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Interpretation of the ASPIS and JANUS shielding experiments

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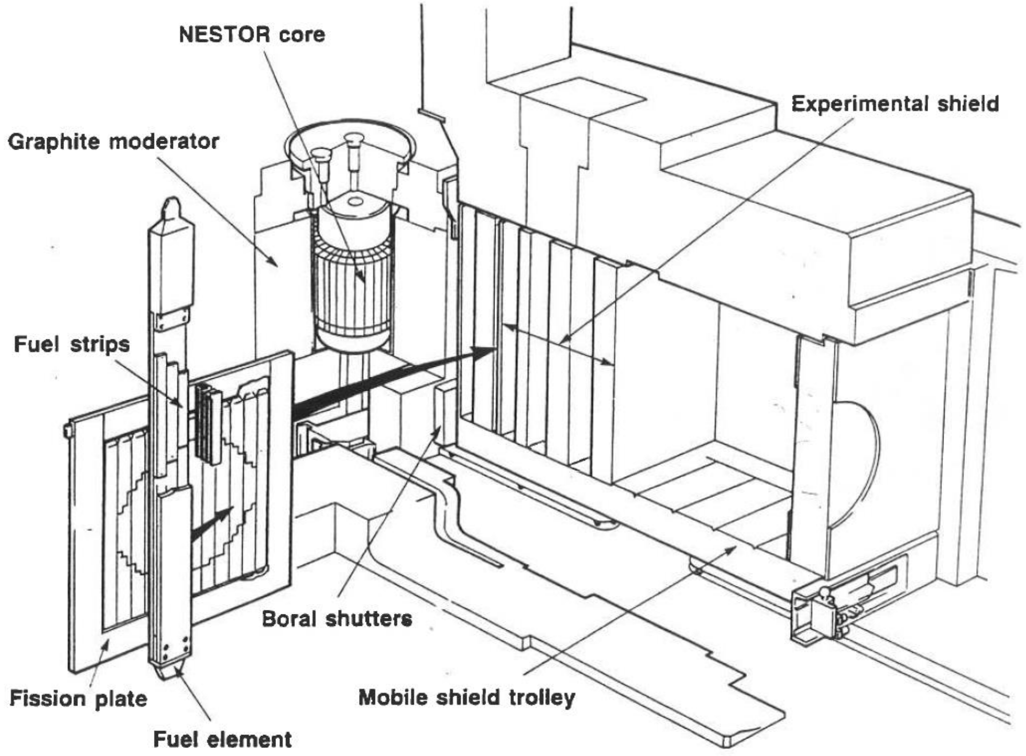
Importance of neutron shielding: leaking neutrons may have several consequences

- Activation of sodium in the secondary loop: gamma dose on the personnel complicating maintenance operations
- Damage on the reactor vessel and structures: impact on the lifetime of the reactor
- Size of neutron shielding affects that of the reactor vessel and therefore the cost of the reactor

Reliable calculation tools are therefore necessary in order to design efficient neutron shielding

As part of the VVUQ methodology, experiments are needed to validate the calculation tools and the used nuclear data

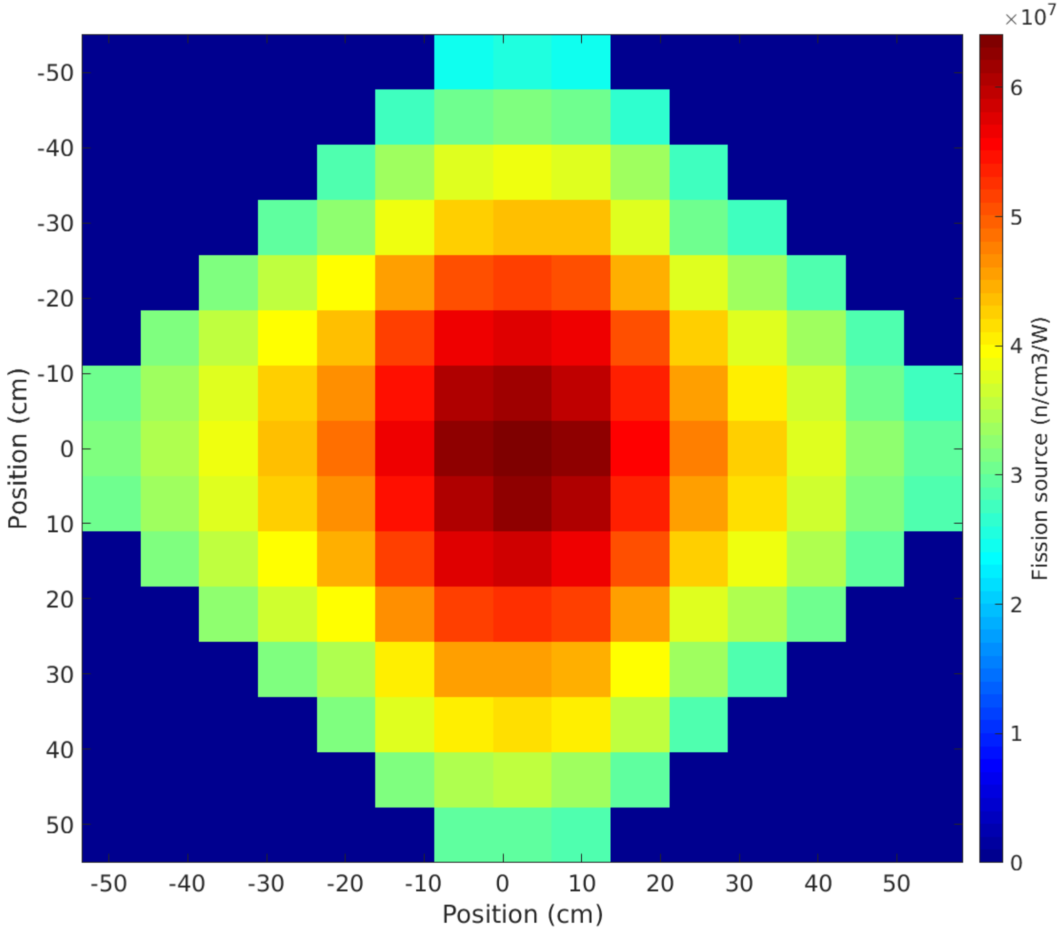
The ASPIS and JANUS are a set of experiments realised on the NESTOR reactor in Winfrith, United Kingdom, during the late 1980's and early 1990's



NESTOR is a graphite-moderated water-cooled termal reactor with a thermal power of 30 kW

An experimental zone is installed beyond the graphite reflector of the reactor

Inside the experimental zone, a fission plate made of highly enriched uranium-aluminium alloy is installed



Thermal neutrons leaking from the reactor induce fissions in this plate

The fission plate is followed by a shielding zone composed of several layers of different materials: steel, boron carbide and sodium

Activation detectors are placed between two successive layers

The following experiments are studied:

- ASPIS Iron 88: around 65 cm of mild steel
- JANUS Phase 2: around 20 cm of mild steel, 20 cm of stainless steel and 90 cm of Na
- JANUS Phase 7: around 20 cm of mild steel, 50 cm of B4C, 90 cm of Na

The following detectors are interpreted:

- ^{197}Au (n, γ) ^{198}Au under cadmium: Epithermal reaction
- ^{32}S (n,p) (n, p) ^{32}P: > 900 keV threshold reaction

