Status of Blykalla’s commercial LFR development in Sweden

Blykalla

Blykalla - Our Mission

01 Mitigate climate change

02 Provide energy security

03 Decarbonise industry

04 1000 units by 2050

Blykalla - Nuclear Innovation at Work

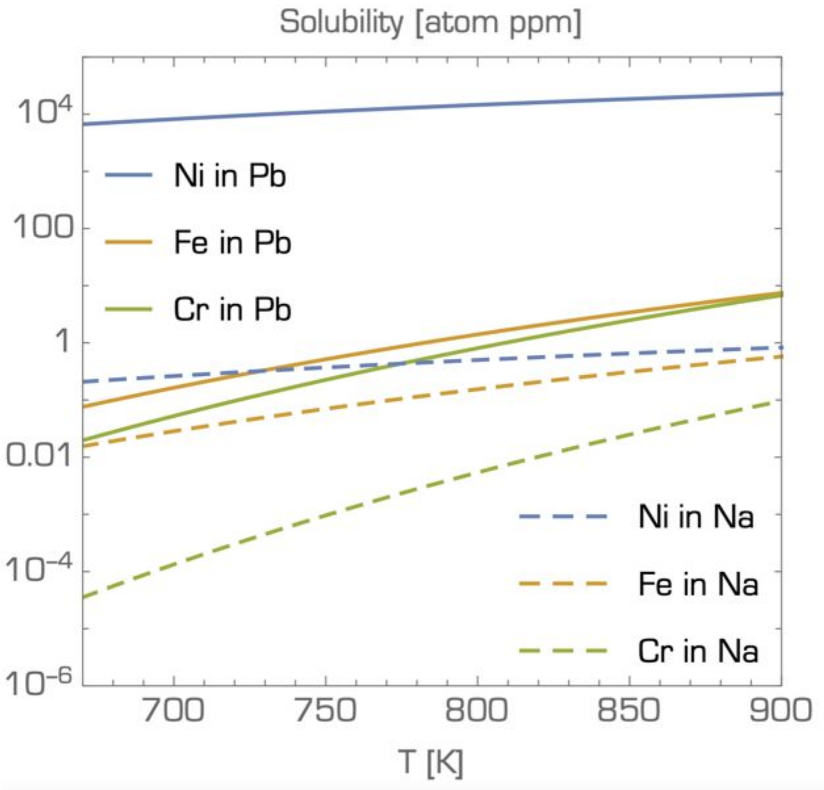
Why Liquid Lead?

Advantages of Liquid Lead

- Low pressure
- Large buoyancy head
- Retains fission products
- Chemically inert
- High boiling temperature
- In situ gamma shield

Safety in Most Compact Format

Challenges to be addressed



01 Corrosion

02 Erosion

03 High melting temperature

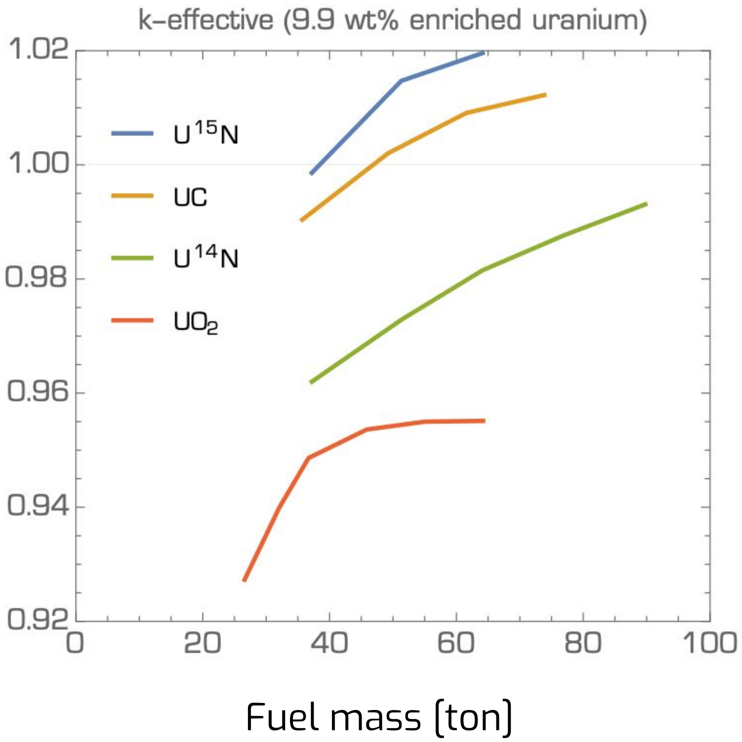
04 Opacity

The SEALER-One Concept

SEALER-One: Sweden’s First Advanced Reactor

Item	Value
Power	70 MWt
Lead coolant mass flow	3170 kg/s
Lead inventory	800 tons
Core inlet/outlet temperature	400°C/550°C
Secondary side inlet/outlet temperature	340°C/530°C
Fuel	Uranium Nitride (UN)
Maximum fuel residence time	5000 days
Peak fuel burn-up	18 GWd/ton
Peak damage dose	35 dpa

SEALER-One: Why $U^{15}N$ Fuel?



