Framatome Solutions to Support Utilities for Long Term Operation

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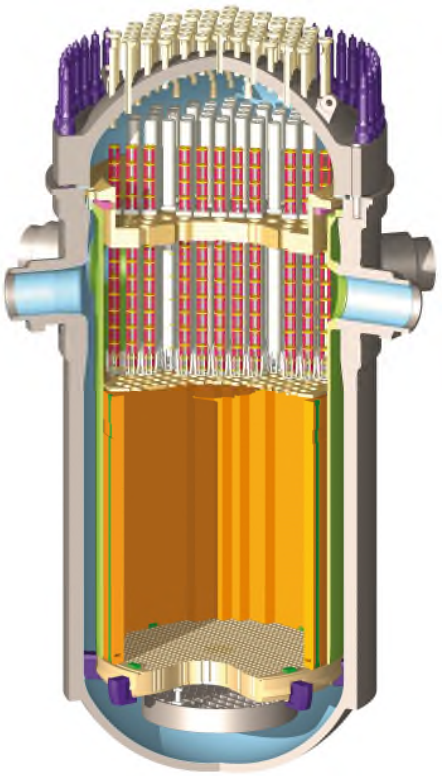
Challenge

- As the demand for electrical power continues to rise, extending the operational lifetime of nuclear power plants becomes increasingly crucial.
- Traditionally, nuclear plants have been designed for a 40-year operational life, but with advancements in technology and safety, these lifespans are now being extended, often to 60 years and potentially beyond 80 years.
- However, the lifetime of a nuclear power plant is largely constrained by the design limitations of its components.
- While many components can be refurbished or replaced, the Reactor Pressure Vessel (RPV) is an exception, making it the most critical and vulnerable component when it comes to lifetime extension and Long-Term Operation (LTO).
- Reducing fast neutron that causes embrittlement is essential to extend the RPV's operational lifetime.

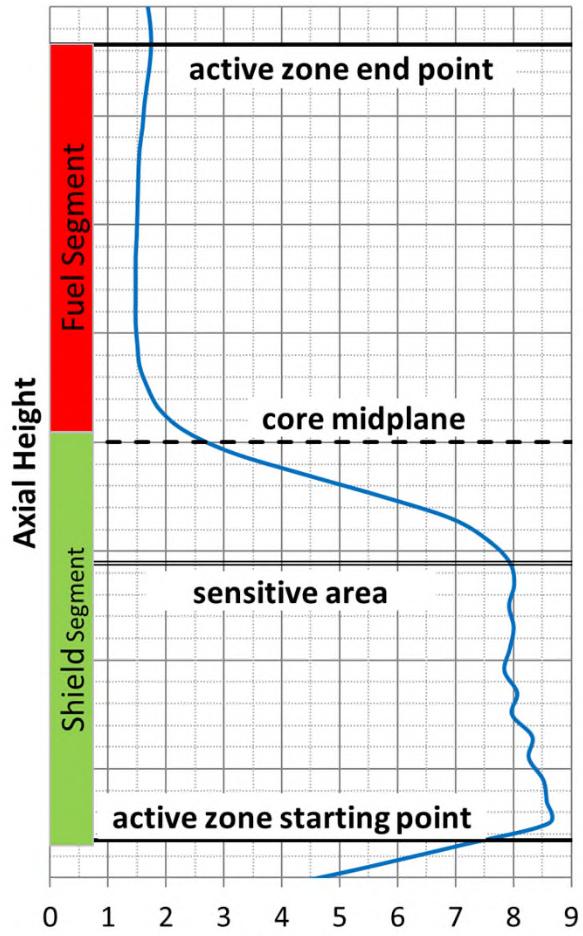


Solutions

- A key strategy for reducing fast neutron fluence at the RPV involves
  - either the implementation of **Shielding Fuel Assemblies (SFAS)** in the reactor core
  - or the insertion of **flux depressor assemblies (FDAS)** in the fuel assemblies at the periphery of the core.

- The **SFAs** can be customized to provide adjustable, in general medium to very high, reduction of the neutron fluence at any elevation or at specific axial location.

- The **FDAs** can be considered when a medium level of reduction of the neutron fluence is requested at all axial locations.