The experiments are interpreted with the TRIPOLI-4® Monte-Carlo calculation code

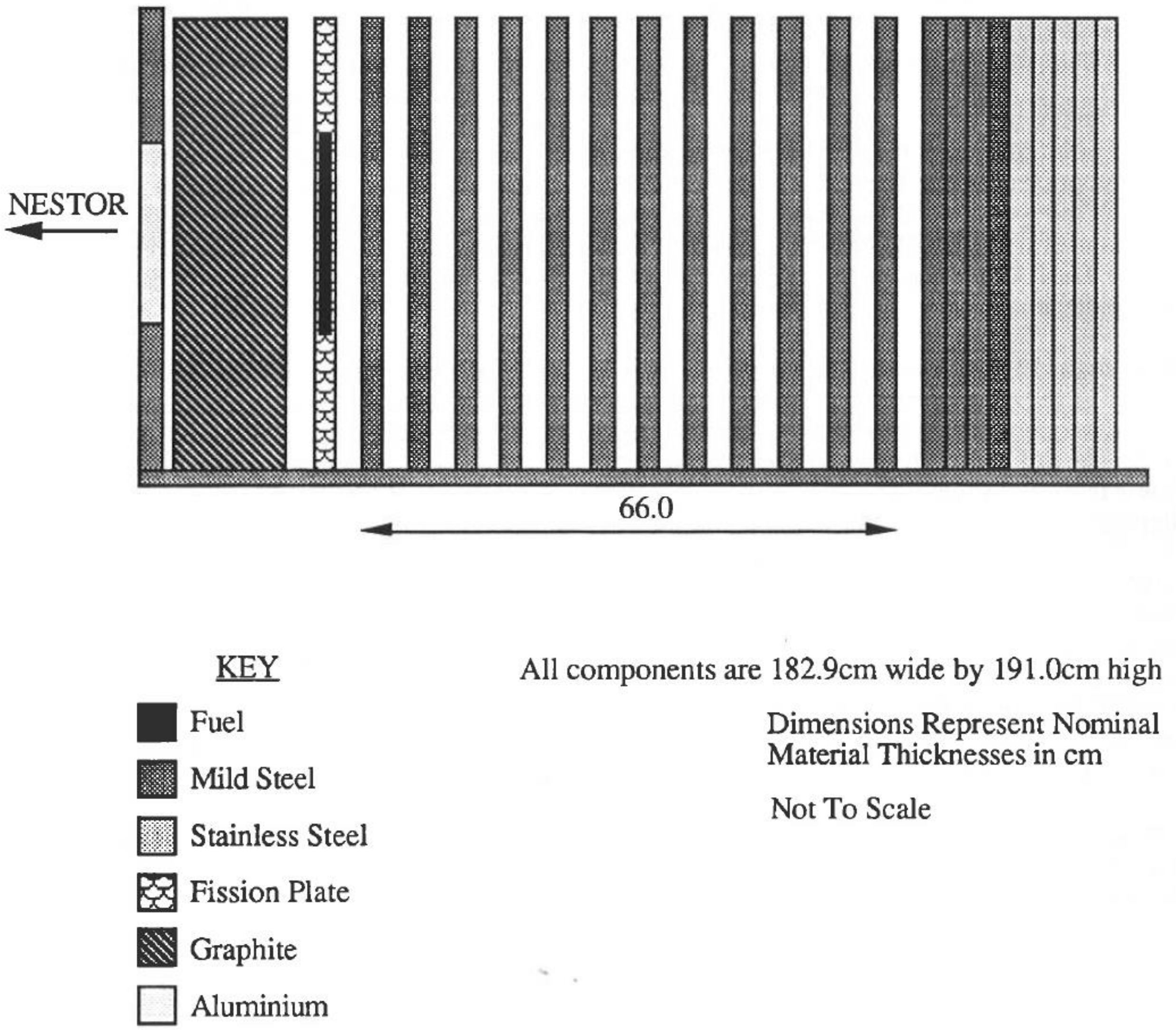
Several nuclear data are used:

- JEFF-3.1.1
- JEFF-3.2
- JEFF-3.2 + Fe56 of ENDF/B-VIII.0
- JEFF-3.2 + Fe56 of JENDL-4.0
- JEFF-3.2 + Angular distributions of JENDL-4.0 for Fe56

The following activation libraries are used:

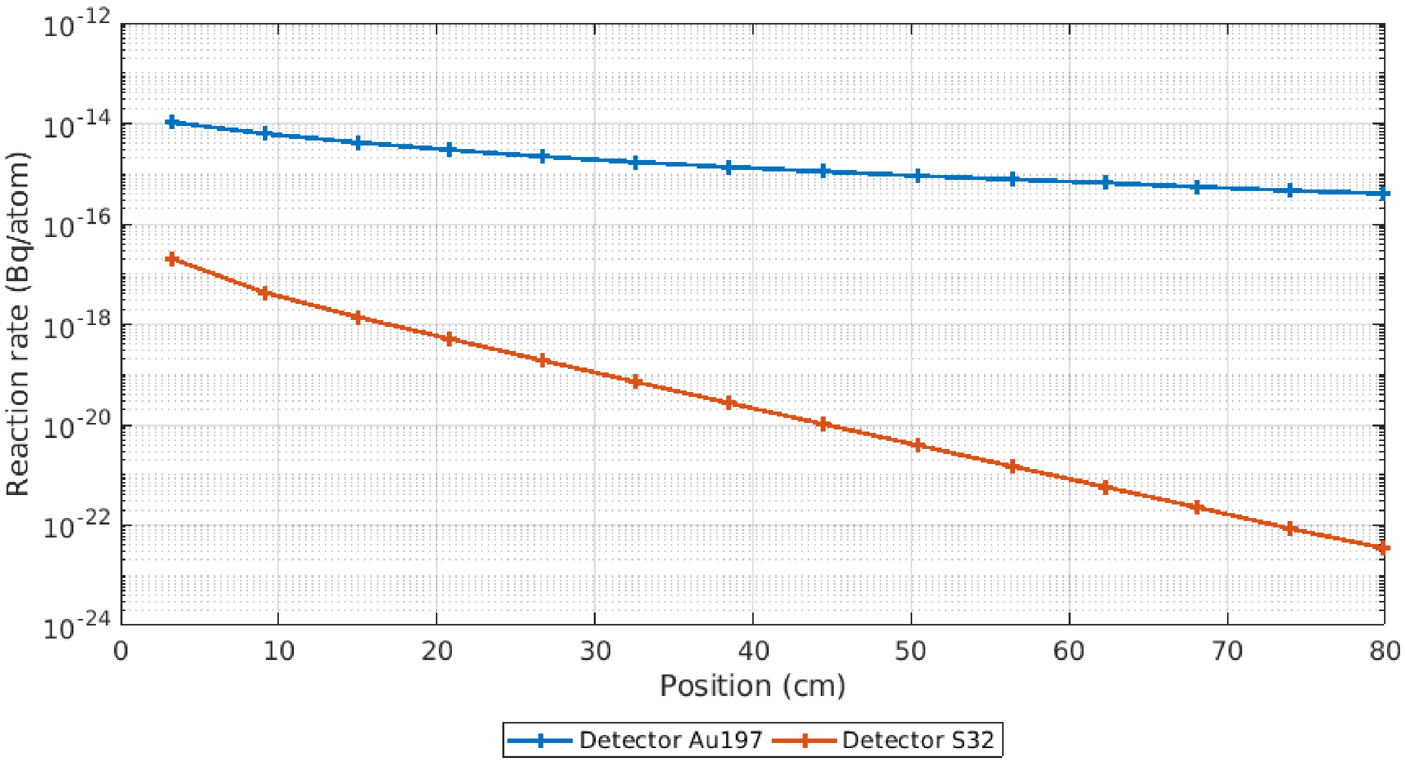
- IRDFF-1.05
- EAF-2010

The ASPIS Iron 88 experiment



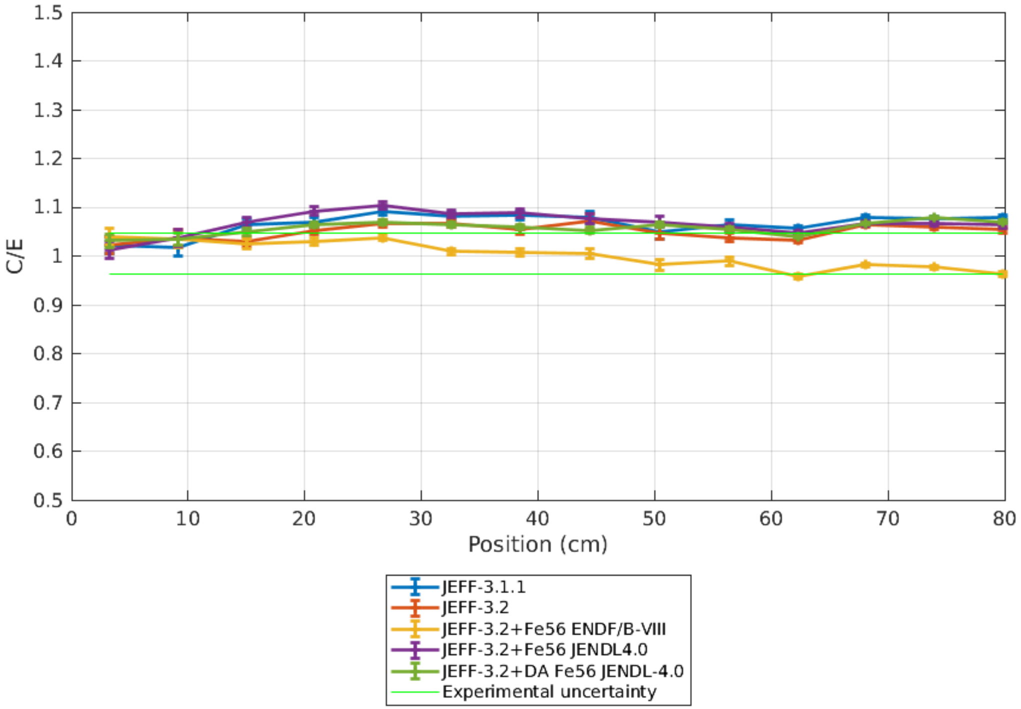
- The steel plates are around 5 cm thick
- The steel used is more than 99 % iron and less than 1 % carbon and manganese

Measured reaction rates



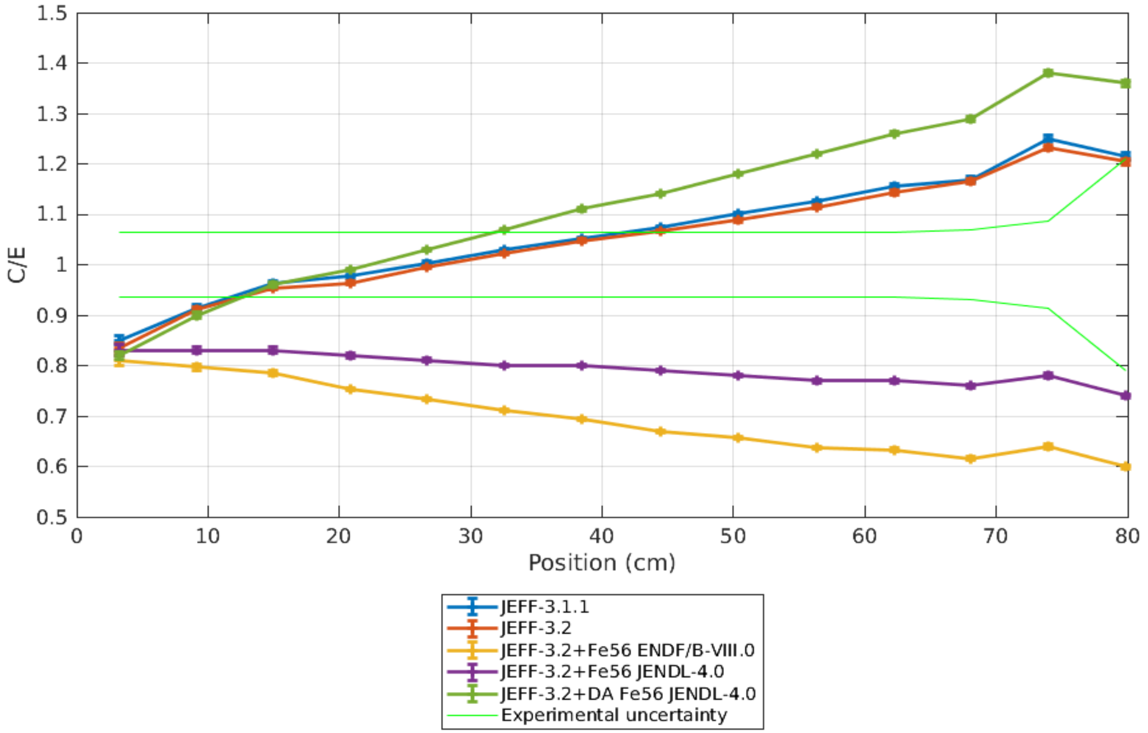
Slow decrease for the gold detector (2 decades) fast decrease for sulphur detector (6 decades)

The results obtained with the gold detector using the IRDFF-1.05 activation library



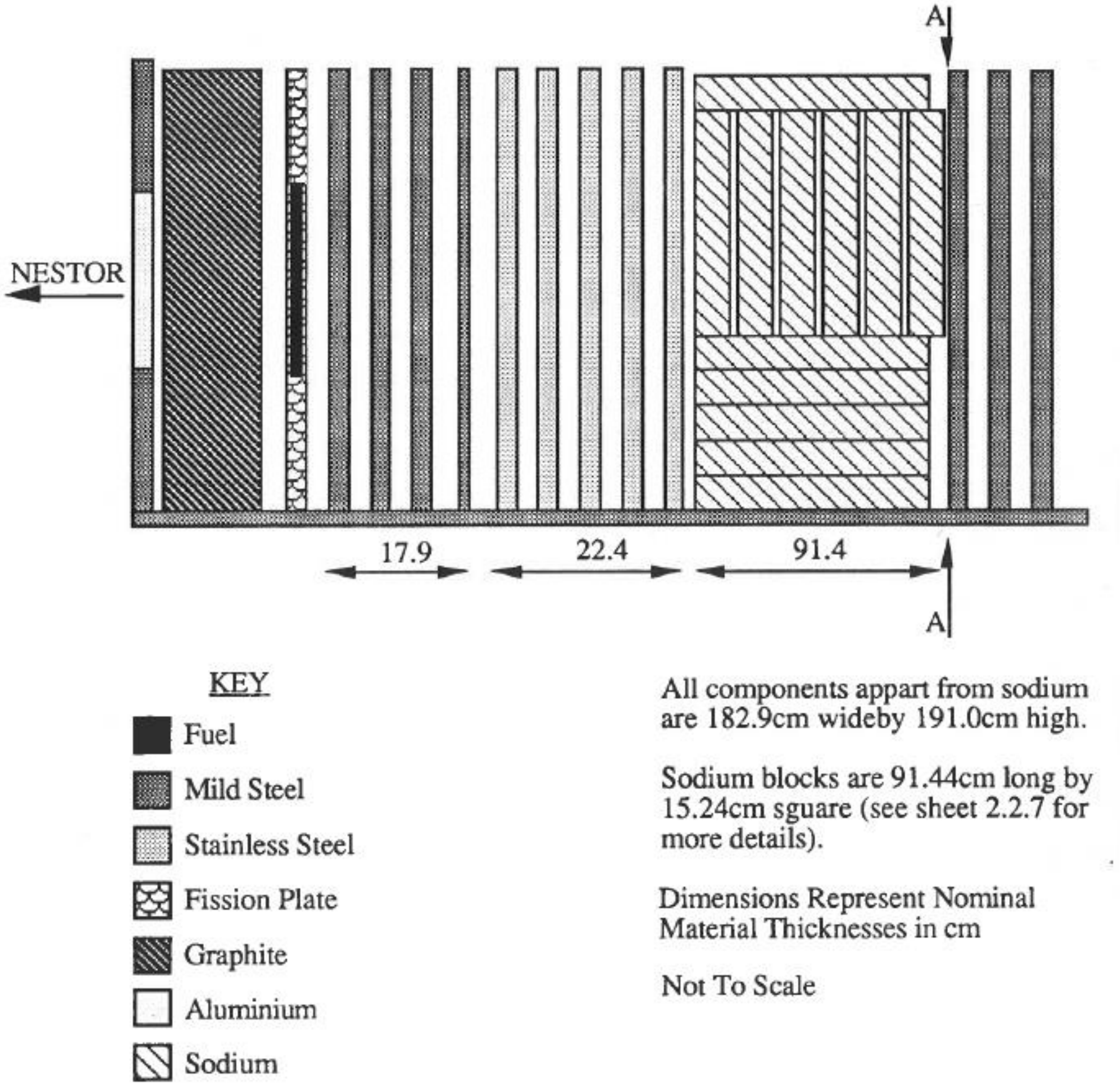
- Relatively low biases in comparison to the experiment with all nuclear data libraries

