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Online neutron measurement systems for in-vessel monitoring in fission reactors: applicability to breeding blankets of DEMO

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Outline

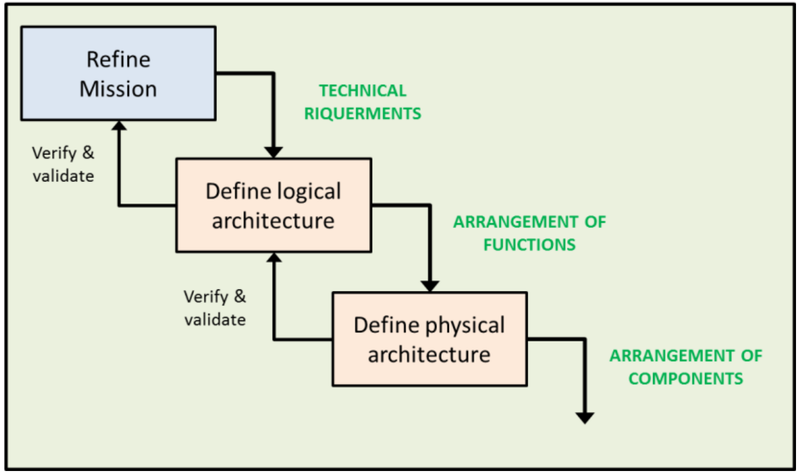
- Design strategy for neutron measurement systems in fission reactors
- The case of DEMO breeding blankets
- Similarities/differences with fission reactors
- State of the art of some detectors, blocking points for BB use

Neutron flux follow-up in fission reactors

- ❑ Requirement: real time, reliable, easy to interpret (i.e. linear)

- ❑ Dependability = reliability x maintenability
  - ➢ Can be inserted (think about the cable path!)
  - ➢ Stringent constraints (temperature, corrosion…)
  - ➢ Self-diagnosis
  - ➢ Sensitivity to parasitic signals (e.g. activation gamma)

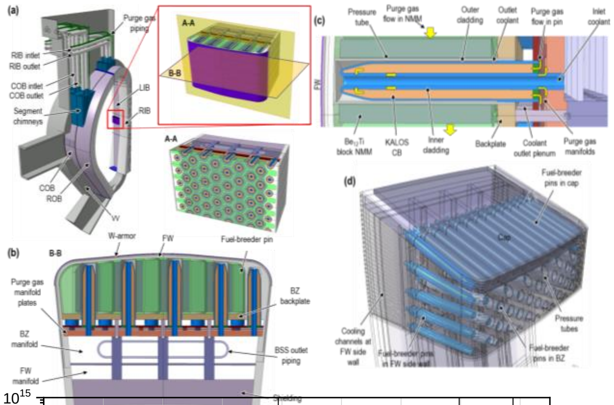
SYSTEM DEFINITION METHODOLOGY

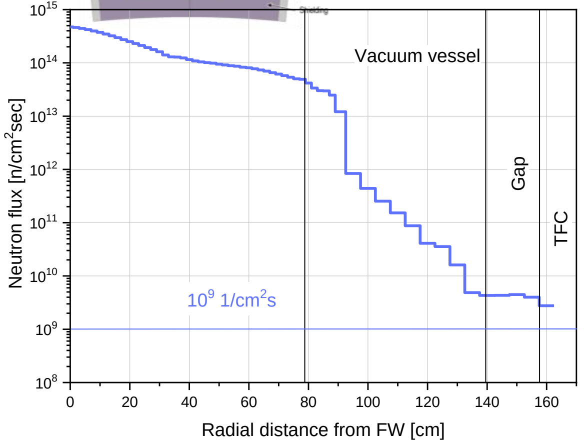


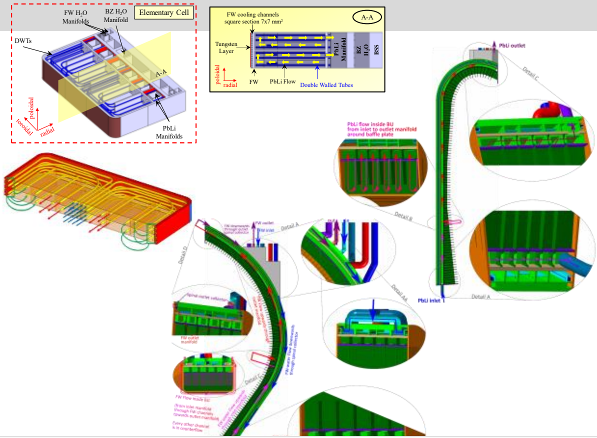
$\Rightarrow$ Designing a measurement system includes:

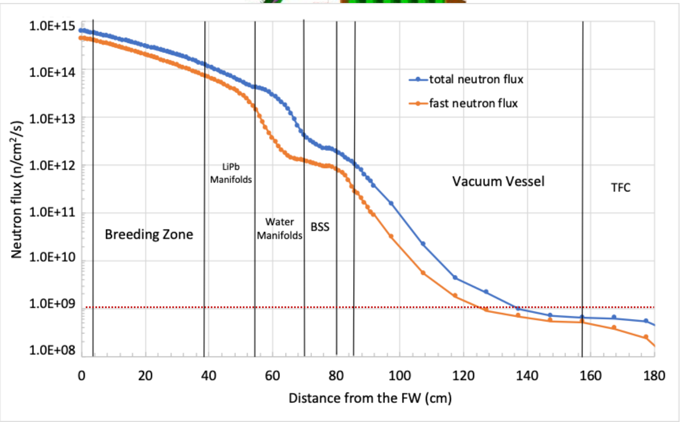
- $\Rightarrow$ A comprehensive physical description/simulation of the the system
- $\Rightarrow$ An assessment of the performances/constraints
- $\Rightarrow$ And then we can look for what we have on the shelf, and what to improve…

Input data on HCPB and WCLL of DEMO









Bachmann C. PDD plant description document. - 2021. - EFDA_D_2KVWQZ

Del Novo A. et al. WCLL Design Report. - 2018. - IDM EFDA D 2NUPDT

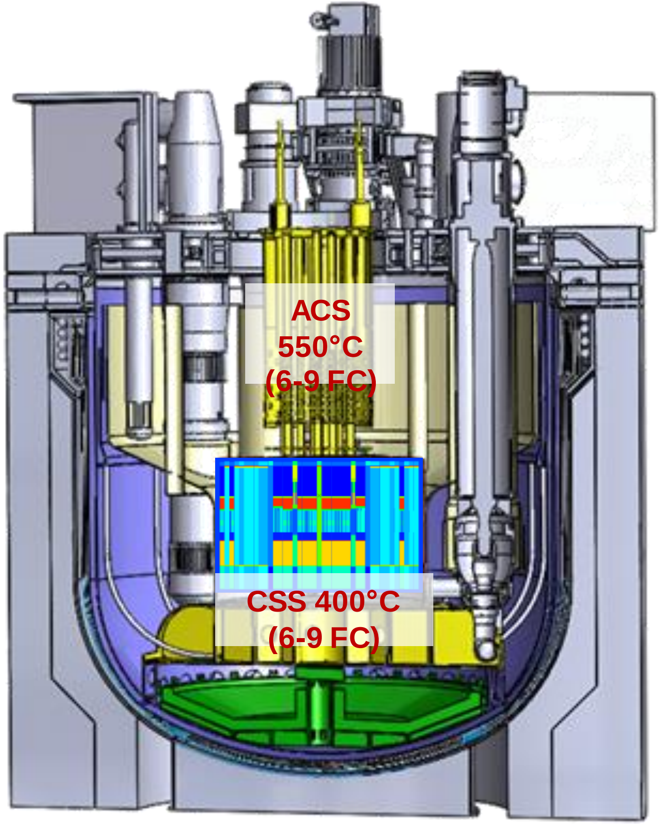
Hernandez F. et al. Final report on HCPB design and integration studies 2019. - 2020. - IDM EFDA D 2NKC7G

Tentative performances/constraints for BB

N flux measurement uncertainty	10%
N flux spatial distribution	10% everywhere
Temporal resolution	1 s
Dynamic range	10^{14} n/cm²/s down to 5 decades, DD/DT
Lifetime and maintenance	3 years (same as BU)
Bonus: spectral discrimination	(^{6}Li(n,α)t and ^{7}Li(n,n' α)t)

N flux	10^{14} n/cm²/s at FW
Gamma flux	10^{14} γ/cm²/s at FW
Radiation dammage	9.5 DPA/FPY at FW
Magnetic field	3 – 8 T
Steric constraints+cable passage	Sensors of few mm
Temperature	600°C, highly dependent on location

