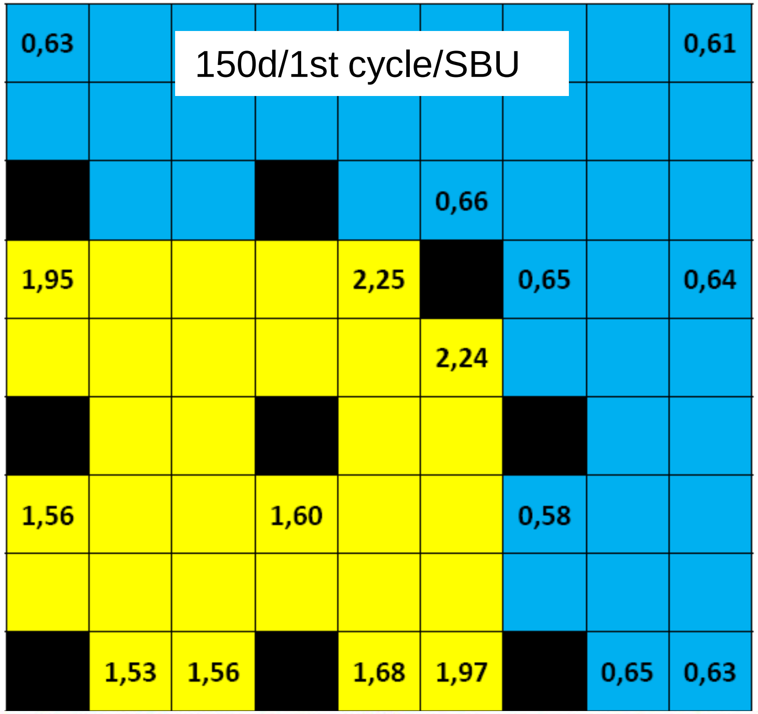
- Academic problems with professional tools. Monte Carlo Codes MCNP, Serpent, FLUKA, and burnup codes CASMO, Serpent, Monteburns, DeTra
- Educational goals
- Benefits for code development and validation
- A soft transition from present generation systems into a fully new fuel structure: Th contained in single rods, fuel assemblies, and full core loads
- **A single Radkowsky type seed blanket unit (SBU) in a PWR**. Comparision between Serpent and CASMO. Neutronics and burnup calculations.
- **Full Th-U core in a BWR**. Possibilities for 3D enrichment and spectral shifts. Core load optimization
- Miscellaneous comments on proliferation, spent nuclear waste
- Consideration of test rods for isotope separation and materials tests, licensing requirements

Thorium in PWR

- Use of thorium fuel in a commercial PWR UO_2 core (4% enriched)
- Performance of a single Radkowsky thorium fuel assembly : 17×17 Westinghouse PWR, separate blanket (BSA) and seed sub-assemblies (SSA); details as in Todosov and Kasimi (2004)
- Seed blanket changed in 54 month cycles
- Calculations by CASMO-4E and by a Monte Carlo code Serpent
- Role of soluble boron, typical values used here