The results obtained with the sulphur detector using the IRDFF-1.05 activation library



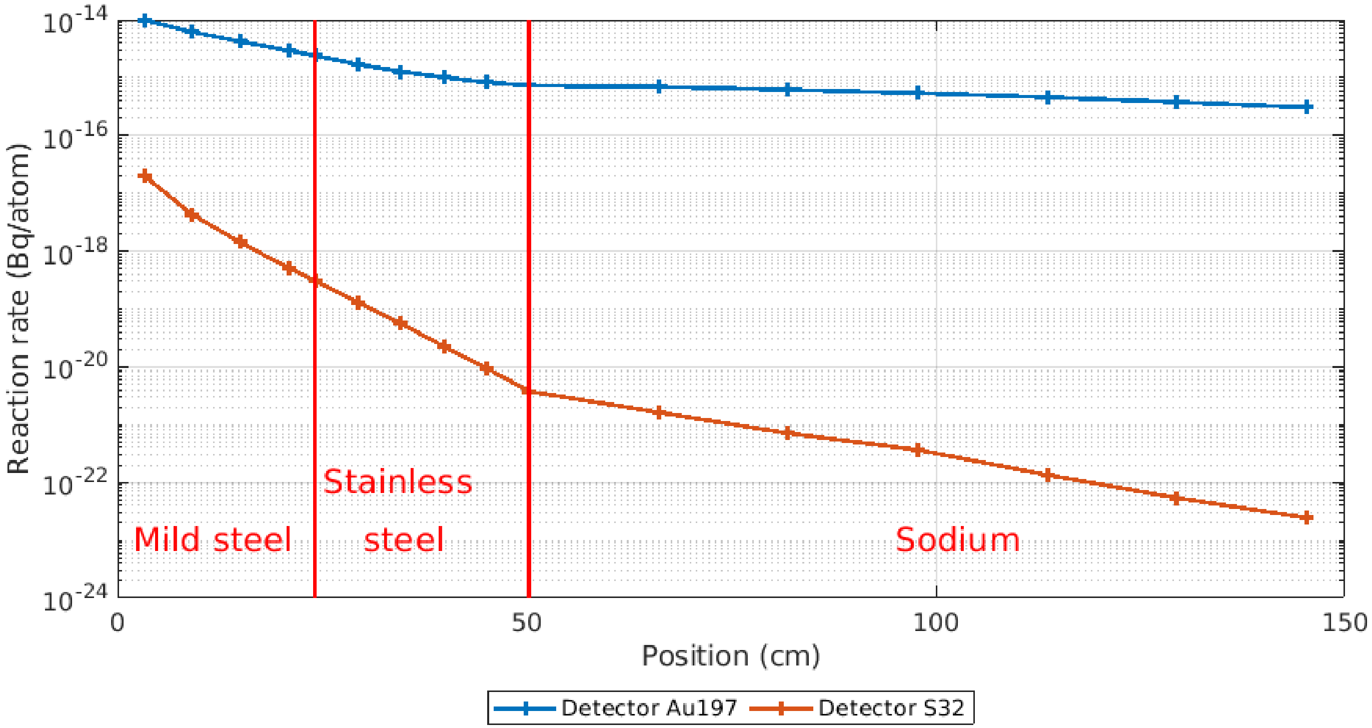
- Large biases obtained in comparison to the experiment
- Large dependence to the nuclear data library used, JEFF ↗, ENDF ↘, JENDL →
- Dependence to the angular distributions of iron 56

The JANUS Phase 2 experiment



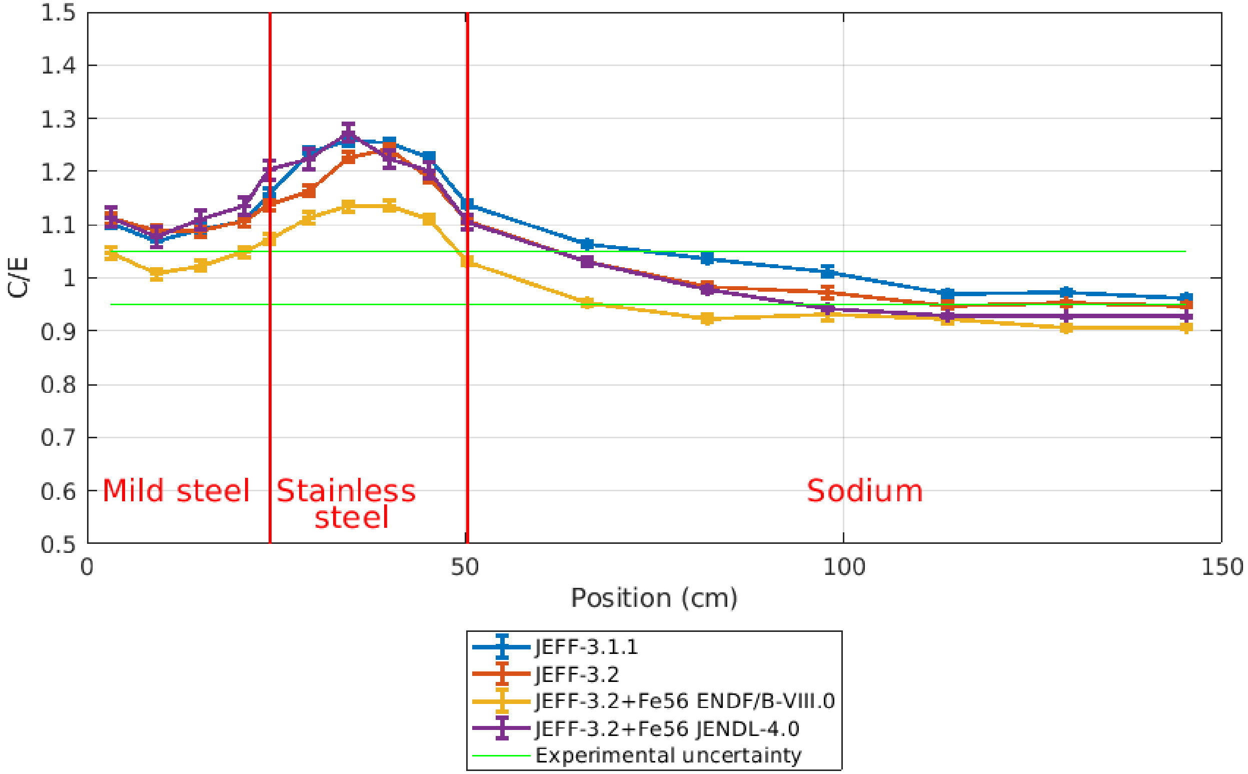
- Mild steel is the same that has been used in ASPIS Iron 88
- Stainless steel contains also chromium, nickel among others
- Sodium is put in steel boxes that are around 90 cm × 15 cm × 15 cm