Something close to BB within fission reactors : monitoring in ASTRID



❑What is common with BB:

- n/gamma level : $10^{10\text{-}15}$ cm²/s
- Need for spatial coverage
- Temperature 400-900°C

❑What differs, but not that much:

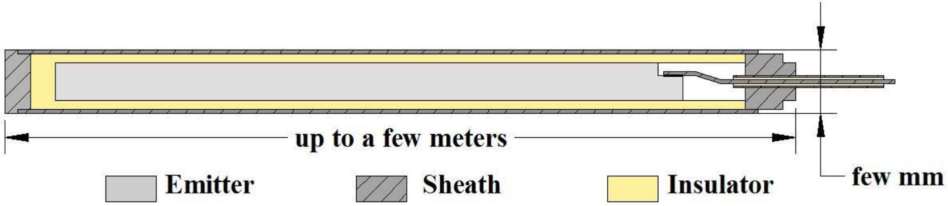
- Cable passage (through vessel plug)
- Integration from design phases of the reactor, not after!
- Lifetime (several reactor cycles)

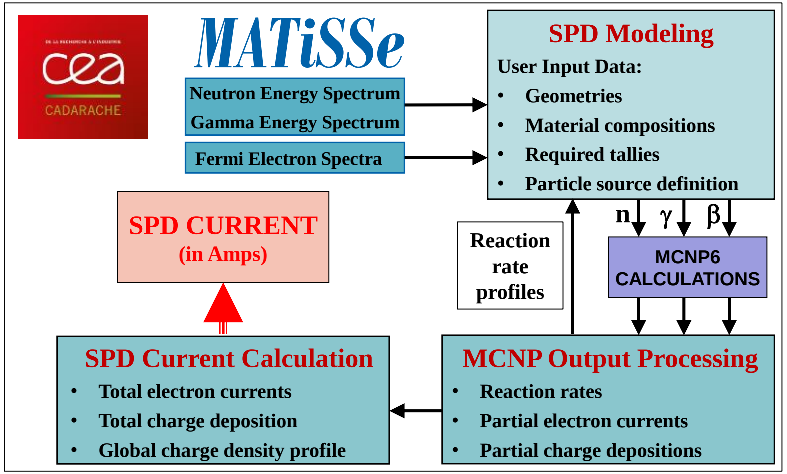
❑What is absent:

- Magnetic field

Self-powered neutron detectors (SPND)

- State of the art
  - ❑Cheap, robust
  - ❑Simulation toolbox (Matisse)
    - L. Barbot et al., ANIMMA 2017, 170, 08001
  - ❑Platinum: almost real time linear response in Astrid centre
    - V. Verma et al., NIM A 880 (2017) 6
- Blocking points for BB use
  - ❑Extension to fast neutrons
    - PhD underway for JHR use
  - ❑Sensitivity to activation gamma
    - need for detailed computations
  - ❑Limited dynamics



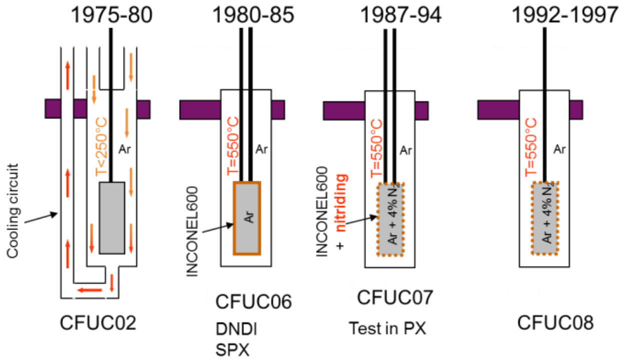


High-temperature fission chambers (HTFC)

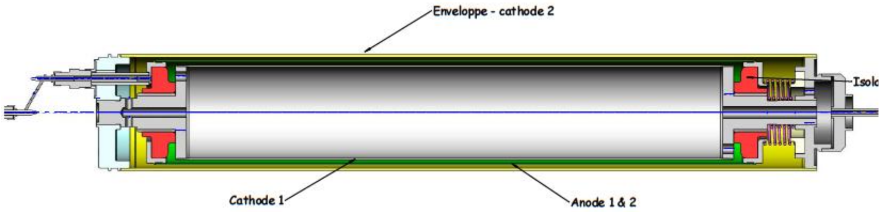
State of the art

- ❑ Several decades experience
- ❑ Computation of evolution of fissile coating
  - P. Filliatre et al., NIM-A 593 (2008) 510
- ❑ Various deposits/spectral discrimination (Chicade facility)
- ❑ Simulation of neutron/gamma signals in all modes
  - P. Filliatre et al., NIM-A 678 (2012) 139 & 648 (2011) 228
- ❑ High dynamics (8 decades, precision 5%, experimental validation done at MINERVE)
  - Z. Elter et al., NIM-A 835 (2016) 86
- ❑ Use up to 800°C experimentally validated (LINAC + oven)
  - H. Hamrita et al., NIM-A 848 (2017) 109