01 Availability of uranium enrichment from commercial suppliers outside of Russia is limited to 9.9% until at least 2028.

02 Supply of UO_2 with sufficient enrichment cannot be guaranteed in time for SEALER-One.

03 Practicable options: $U^{15}N$ and UC.

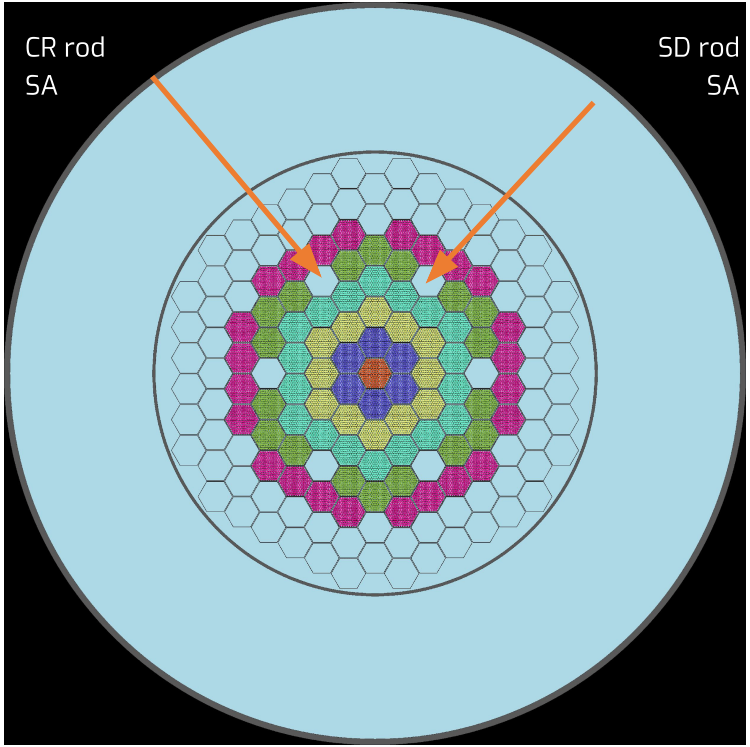
04 Cost penalty for UC: 25%

05 No industrially viable path for reprocessing of UC. Direct disposal questionable.

06 Reference fuel for SEALER-One is $U^{15}N$.

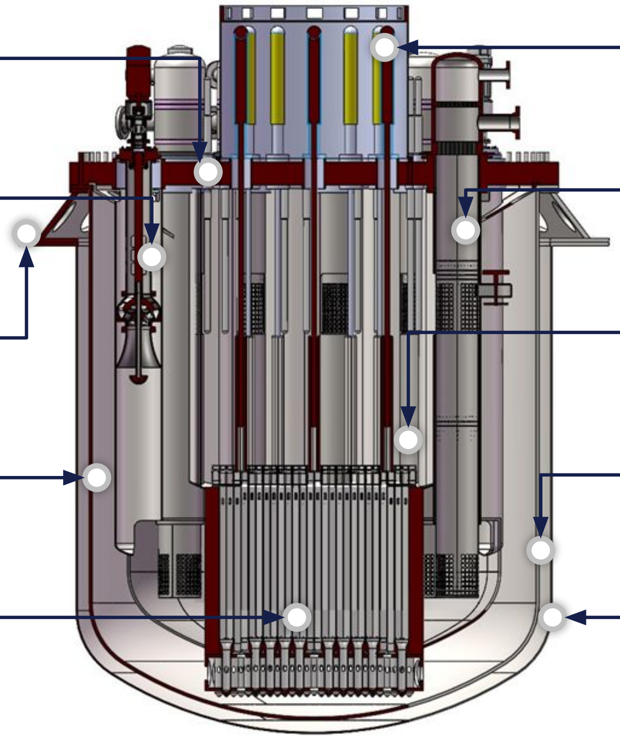
SEALER-One: Preliminary core design

9.9% enriched uranium available for commercial delivery in 2025. Requires non UO_2 fuel to allow operation in critical mode



Item	Value
Power	**70 MWth**
Fuel	**$U^{15}N$**
^{235}U enrichment	**9.9 wt%**
Fuel mass (uranium)	**27 tons**
No of fuel assemblies	**79**
Hex-can pitch	**194 mm**
Full power life	**5000 days**
Peak fuel burn-up	**18 GWd/ton**
Peak clad damage	**35 dpa**