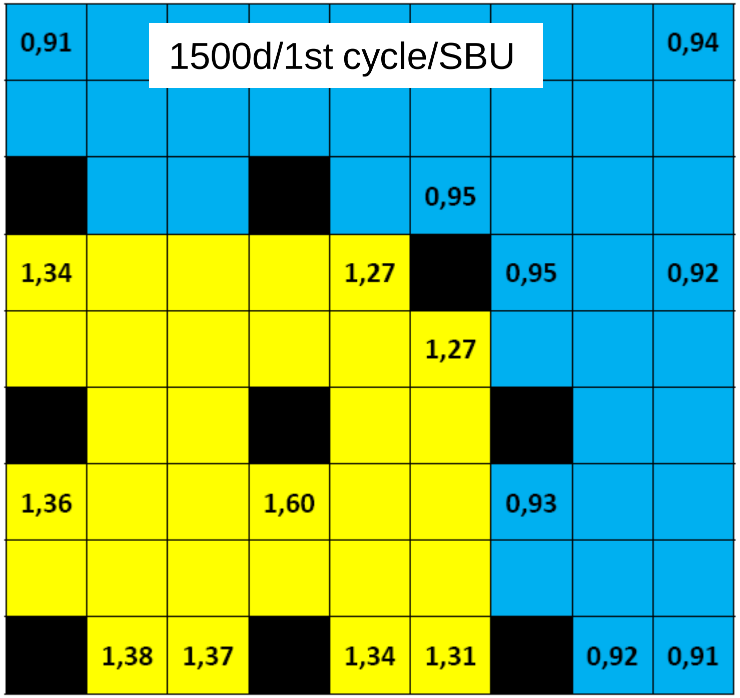


Neutron flux and fission rate distribution



150d/1st cycle/SBU

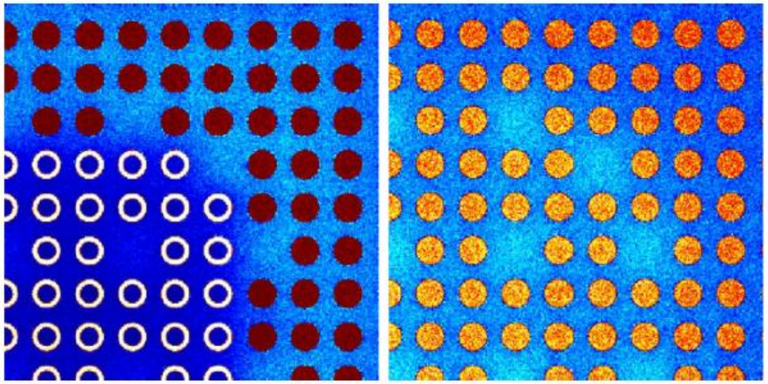
0,63								0,61
■			■		0,66			
1,95				2,25	■	0,65		0,64
					2,24			
■			■			■		
1,56			1,60			0,58		
■	1,53	1,56	■	1,68	1,97	■	0,65	0,63



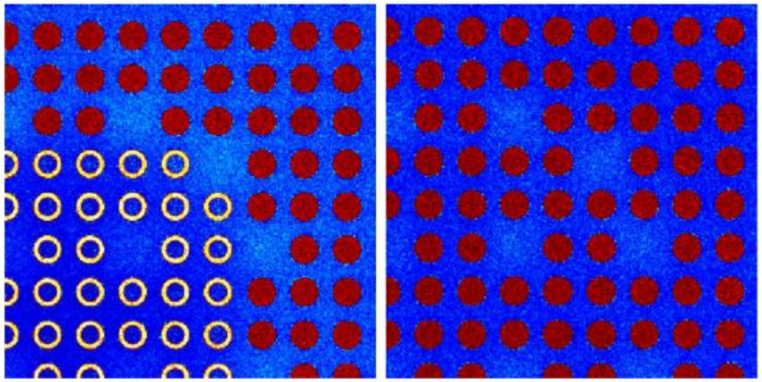
1500d/1st cycle/SBU

0,91								0,94
■			■		0,95			
1,34				1,27	■	0,95		0,92
					1,27			
■			■			■		
1,36			1,60			0,93		
■	1,38	1,37	■	1,34	1,31	■	0,92	0,91