Measured reaction rates



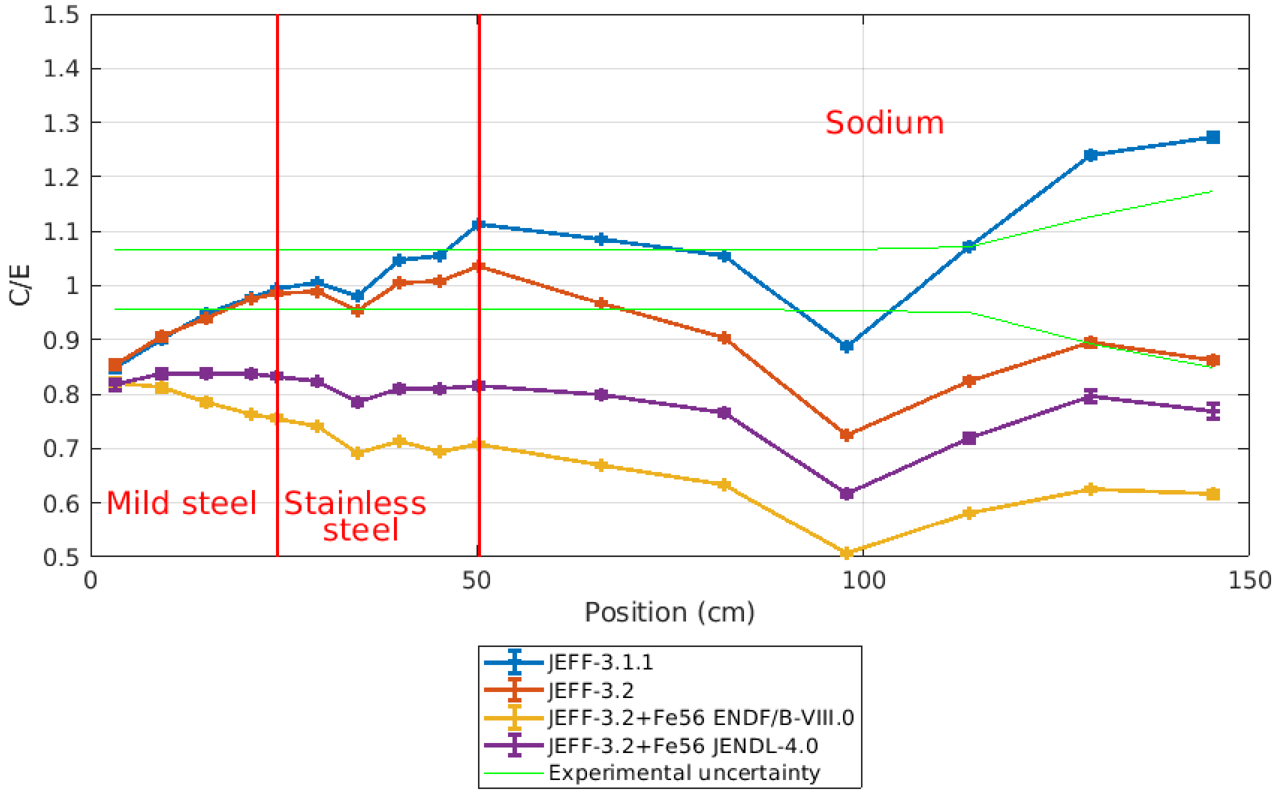
Slower decrease in sodium than in steel for both detectors

- The results obtained with the gold detector using the IRDFF-1.05 activation library



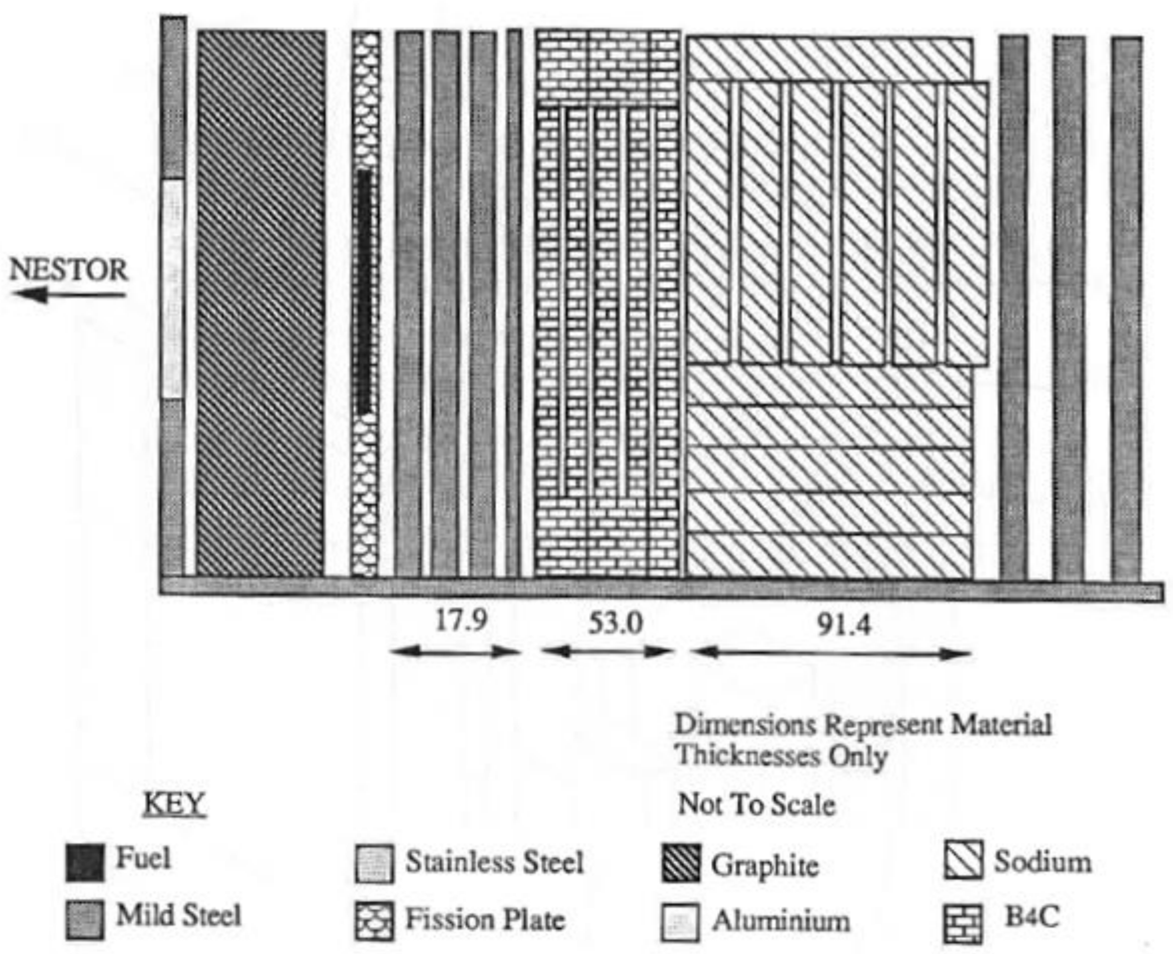
- C/E close to 1 except in stainless steel: problem with XS of Cr, Ni, or others ?
- Small dependency to XS of Na (JEFF-3.1.1 -> JEFF-3.2)

- The results obtained with the sulphur detector using the IRDFF-1.05 activation library