Preliminary Primary System Layout



Novel Materials for Corrosion Protection in Lead

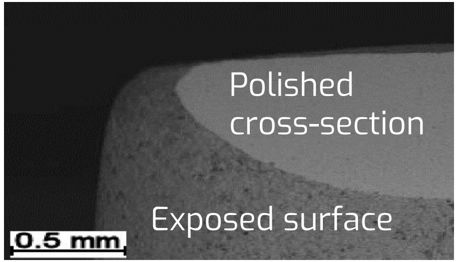
FeCrAl

AFA

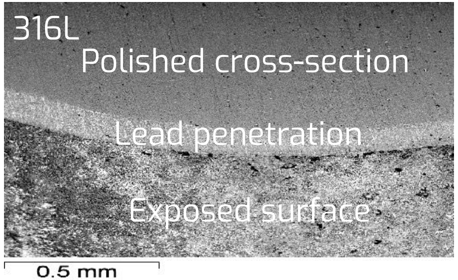
Corrosion protection is achieved through use of novel alumina forming materials as overlay welds on codified pressure boundary materials, and as bulk material for other components.

AFM

No weight loss and no visible erosion corrosion

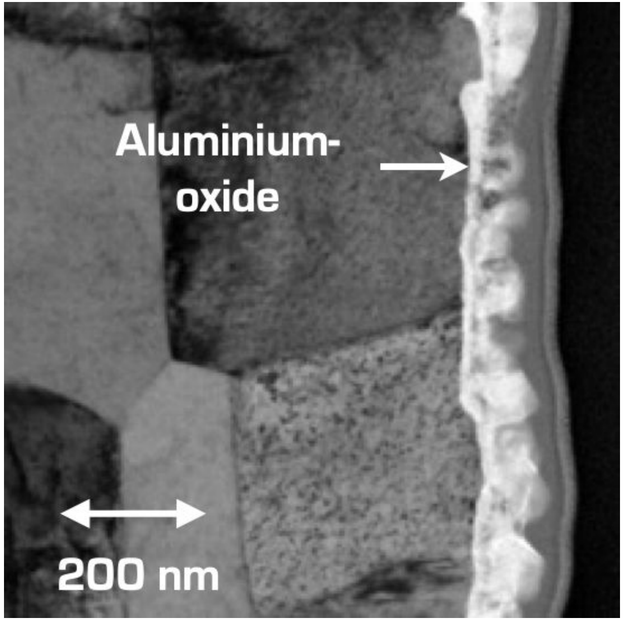


Severe erosion corrosion, weight loss and lead penetration

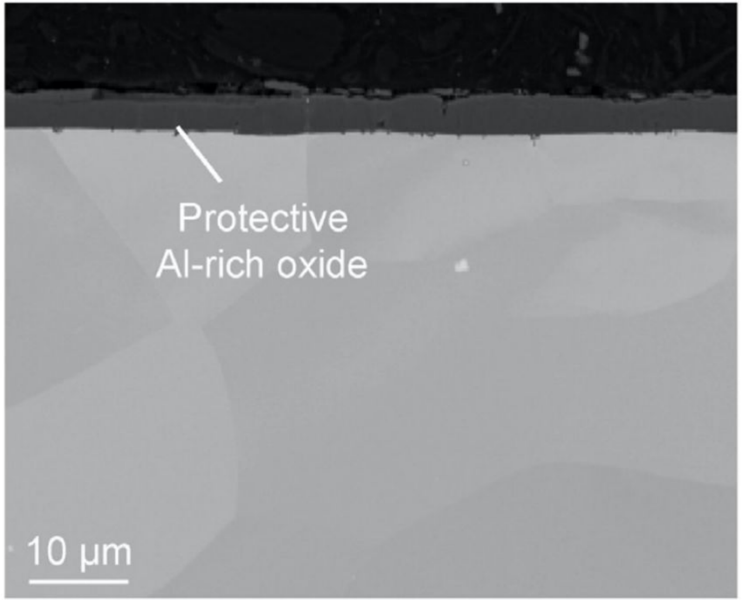


Corrosion Protection at the Microscopic Scale

Fe-10Cr-4Al-RE exposed to lead at 550°C for two years

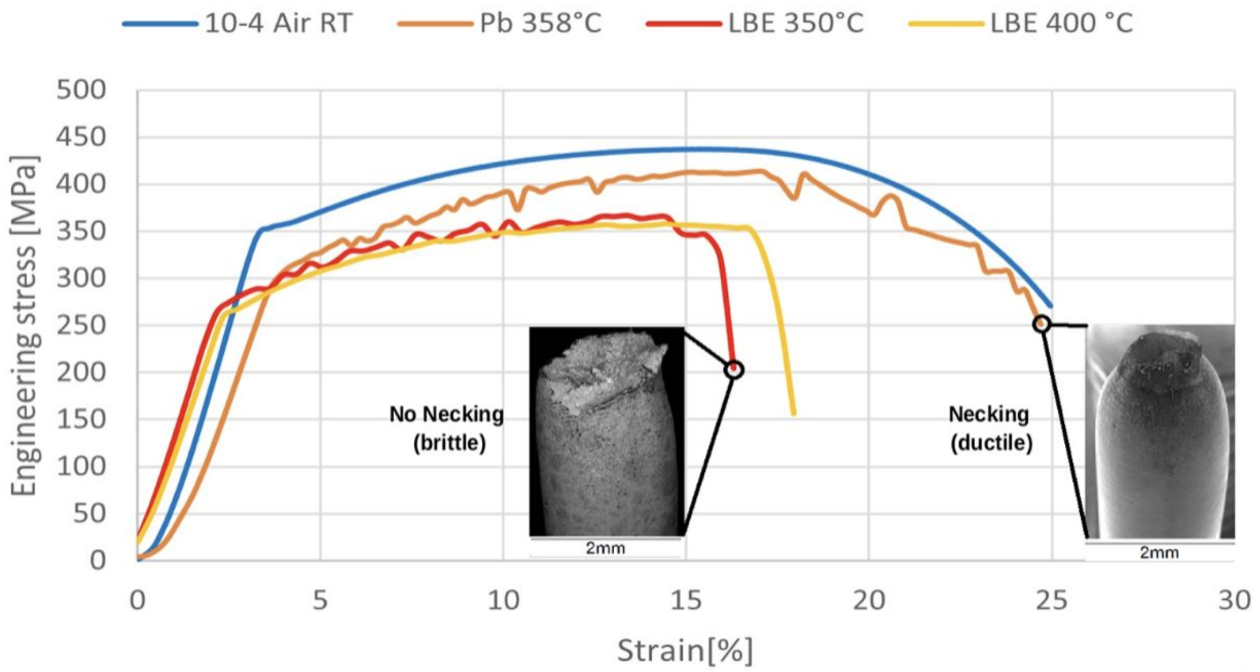


Fe-10Cr-4Al-RE exposed to lead at 800°C for ten weeks

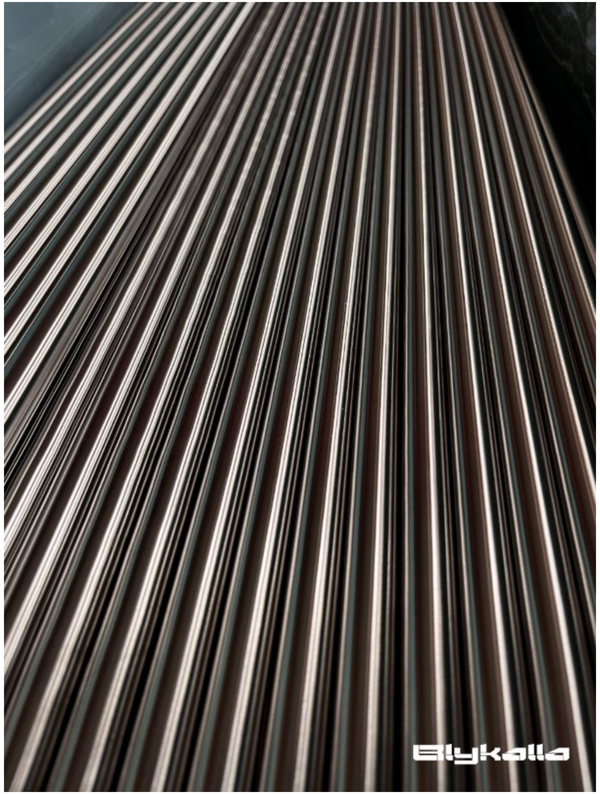


Blykalla's FeCrAl is Not Embrittled by Pb!