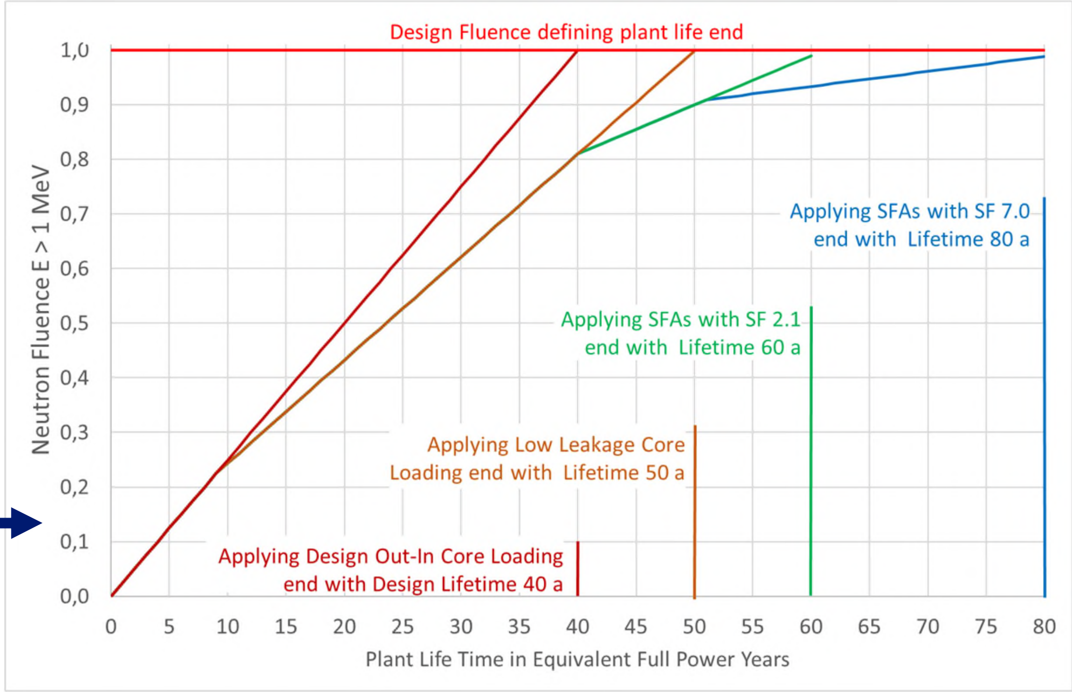


$$Shielding\ Factor = \frac{neutron\ flux\ with\ SFAs\ or\ FDAs}{neutron\ flux\ without\ SFAs\ or\ FDAs}$$

Neutron Flux

$$SF = \frac{neutron\ flux\ with\ SFAs\ or\ FDAs}{neutron\ flux\ without\ SFAs\ or\ FDAs}$$

- If the limiting fluence can not be changed, one must change the flux on the critical area
- → Shielding Factor or SF = factor of lifetime scale
- Reduction of the neutron flux by:
  - Low Leakage loading patterns
  - Applying Flux Depressor Assemblies or Shielding Fuel Assemblies with smooth shielding factor
  - Applying Shielding Fuel Assemblies with high shielding factor
- Example for Design Fluence 40 Full Power Years →
- In case of late application, anti-aging measure has to be highly efficient