Former designs



Re-design for ASTRID

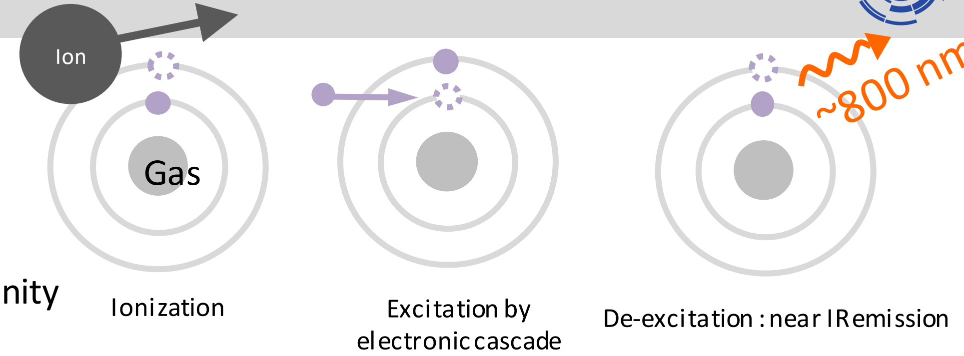


J-C. Nappé et al. (Photonis)

Blocking points for BB use

- ❑ Leakage current when miniaturizing.
  - Qualified chambers of 7mm, but not below.
- ❑ Magnetic field effects on moving electric charges
- ❑ Hardness to radiation field

Optical fission chambers (OFC)

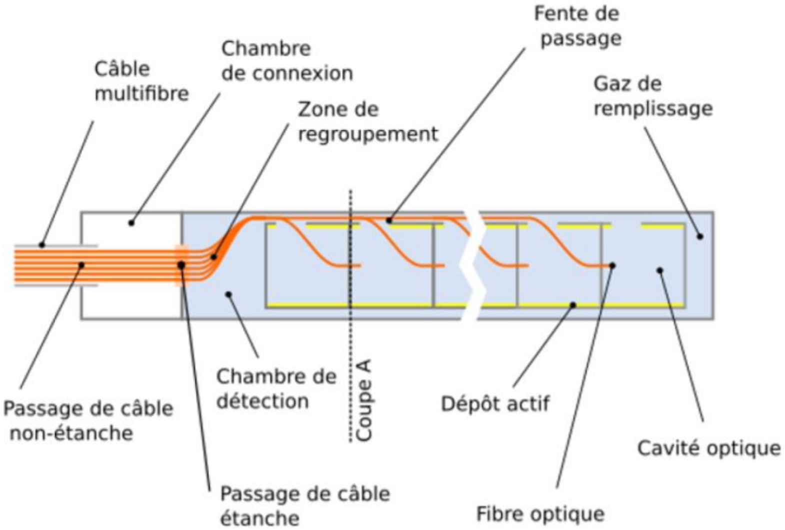


State of the art

- Innovative concept
  - M. Lamotte, PhD thesis, UGA, 2021
- Developed for neutron flux monitoring in MSR
- Optical transduction: perfect electromagnetic immunity
- Various deposits/spectral discrimination
- Excellent linearity by physics
- High dynamics (7 decades, experimentally validated)

Blocking points for BB use

- Sealing of the feed-through with a bundle of optical fibres
- Thermal (blackbody) noise rejection
  - experiments with an oven and neutron sources



Conclusions

- Many efforts for fission instrumentations are beneficial for fusion:
  - General design/integration strategy
  - Demanding environments (temperature, high flux…)
  - Innovative detectors
- Some specificities require specific efforts
  - Integration
  - Magnetic field
- Future: theoretical/simulation + experimental studies
  - Laboratory scale
  - Dedicated campaigns with facilities partially representative of the DEMO conditions

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