Fe-10Cr-4Al-RE exhibits no loss of ductility during slow strain rate test in Pb



Materials Programme

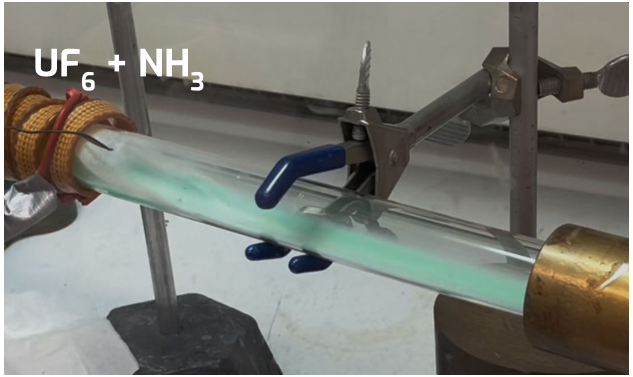


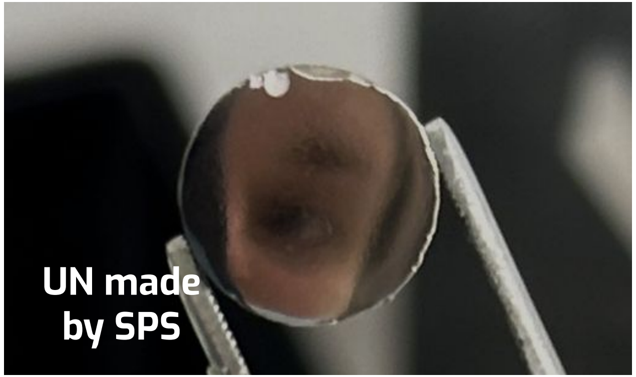
Done

- Manufacture of 140 thin-walled, three meters long Fe-10Cr-4Al-RE tubes
- Laser overlay weld of 15-15Ti with FeCrAl microwire (0.2 mm)
- Irradiation test to > 35 dpa
- Laser overlay weld of Alloy 800 with FeCrAl powder

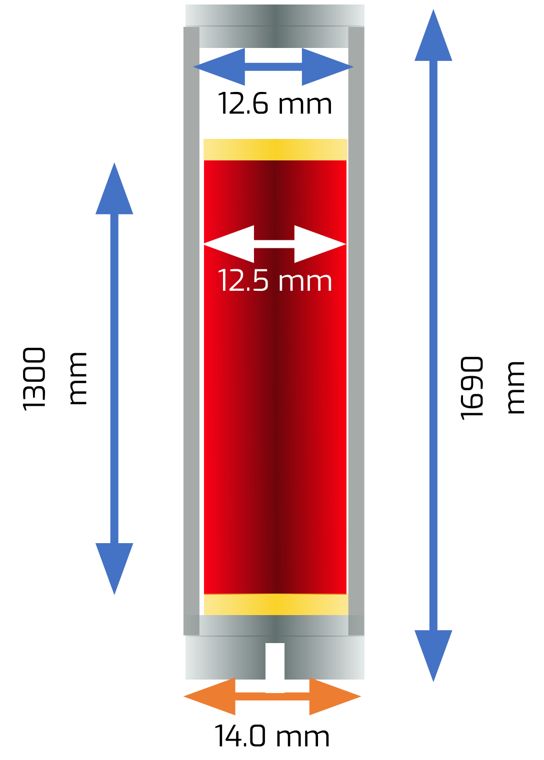
Fuel manufacture and qualification

- UN-15 fuel provides best neutron economy and largest margin to fuel failure - reference for SEALER.
- Ammonolysis of UF_6 to be used in production of UN powder - cheapest process, cleanest product.
- Spark plasma sintering of UN powder to be used for production of 98% dense UN pellets.
- Melting tests of UN simfuel to be conducted.
- Test irradiation of UN rods planned to amend existing database, with burn-up ≈ 2% FIMA, including transient tests.





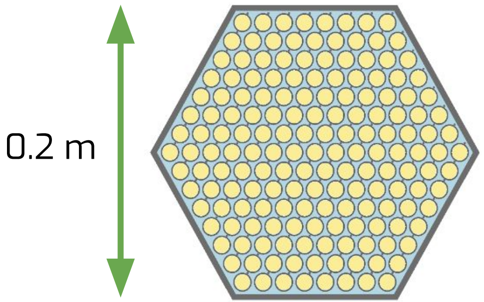
SEALER-One: Preliminary fuel rod design

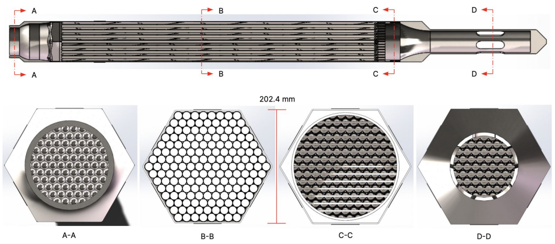


Item	Value
Rod inner/outer diameter	**12.6/14.0 mm**
Fuel pellet diameter	**12.5 mm**
Fuel column height	**1300 mm**
End pellet height	**10/10 mm**
Gas plenum height	**260 mm**
End plug in-rod height	**20/20 mm**
End plug ex-rod height	**50/20 mm**
Fuel rod length	**1690 mm**

SEALER-One: Preliminary Fuel Rod Assembly Design

Item	Value
Fuel rod pitch	**15.0 mm**
Spacer wire diameter	**0.96 mm**
Fuel rods per assembly	**169**
Hex-can inner flat to flat	**198.4 mm**
Hex-can outer flat to flat	**204.4 mm**