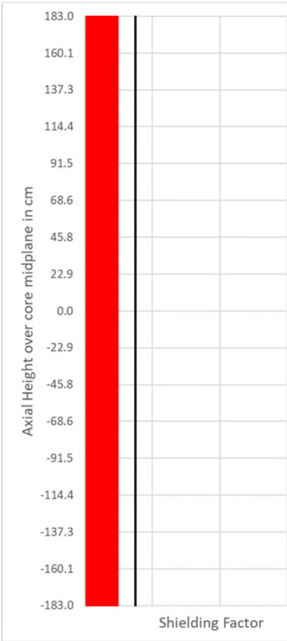


- SFAs = Shielding Fuel Assemblies
- FDAs = Flux Depressor Assemblies

Shielding Fuel Assemblies
Neutronic optimization

1

- Simple Design as a full-length shield bar



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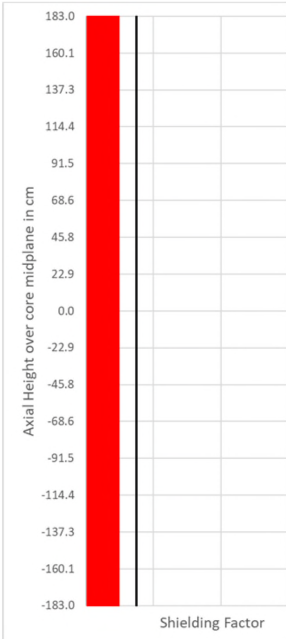
Shielding Fuel Assemblies
Neutronic optimization

1
- Simple Design as a full-length shield bar

2
- Or axial split if shielding is only needed in a specific axial height
  - o Example: for RPV beltline weld protection



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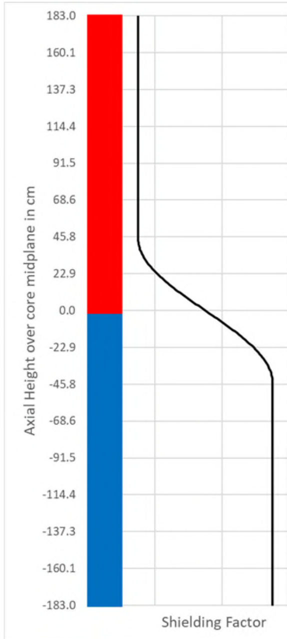

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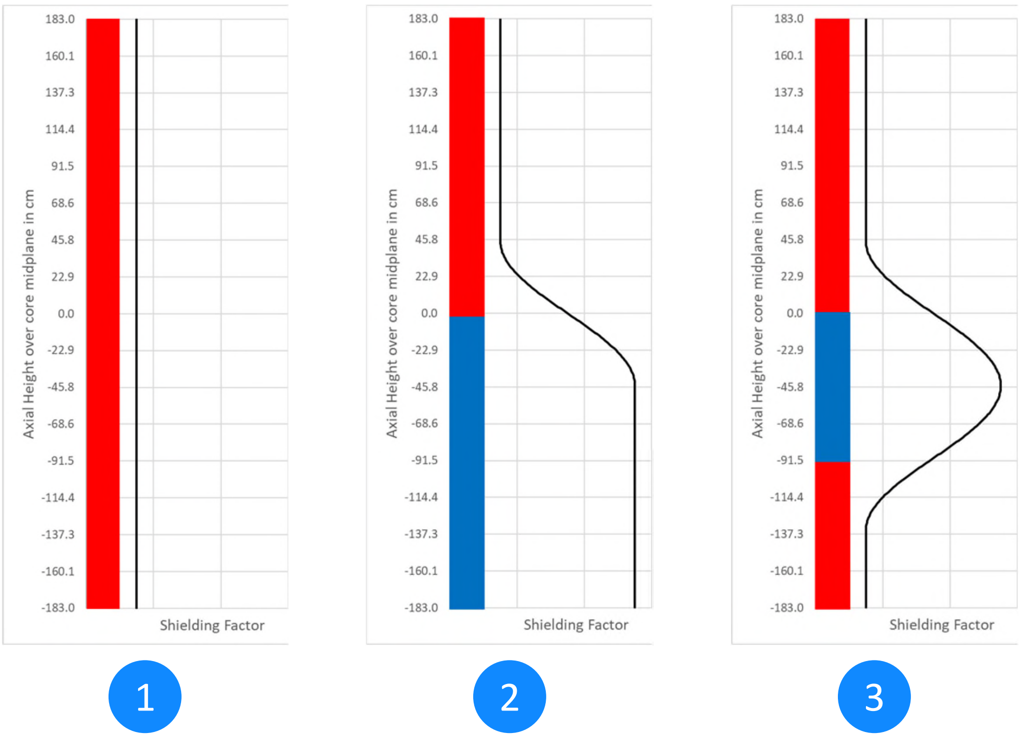
Shielding Fuel Assemblies
Neutronic optimization