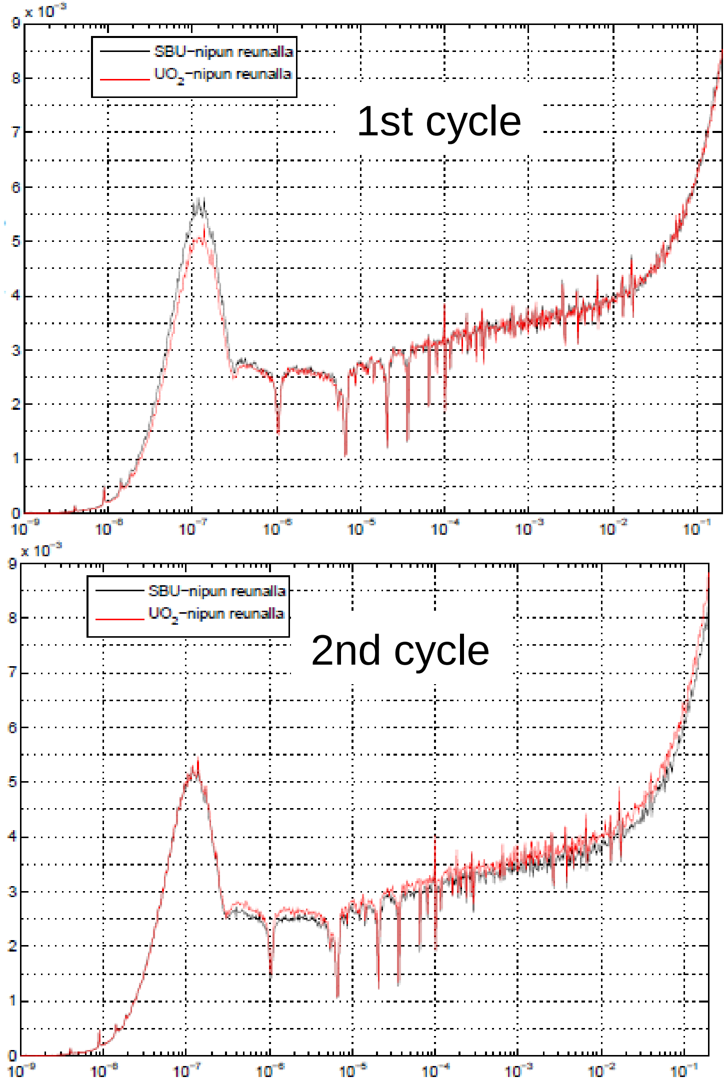
SBU



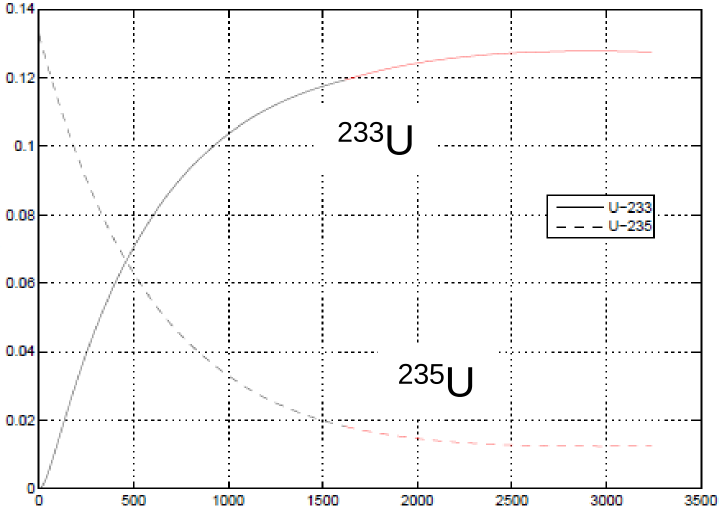
UO_2



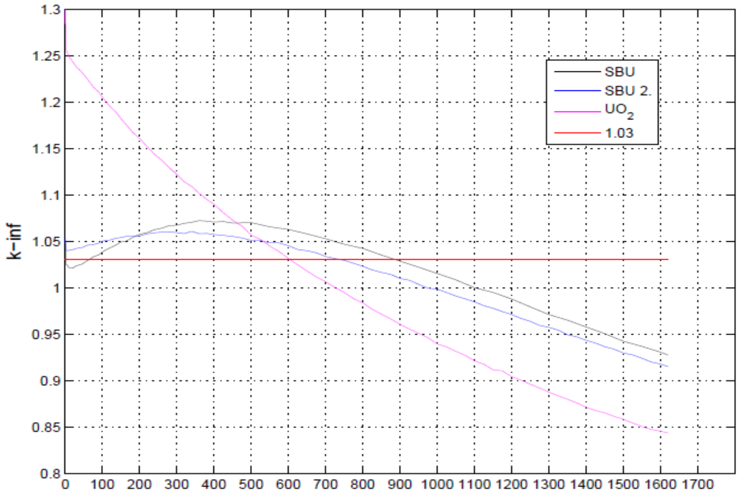
Neutron flux/lethargy at the SBU border (red) and in the UO_2 region (black)