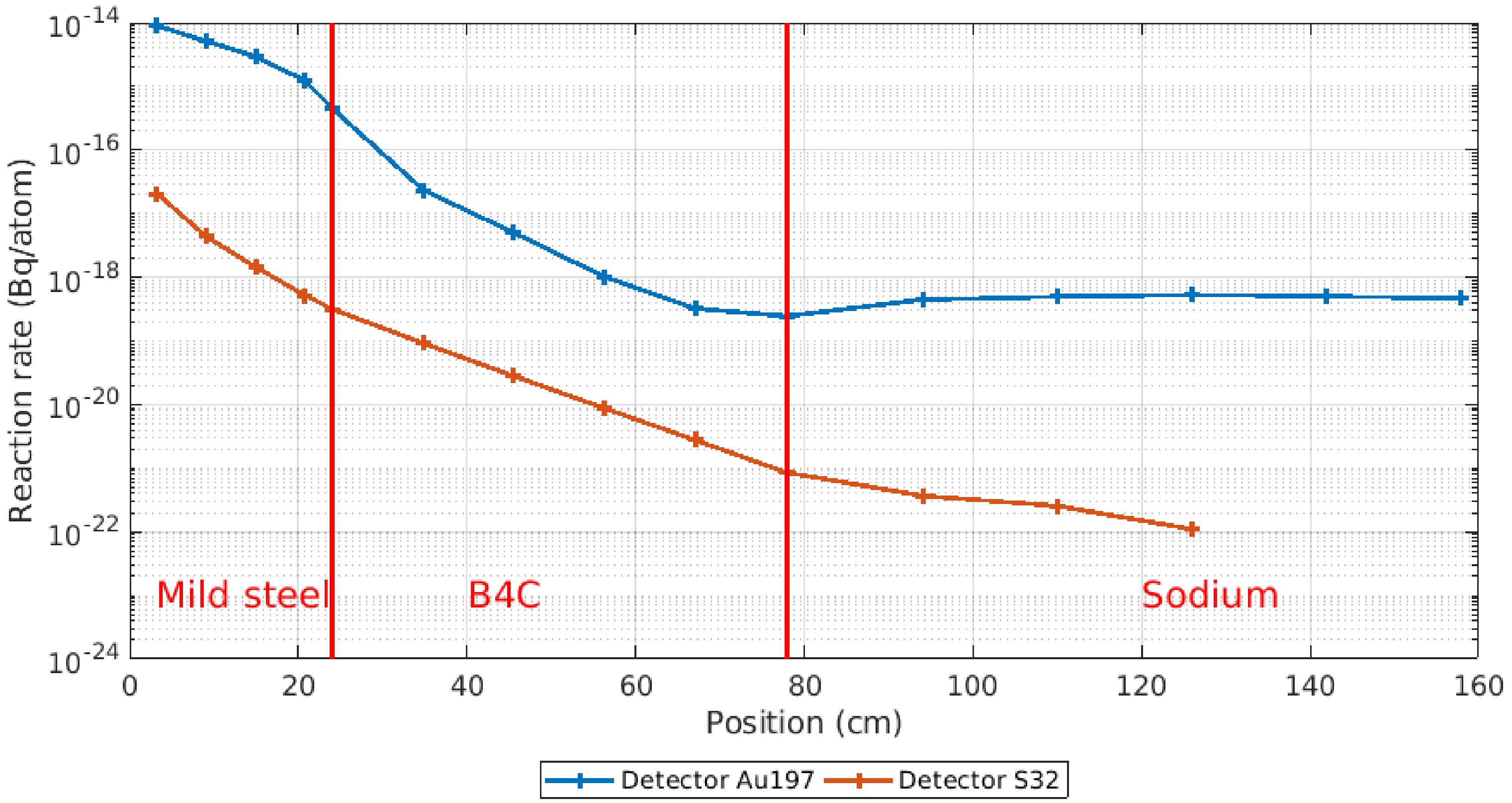
- C/E behaviour strongly varies with material and XS of both Na and Fe

The JANUS Phase 7 experiement



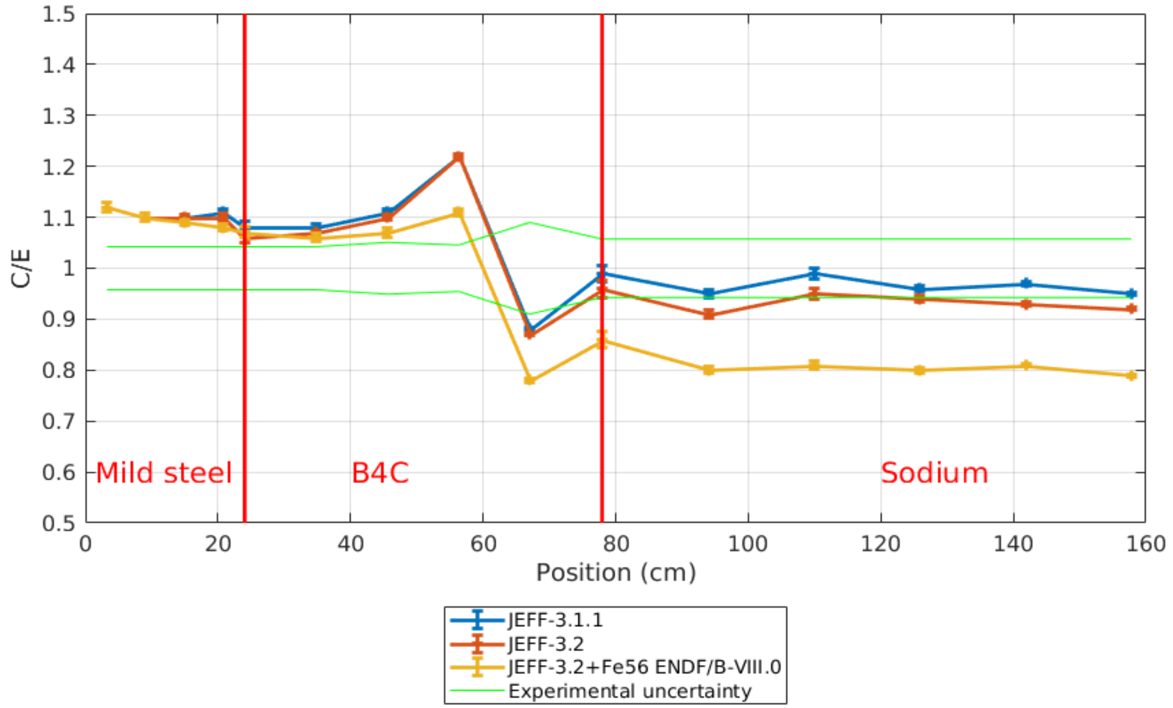
- The steel plates are the same as those used in the ASPIS Iron 88 experiment
- Sodium and boron carbide are put in steel boxes
- Boron carbide boxes are around 10 cm thick horizontally, and sodium boxes are around 15 cm thick

Measured reaction rates



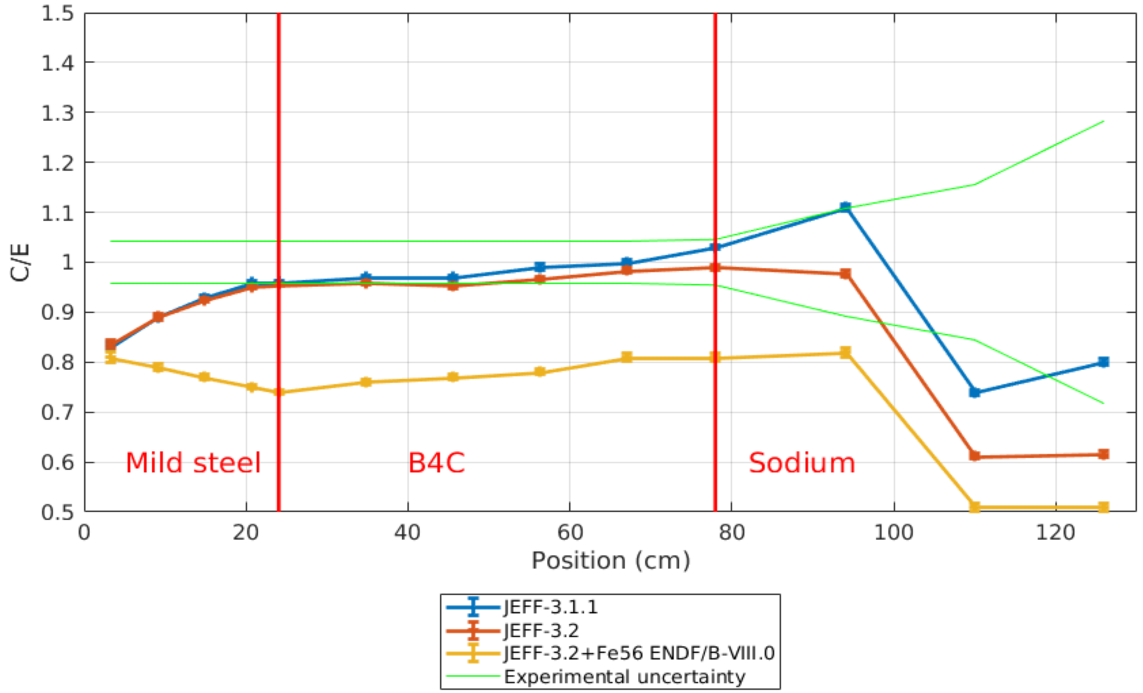
- Slow decrease for gold in steel and sodium, fast decrease in boron carbide
- Almost uniform decrease for sulphur: B4C efficient for thermal neutrons