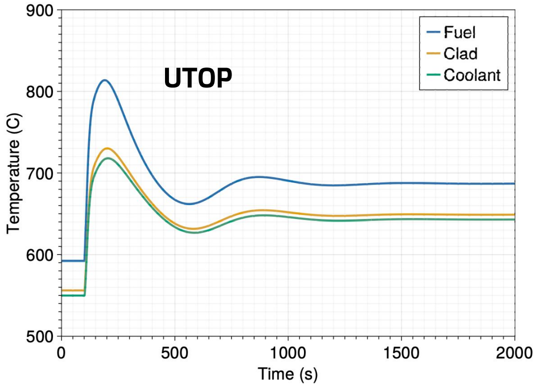
SEALER-One: Core Thermal Hydraulics

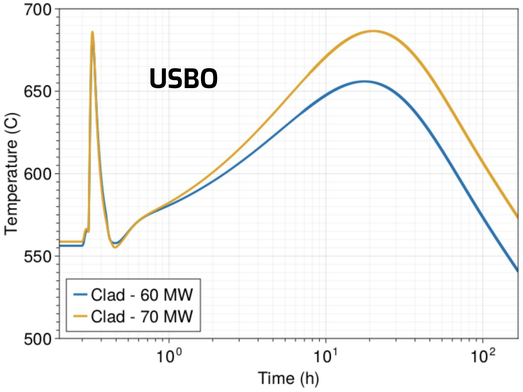
Item	Sealer-One
Core power	**70 MWth**
Core outlet/inlet temperature	**400/550°C**
Lead mass flow	**3170 kg/s**
Coolant area fraction in rod lattice	**23 %**
Peak lead flow velocity	**0.9 m/s**
Coolant channel pressure drop	**0.6 bar**
Fuel assembly pressure drop	**0.7 bar**

Kinetics & Reactivity Feedbacks

Item	Sealer-One
Beta-effective	**735 pcm**
Doppler constant	**- 684 pcm**
Fuel column axial expansion	**- 0.05 pcm/K**
Diagrid radial expansion	**- 0.47 pcm/K**
Coolant density in active zone	**+ 0.11 pcm/K**
Coolant density above active zone	**- 0.05 pcm/K**
Coolant density above active zone	**- 0.02 pcm/K**
Coolant density in reflector	**- 0.15 pcm/K**

Passive response to unprotected transients (Design Extension Condition)





- Enveloping transients: Unprotected TOP & SBO
- TOP: Withdrawal of most reactive control rod assembly.
- SBO: Station blackout
- “U”: Combined with failure to insert shut-down rod assembly
- Fuel cladding of SEALER remains intact

Waste management

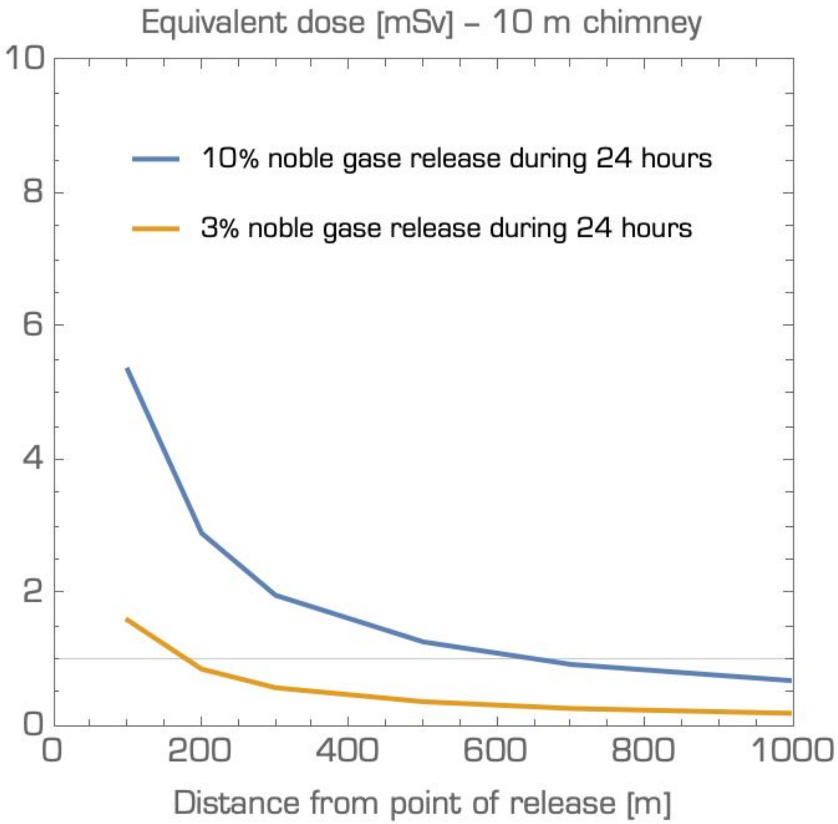
Waste Management Approach

- Irradiated nuclear fuel management options:

1. Conversion to oxide form compatible with current Swedish approach - tested for irradiated metallic fuel from R1, tested in lab for unirradiated UN.
2. Reprocessing and disposal of vitrified fission products - UN is soluble in nitric acid at room temperature. Industrialisation investigated in FREDMANS EU project.
3. Direct disposal of nitride form - UN is better compatible with geological repository conditions than UO_2.