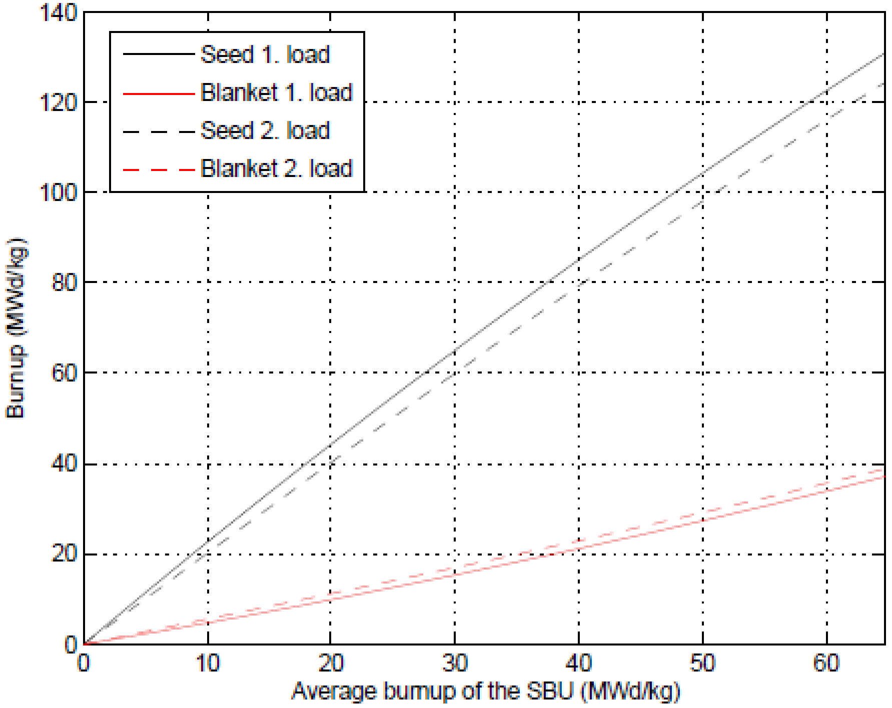
Fissile mass density (g/cm³) vs. time (d)

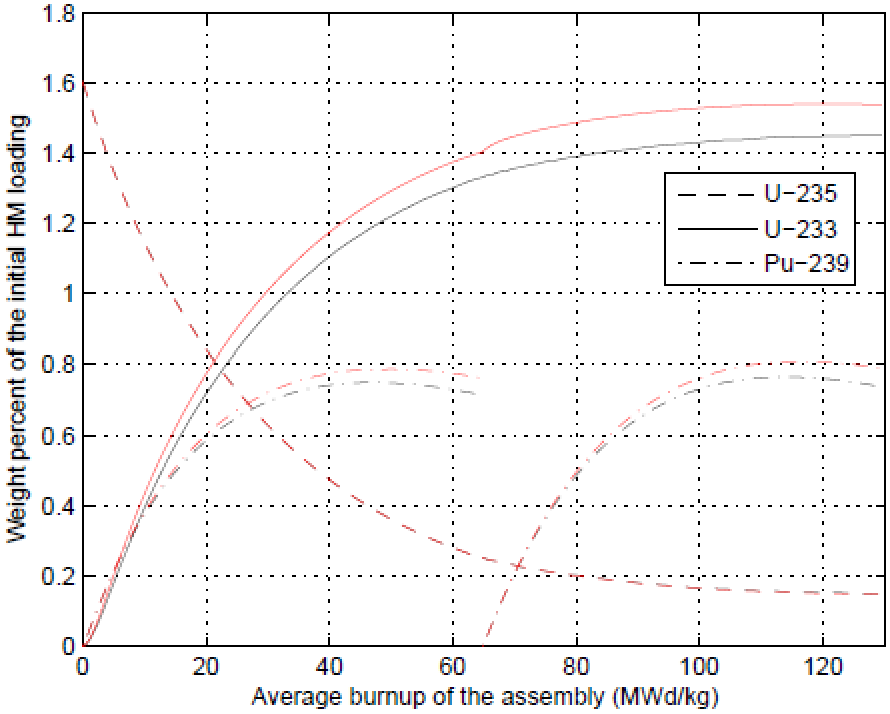


Multiplication factor vs. time (d)