1
- Simple Design as a full-length shield bar

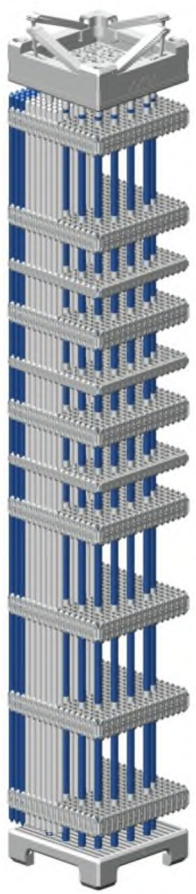
2
- Or axial split if shielding is only needed in a specific axial height
  - o Example: for RPV beltline weld protection

3
- Or three segmented design
  - o Modify axial placing of shield part
  - o Modify length of shield part

- ^{235}U Enrichment level can be adapted
- Axial design and radial design can be combined to provide the requested flux attenuation

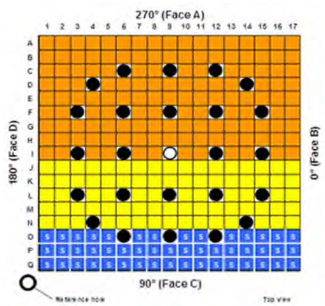


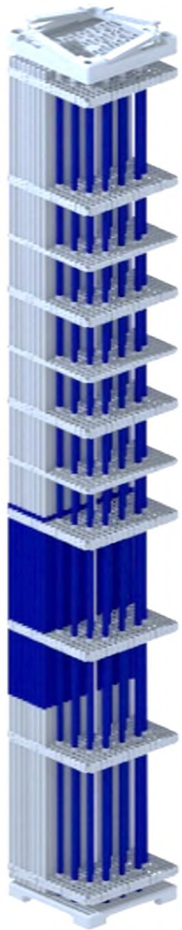
Shielding Fuel Assemblies
Examples of neutronic designs

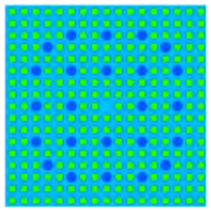


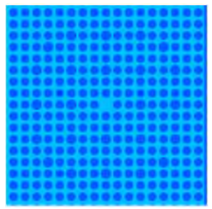
- Guide tubes made of solid steel bars
- 9 rows of fuel rods with 1.0 wt-% 235U
- 5 rows of fuel rods with 0.2 wt-% 235U
- 3 rows of solid steel rods
- Axially homogenous
- No rotational symmetry

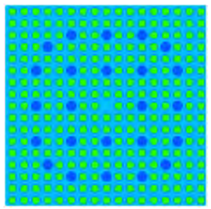
➢ Shielding factor ~ 2.0











- Guide tubes made of solid steel bars
- Top half fuel rods with 1.0 wt-% 235U
- Bottom half: axially 2/3 solid stainless-steel bars
- Bottom half: axially 1/3 fuel rods with 1.0 wt-% 235U
- Segments linked and mechanically fixed
- Rotational symmetry

➢ Shielding Factor > 7.0

Shielding Fuel Assemblies
Adaptable to customers needs

Adaptable Fuel Assembly Designs:
- Compatible with various fuel assembly designs e.g. HTP or GAIA
- Full fuel handling machine compatibility
- High fuel assembly dimensional stability thanks to solid steel bars instead of guide tubes
- Available with PROtect technologies

Adaptable Shielding Designs:
- Variable Shielding Factor: < 2 to > 7.5
- 235U enrichment adaptable according to:
  - Required fuel economics
  - Optimizations regarding Core Design
  - Lifetime of Shielding Fuel Assemblies

Lifetime:
- Up to 8 consecutive cycles

Customer benefits from:
- Easy implementation of shielding fuel assemblies during outage
- Significant neutron flux reduction on desired areas
- Delivering period comparable like for normal Fuel Assemblies
- Easy justification process through core design evaluation and high-resolution neutron fluence analysis
- Core design evaluation including all documents for licensing