Severe accident management

Radiological Exposure from Noble Gases



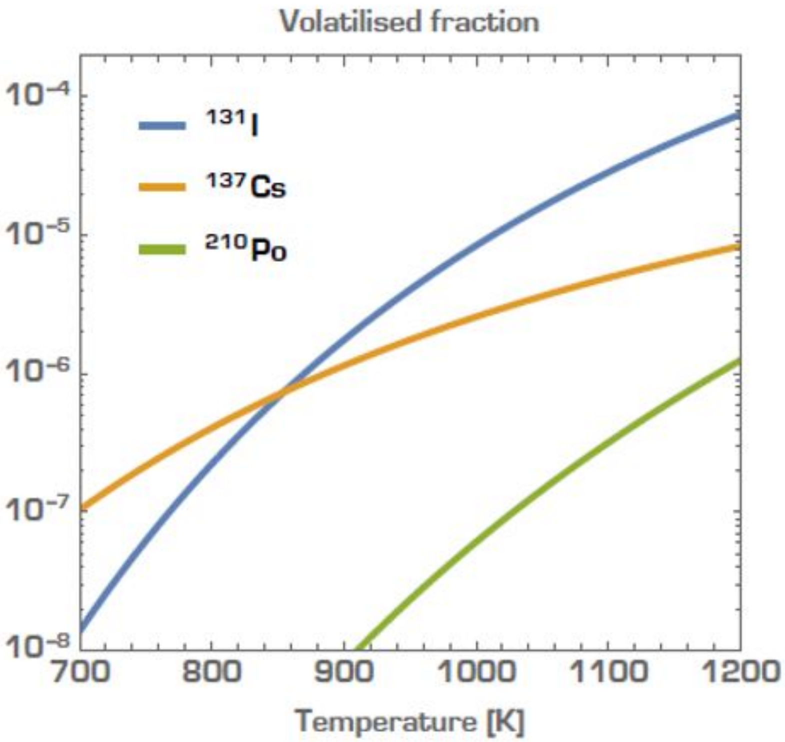
Release simulated with NRC code RASCAL4.2.

Least favourable weather conditions (highly conservative)

SSM proposed DEC condition meets 10 mSv acceptance criterion at > 100 m from release point

SSM proposed DBA condition meets 1 mSv acceptance criterion at > 200 m from release point

Strategy for Management of Significant Release



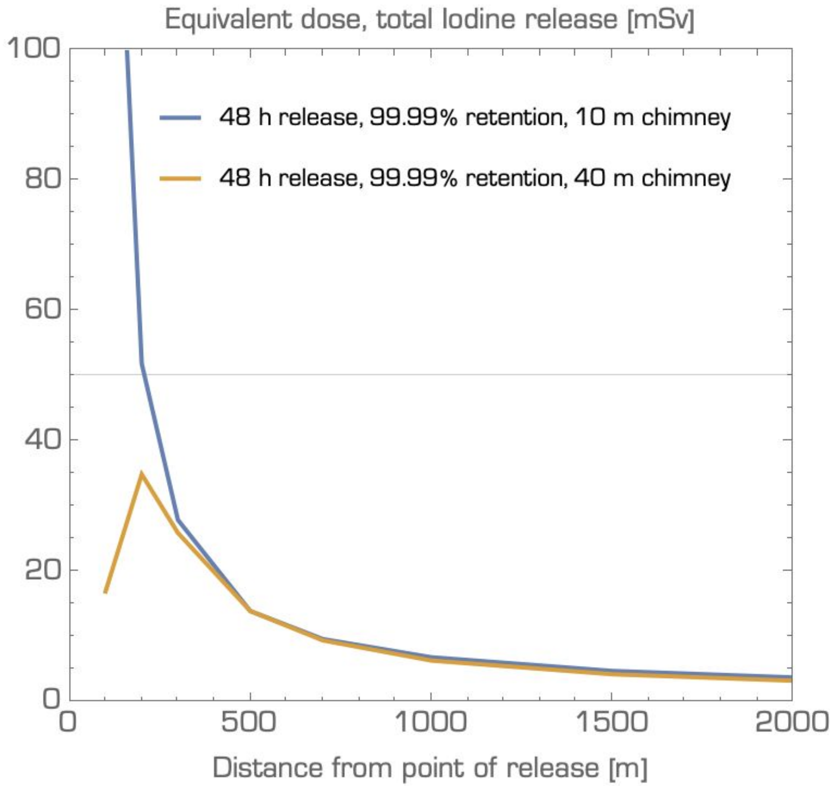
Minimise source term by limiting fuel average burn-up to 10 GWd/ton (1% FIMA)

Retain > 99.99% of volatile fission products in primary lead coolant by formation of compounds with low vapour pressure

Ensure low pressure in primary system and confinement by minimizing water inventory