The results obtained with the gold detector using the IRDFF-1.05 activation library



- Around 20 % bias inside the boron carbide zone, probably because the detector is used outside its usual conditions (fast spectrum in boron carbide)

The results obtained with the sulphur detector using the IRDFF-1.05 activation library



- **Biases with the JEFF evaluations are low in boron carbide, but increase in the sodium zone**

The interpretation of the ASPIS Iron 88 experiment with TRIPOLI-4® shows different behaviour with the detector used:

- For the gold detector, the biases obtained are low and there is a low dependency to nuclear data
- For the sulphur detector, the biases obtained are much higher, with a strong dependency to nuclear data

The interpretation of the JANUS Phase 2 experiment shows that

- For the gold detector, the largest biases are obtained inside the stainless steel zone, that seems to indicate issues with thermal XS of elements such as Ni or Cr
- For the sulphur detector, large biases can be obtained, with a strong dependency to both XS of iron 56 and sodium 23

The interpretation of JANUS Phase 7 shows also a different behaviour with the detector used:

- For the gold detector, low biases are obtained for the JEFF evaluations except for some detectors inside boron carbide
- For the sulphur detector, the biases are also low for the boron carbide zone using the JEFF evaluations, but increase in the sodium zone

The strong dependence to the nuclear data libraries can be explained by:

- Larger inelastic XS in JENDL-4.0 than in JEFF for iron 56: effect for sulphur detector
- Larger inelastic and radiative capture XS in ENDF/B-VIII.0 than in JEFF for iron 56: effect for both gold and sulphur detector
- Change in sodium 23 XS from JEFF-3.1.1 to JEFF-3.2: effect for the sulphur detector

- An impact of the angular distributions of iron 56 has been found for the sulphur detector
- The larger biases obtained with the ENDF/B-VIII.0 evaluation for iron 56 seem not to validate this evaluation
- Large biases indicate that additional work has to be done on isotopes used in structure material, as well as activation evaluations used in the detectors
- In order to explain the obtained biases, sensitivity calculations have to be done, however this kind of studies is difficult in both deterministic and Monte-Carlo

Thank you for your attention

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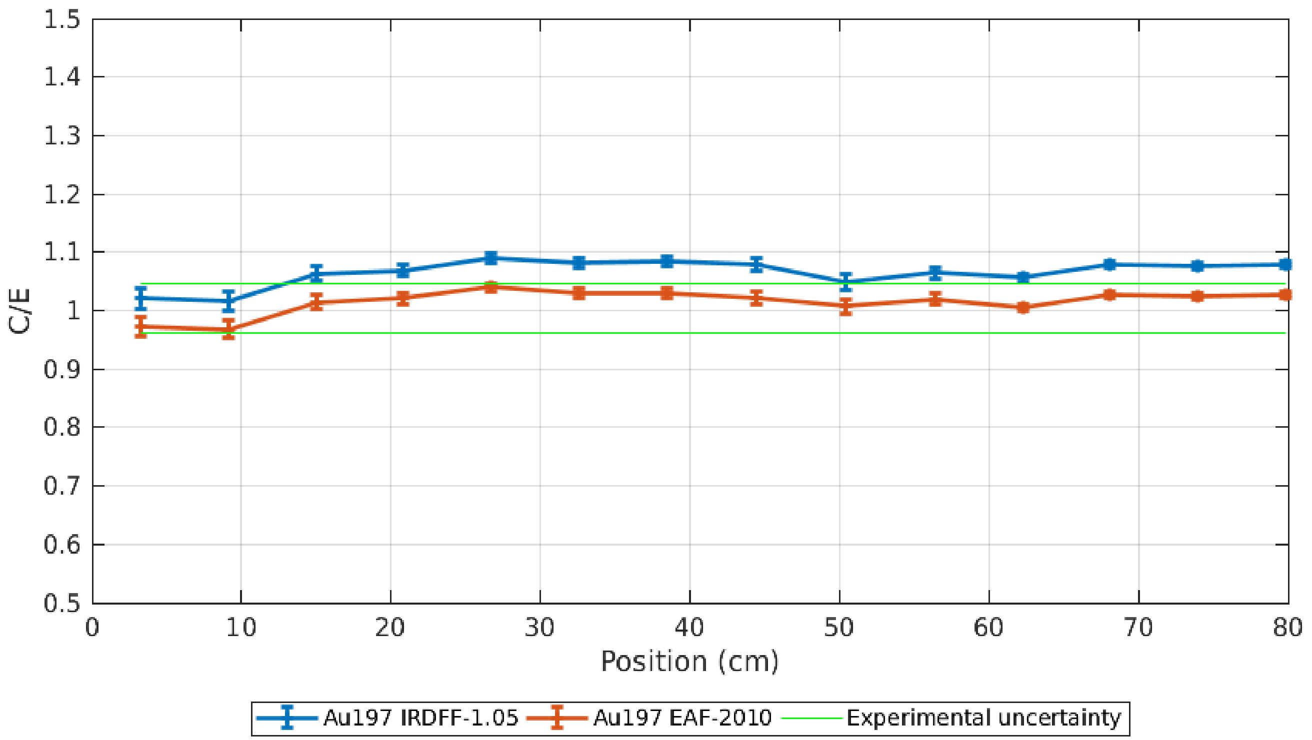
Appendices