Burnup and fissile production



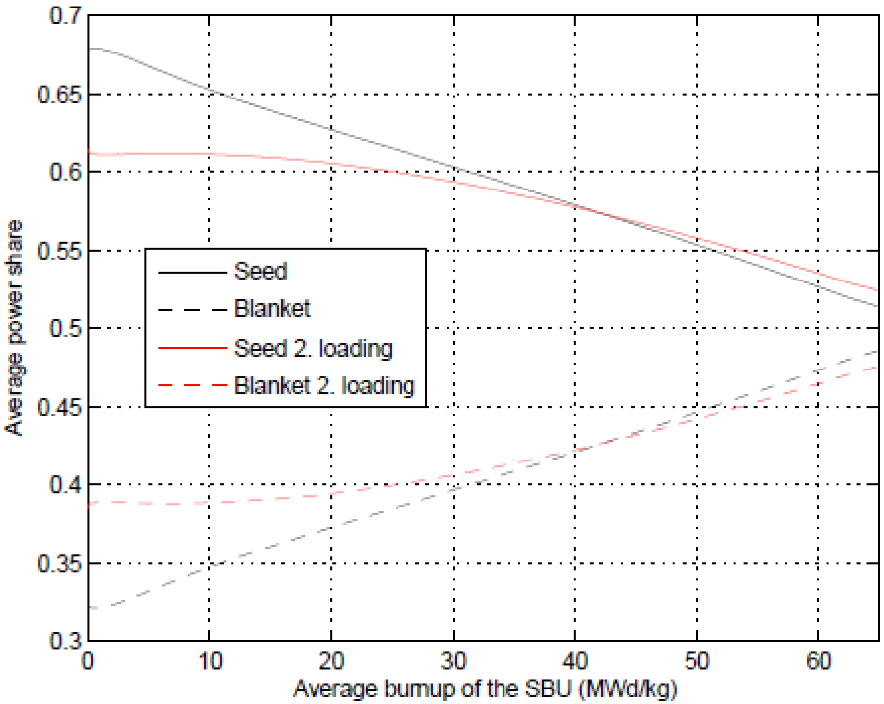


Burnup for a 54-month cycle. Discharge burnups (MWd/kg):

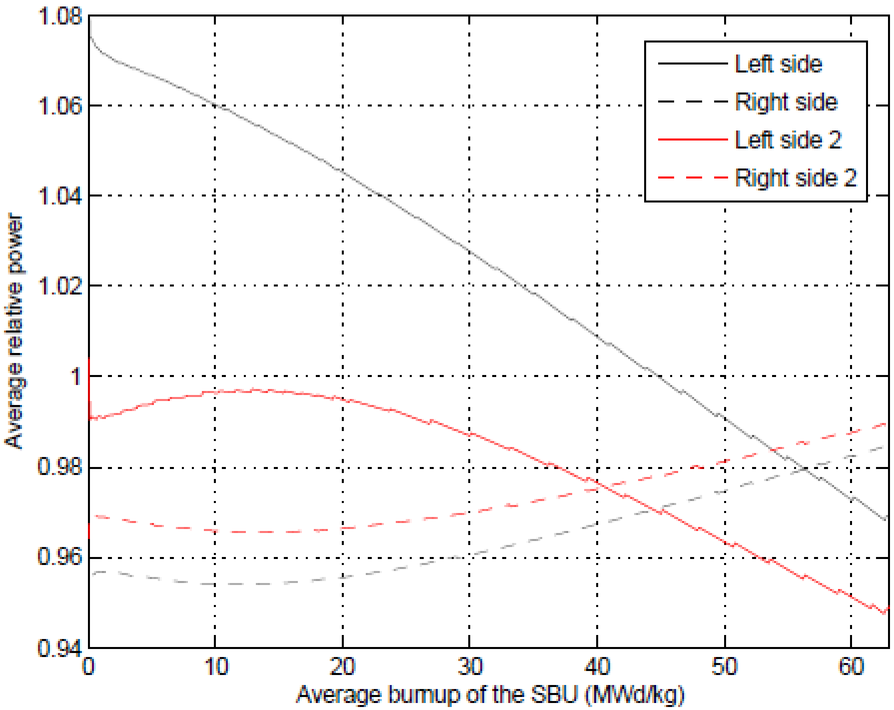
seed (1st cycle)	130.9	(129,5)
seed (2nd cycle)	124.4	(122,5)
blanket (1st cycle)	37.2	(37,7)
blanket (2nd cycle)	38.9	(39,7)
	Casmo	(Serpent)

Serpent predicts slightly more U^{233} production than Casmo-4E; very little difference in U^{235} depletion