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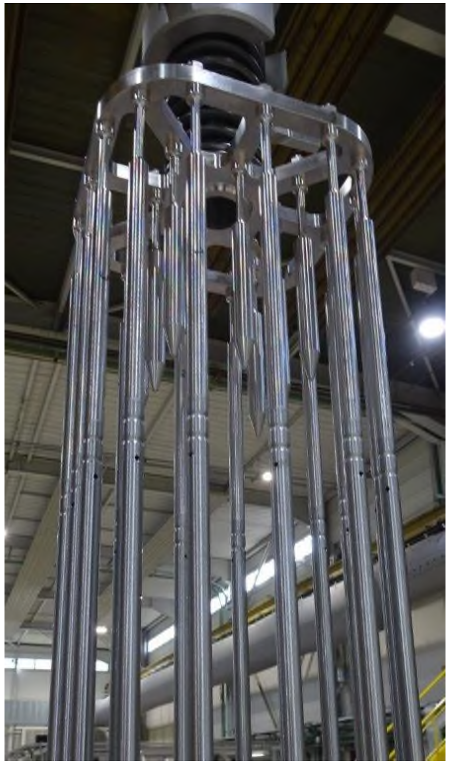
Flux Depressor Assembly

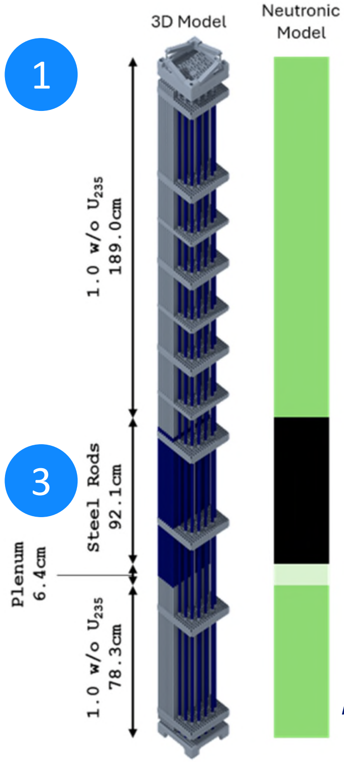
- Flux Depressor Assemblies constitute an alternate solution for low to medium fast neutron flux attenuation
- Framatome Flux Depressor Assemblies are based on Hafnium which is a by-product of the Zirconium chemistry
- Hafnium Flux Depressor Assemblies (HFDAs) are inserted in fuel assemblies at the periphery of the core where the neutron flux needs to be reduced
- HFDAs are composed of*:
  - A spider derived from the Thimble Plug Assembly spider
  - 16 long absorber rods made of Hafnium bars connected to a short stainless-steel bar
  - 8 short stainless-steel rods in central positions to limit the by-pass through the guide tubes
- HFDA typical lifetime is ~20 years
- Flexible design easily adaptable to all types of PWR reactors