Confinement leak rate < 1% per day

Radiological Exposure from Volatiles



Dose from iodine normally dominates exposure

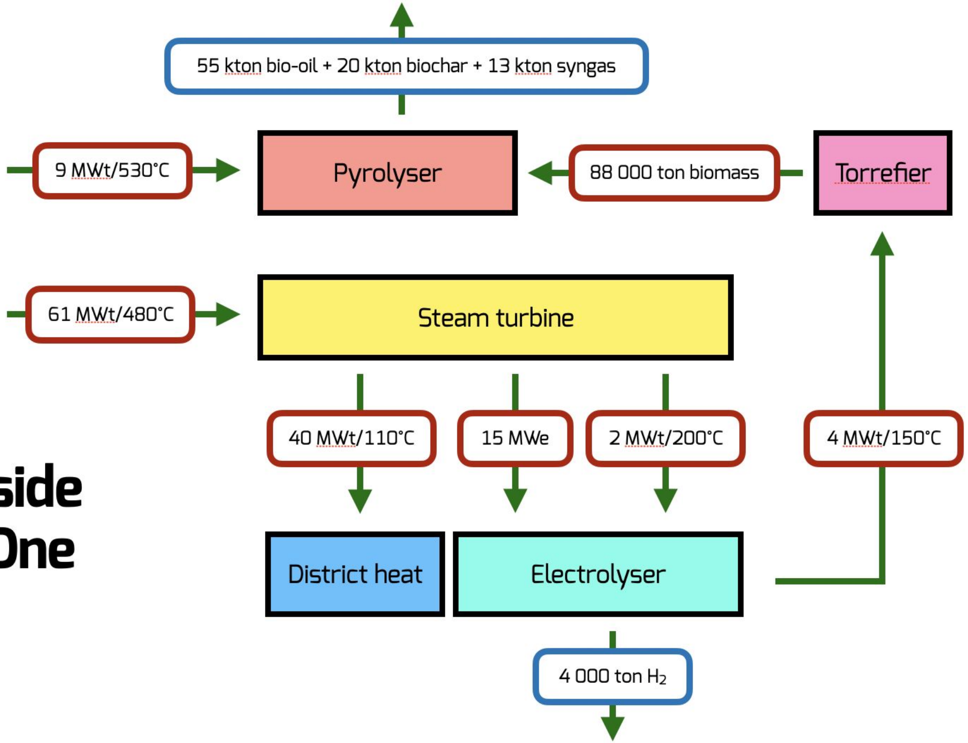
RASCAL4.2 calculation with 99.99% retention

10 mSv dose at 600 m distance from release

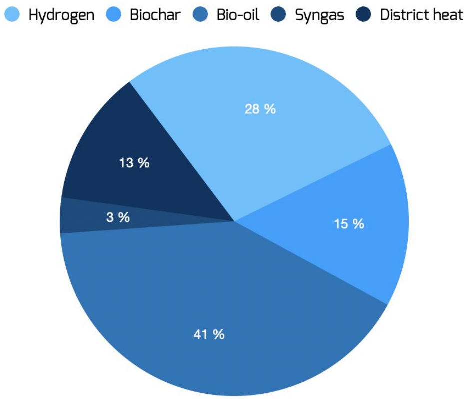
Takes no credit for confinement function

Commercial approach

Revenue streams from SEALER-One (preliminary)



Revenue side SEALER-One



Distribution of revenues from SEALER-One

Licensing

Licensing process in Sweden

Applicant
Submits application according to the Environmental Act and the Act on Nuclear Technology.

The Environmental Court
Prepares the case according to the environmental act and submits its opinion to the government.

The Radiation Safety Authority
Prepares the case according to the act on nuclear technology, and submits its opinion to the government.

Municipality
Recommends to approve, or issues veto.

Government
Decides if the application is permissible according to the environmental act
Grants permission aligned with the act on nuclear technology.
Determines conditions for the permit.

The Environmental Court
Continues the case and issues a permit associated with conditions according to the environmental act.

The Radiation Safety Authority
Determines additional conditions according to acts on nuclear technology and radiation safety, and checks if the application meets the conditions of the government.

Licensing of new reactors with novel technologies

Special features of Swedish process:

1. No restrictions on number of reactors nor location.
2. New technologies can be licensed under current regulation.
3. Applicant may refer to IAEA guidelines to support its argumentation.
4. Government intends to restrict reviewal process to a maximum of 24 months.
5. SSM intends to propose a lower licensing fee for reactors with a thermal power below 100 MW.
6. Vendor may enter into a "SVAR"-process to obtain regulator's early response to particular questions.

Subject to legislation/approval in autumn 2024

Siting

Preliminary siting studies

Preliminary siting study made at Studsvik, site of Sweden's previous research reactors.

Three locations on the site are considered suitable for SEALER-One.

Studsvik AB is willing to provide land for nuclear new-build.

Licensing application to feature detailed site investigation.

Thanks!