Relative power production of RTF and LWR assy

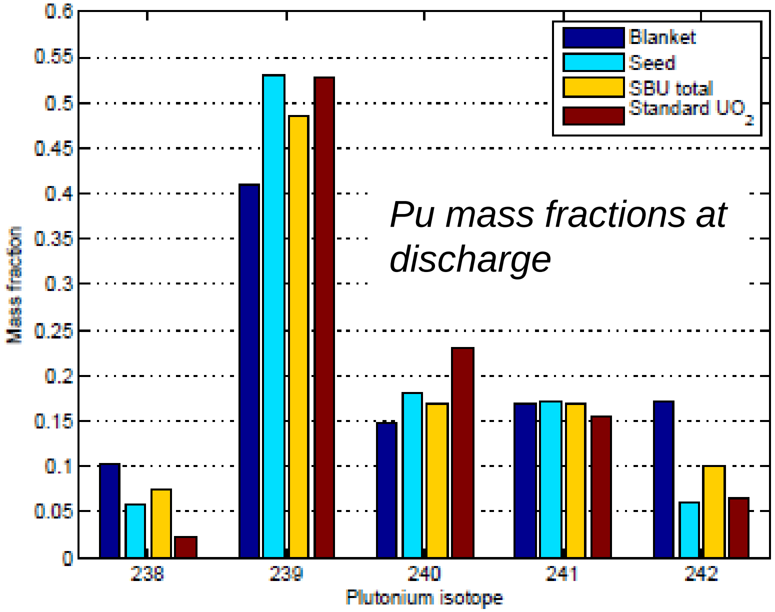


Relative power shares of the blanket and seed

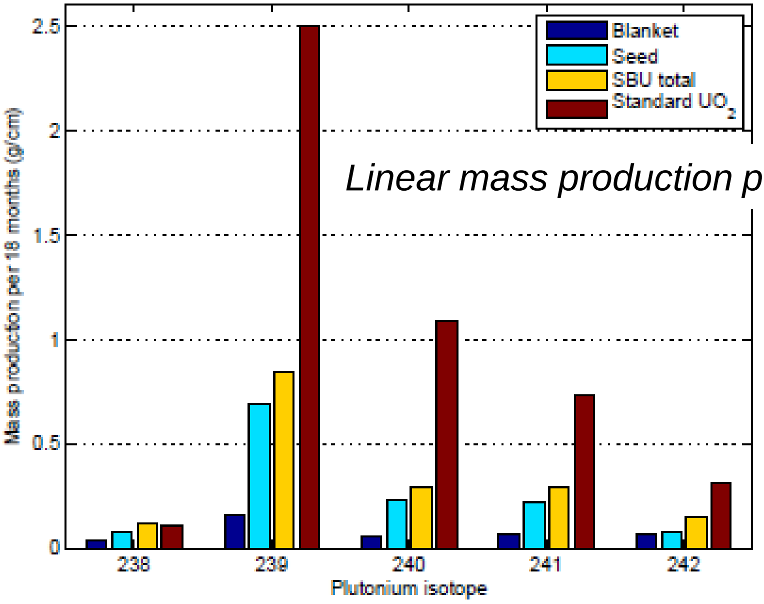


Relative power shares of the left and right side of the UO_2 assembly next to SBU. Average relative power for assembly equals unity. Second cycle in red.

Proliferation aspects



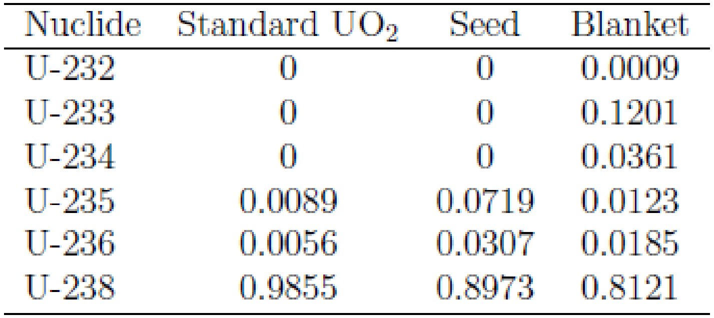
Pu mass fractions at discharge



Linear mass production per refueling

UO$_2$ discharge burnup is 45MWd/kg and that of SBU 64.8 MWd/kg. Spontaneous neutron rates 7.23, 4.46, and 4,12 (in 10^5/kgs) of seed, Blanket, and UO$_2$, respectively.