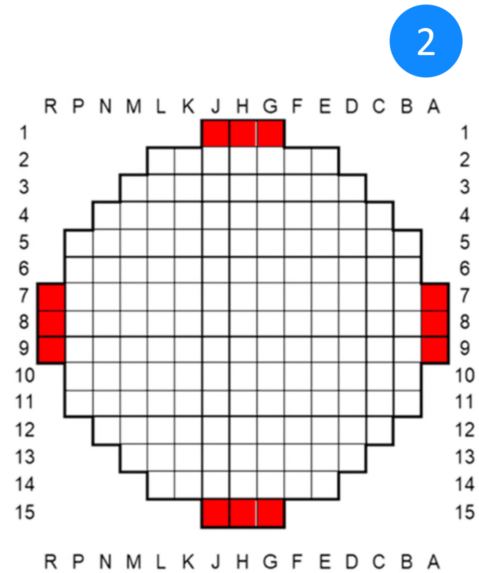


**: example for Framatome 17x17 reactor.*

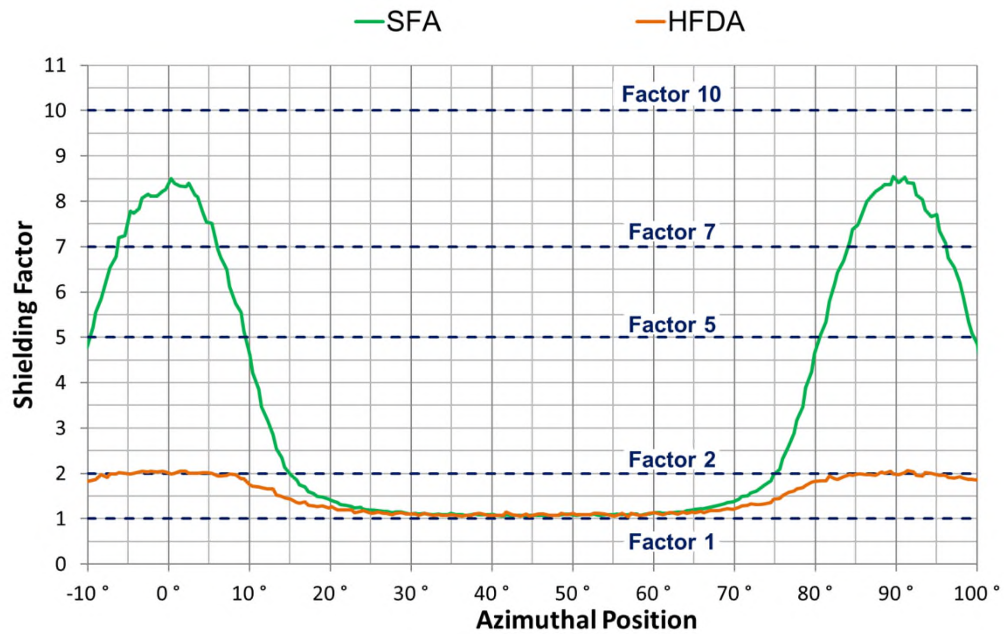
Efficiency of SFA and HFDA

- **Shielding Fuel Assemblies (SFA)** offer **medium to very high** reduction of the neutron fluence at any elevation or at specific axial location
- **Hafnium Flux Depressor Fuel Assemblies (HFDA)** offer **medium level** of reduction of the neutron fluence is requested at all axial locations.





Example of Axial Geometry of the SFA (1) and the positions (red) of the SFA in the core (2)



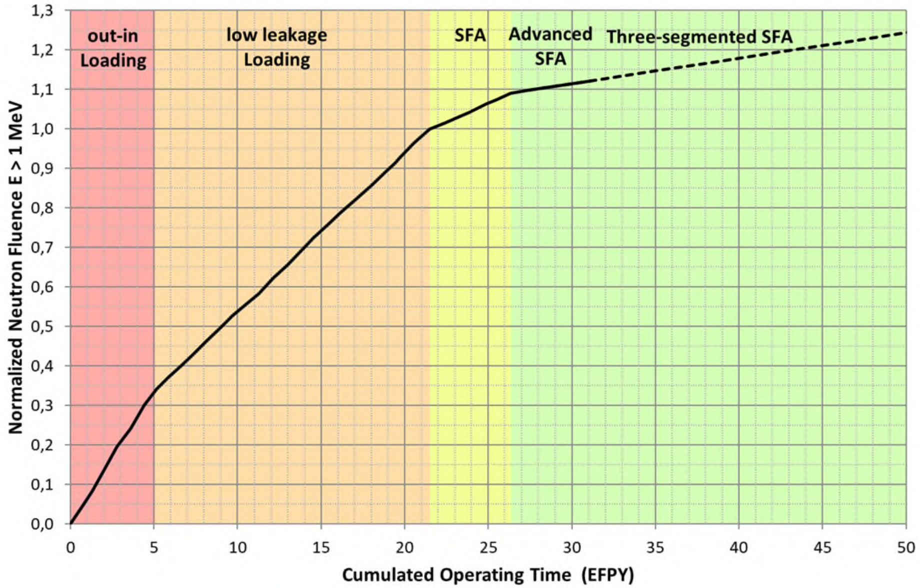
Azimuthal Shielding Factor for the SFA and HFDA at the elevation of steel rods (3)

Conclusions

- Shielding Fuel Assemblies
  - For high flux attenuation
  - 32+ cycle operation experience
  - Shielding fuel assemblies' grant value in plant lifetime extension
  - Design adaptable to all NPPs

- Hafnium Flux Depressor Assemblies
  - For medium and homogenous axial flux attenuation
  - Design adaptable to all NPPs

- Framatome know-how in optimizing the design and manufacturing is key to ensure long term operation



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