Isotopic mass fractions of the discharged uranium

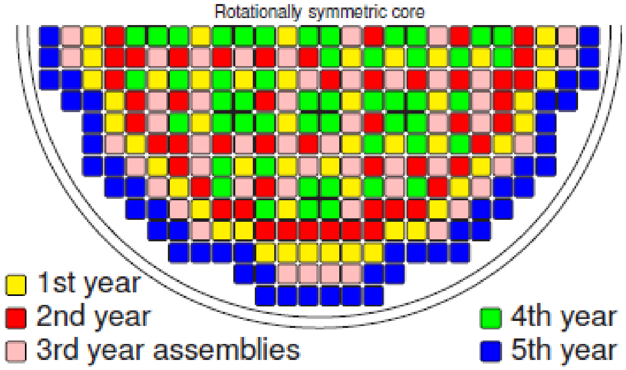


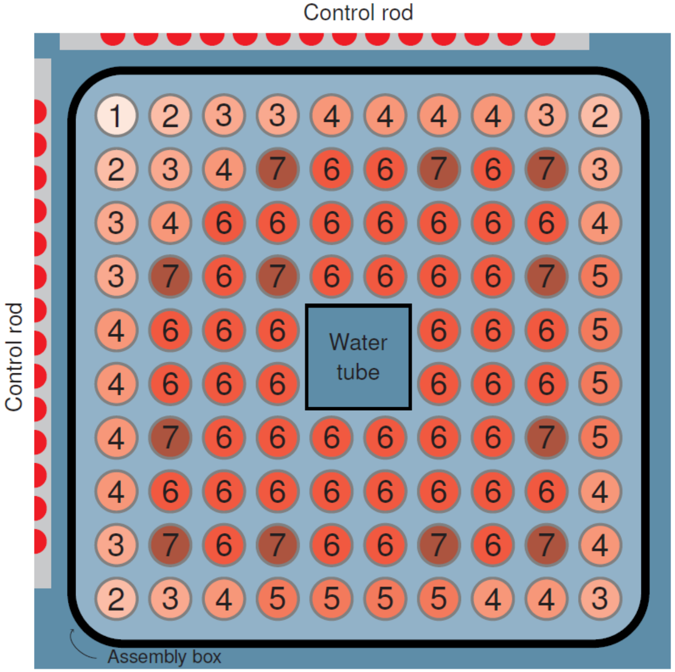
Nuclide	Standard UO$_2$	Seed	Blanket
U-232	0	0	0.0009
U-233	0	0	0.1201
U-234	0	0	0.0361
U-235	0.0089	0.0719	0.0123
U-236	0.0056	0.0307	0.0185
U-238	0.9855	0.8973	0.8121

Full thorium fueled core in a BWR

Thorium simulation in a BWR

Core layout





1	2	3	3	4	4	4	4	3	2
2	3	4	7	6	6	7	6	7	3
3	4	6	6	6	6	6	6	6	4
3	7	6	7	6	6	6	6	7	5
4	6	6	6	Water tube		6	6	6	5
4	6	6	6			6	6	6	5
4	7	6	6	6	6	6	6	7	5
4	6	6	6	6	6	6	6	6	4
3	7	6	7	6	6	7	6	7	4
2	3	4	5	5	5	5	4	4	3

Specification

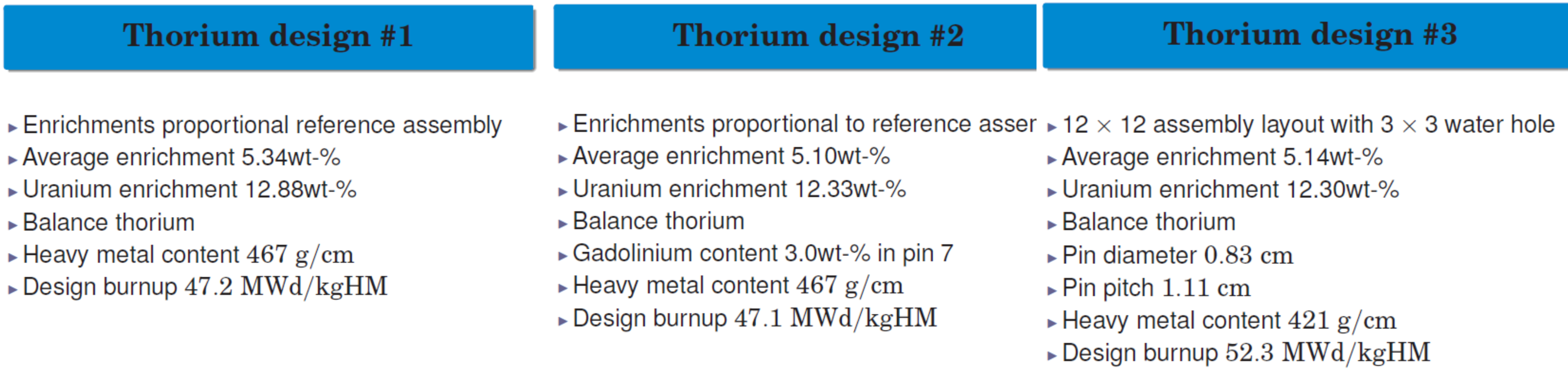
- Thermal power 2500MW
- Cycle 324 days
- Batches 5
- Number of assemblies 500
- B_4C control rods
- Control using core flow and control cells

Specification

- 10×10 lattice, square water hole
- 15.375 cm $\times$ 15.375 cm $\times$ 3.68 m
- The lowest enrichment 1.7wt-% (pin 1)
- The highest enrichment 4.95wt-% (pin 6)
- Average enrichment 4.125wt-%
- Gadolinium content 4.0wt-% in pin 7
- Pin pitch 1.3 cm
- Pin diameter 1.0 cm
- Heavy metal content 492 g/cm
- Design burnup 44.6 MWd/kgHM
- Natural uranium sections at the ends; otherwise no axial variation

An equivalent Th BWR core load

- Spectral changes due to burn-up and void distribution. In a BWR true 3D variation of nuclide compositions. Absorbable poisons (Gd) common.
- The same energy and neutron production during lifetimeproduction
- Very hard task for core load optimization. Reference layout and control plan
- Casmo-4E was used for lattice calculations
- Simulate-3 for full core calculations



Thorium design #1

- Enrichments proportional reference assembly
- Average enrichment 5.34wt-%
- Uranium enrichment 12.88wt-%
- Balance thorium
- Heavy metal content 467 g/cm
- Design burnup 47.2 MWd/kgHM

Thorium design #2

- Enrichments proportional to reference asser
- Average enrichment 5.10wt-%
- Uranium enrichment 12.33wt-%
- Balance thorium
- Gadolinium content 3.0wt-% in pin 7
- Heavy metal content 467 g/cm
- Design burnup 47.1 MWd/kgHM

Thorium design #3

- 12 × 12 assembly layout with 3 × 3 water hole
- Average enrichment 5.14wt-%
- Uranium enrichment 12.30wt-%
- Balance thorium
- Pin diameter 0.83 cm
- Pin pitch 1.11 cm
- Heavy metal content 421 g/cm
- Design burnup 52.3 MWd/kgHM

Th in BWR – some preliminary findings

Assembly performance

	Reference	Thorium #1	Thorium #2	Thorium #3
Local power peaking	1.232	1.258	1.244	1.229
Reactivity feedbacks	> 0 and < 0	< 0	< 0	< 0
Burnup at maximum reactivity (MWd/kgHM)	10.0	12.0	10.0	10.0

Core performance

	Reference	Thorium #1	Thorium #2	Thorium #3
Maximum assembly axial power peaking	1.36	1.50	1.43	1.36
Maximum assembly radial power peaking	1.49	1.47	1.44	1.42
Maximum pin power peaking	2.48	2.49	2.34	2.16

- Th fuel needs less Gd (higher thermal absorption and conversion)
- Power peaking reduced
- Th fuel requires more fissile nuclides and SWU
- No optimization done, yet

Conclusions

- Nuclear energy means a very long time commitment
- Safe and economic production of nuclear energy implies intensive efforts on R&D&D and E&T involving also many emerging concepts.
- Thorium fuel cycle provides interesting possibilities for a soft introduction of it even in current LWRs.
- PWR options with Radkowsky SBU appears feasible
- BWR core optimisation not yet done
- Th SBUs seem to be licensable
- The benefits like waste, proliferation, etc., of Th-cycle have been demonstrated
- Th economy and sustainability require international reprocessing facilities
- To obtain full benefits of Th-cycle would imply a complete redesign of the whole system of the nuclear energy structure.

Thank You!

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