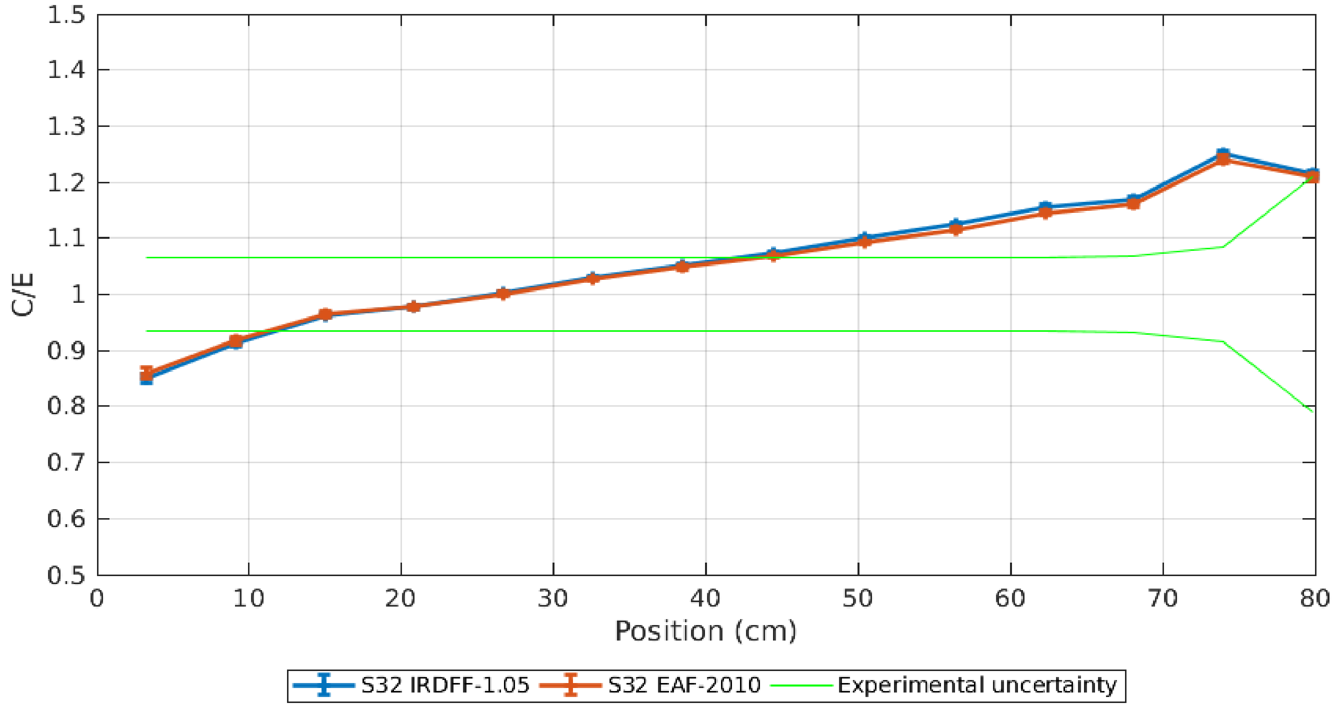
Impact of the activation evaluation

- Gold detector during the Iron 88 experiment



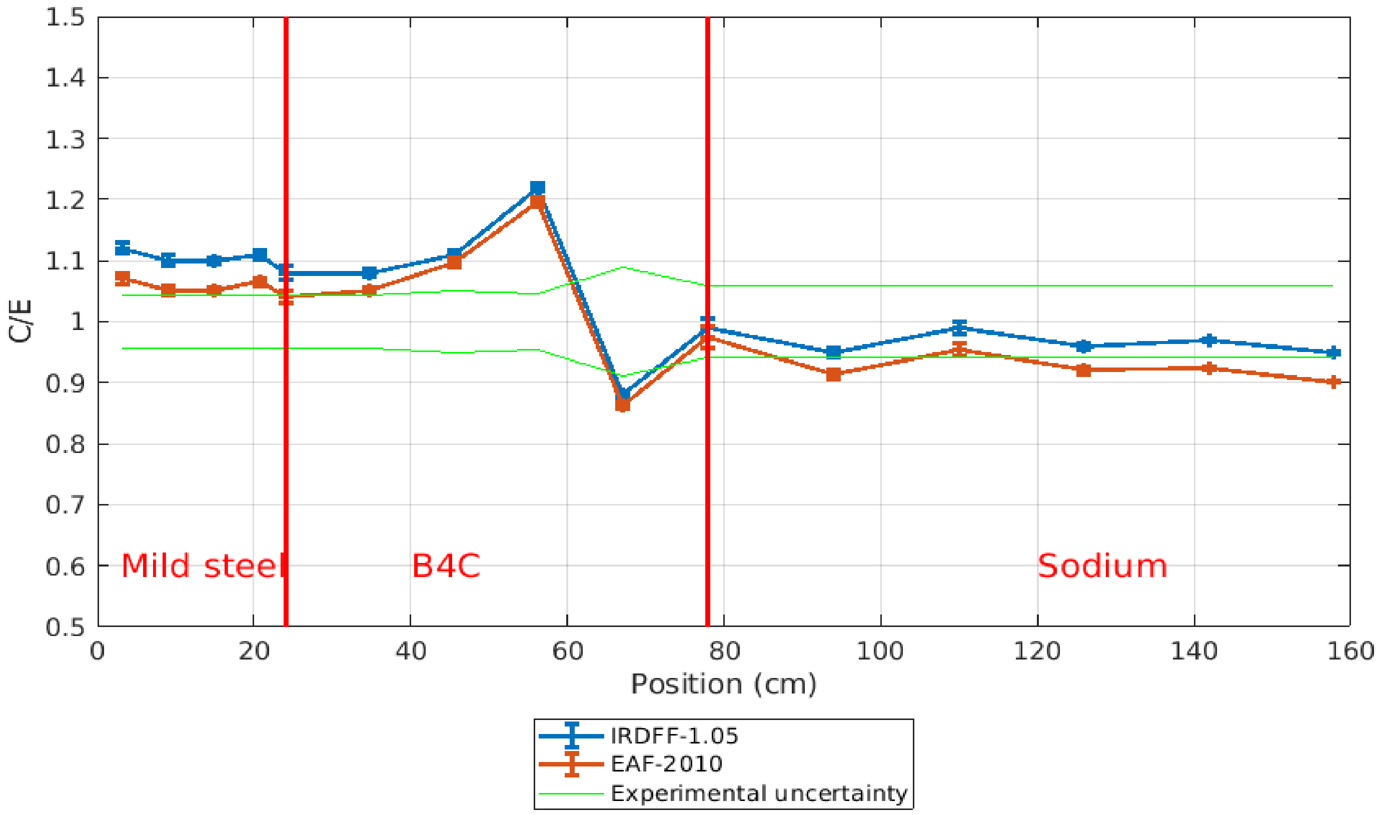
Impact of the activation evaluation

- **Sulphur detector during the Iron 88 experiment**



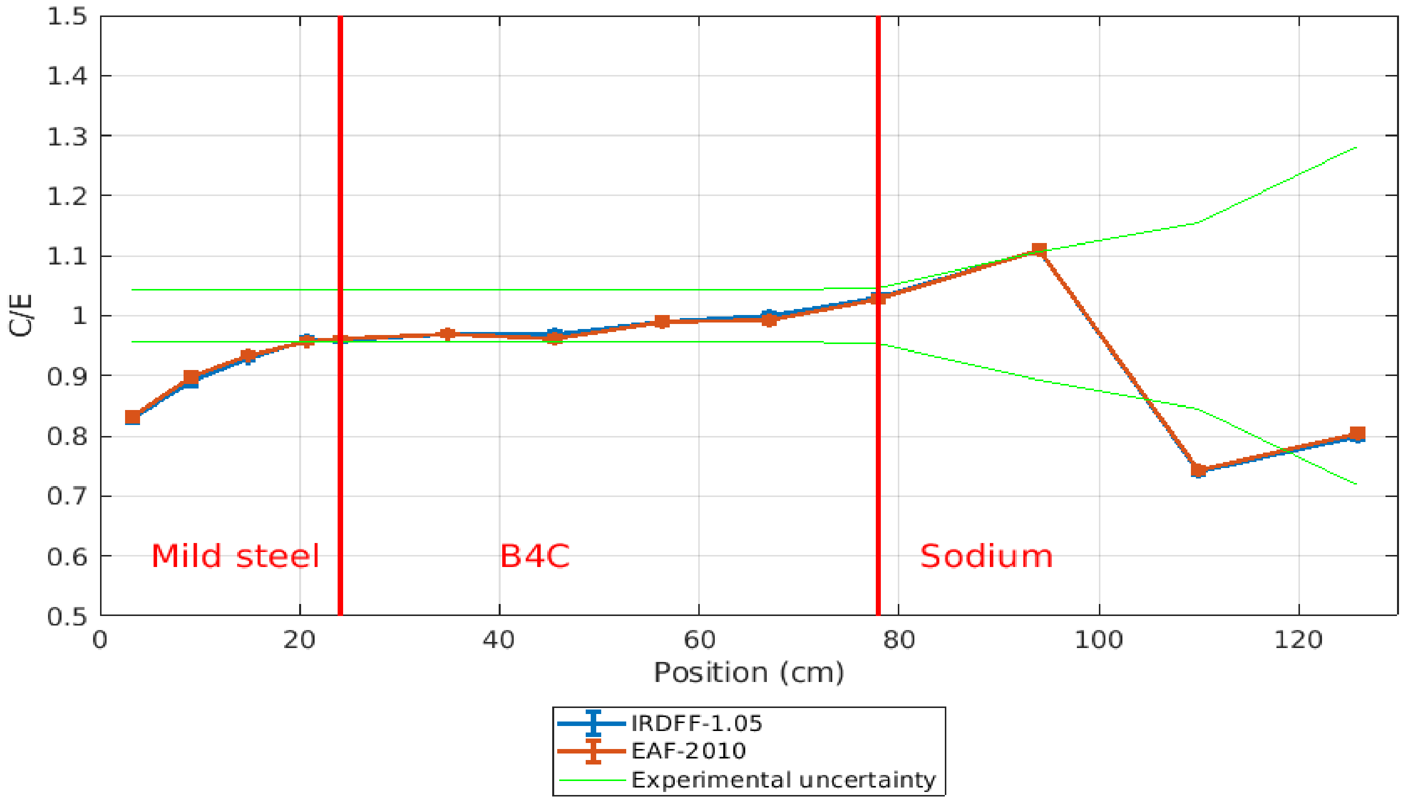
Impact of the activation evaluation

- Gold detector during the JANUS Phase 7 experiment



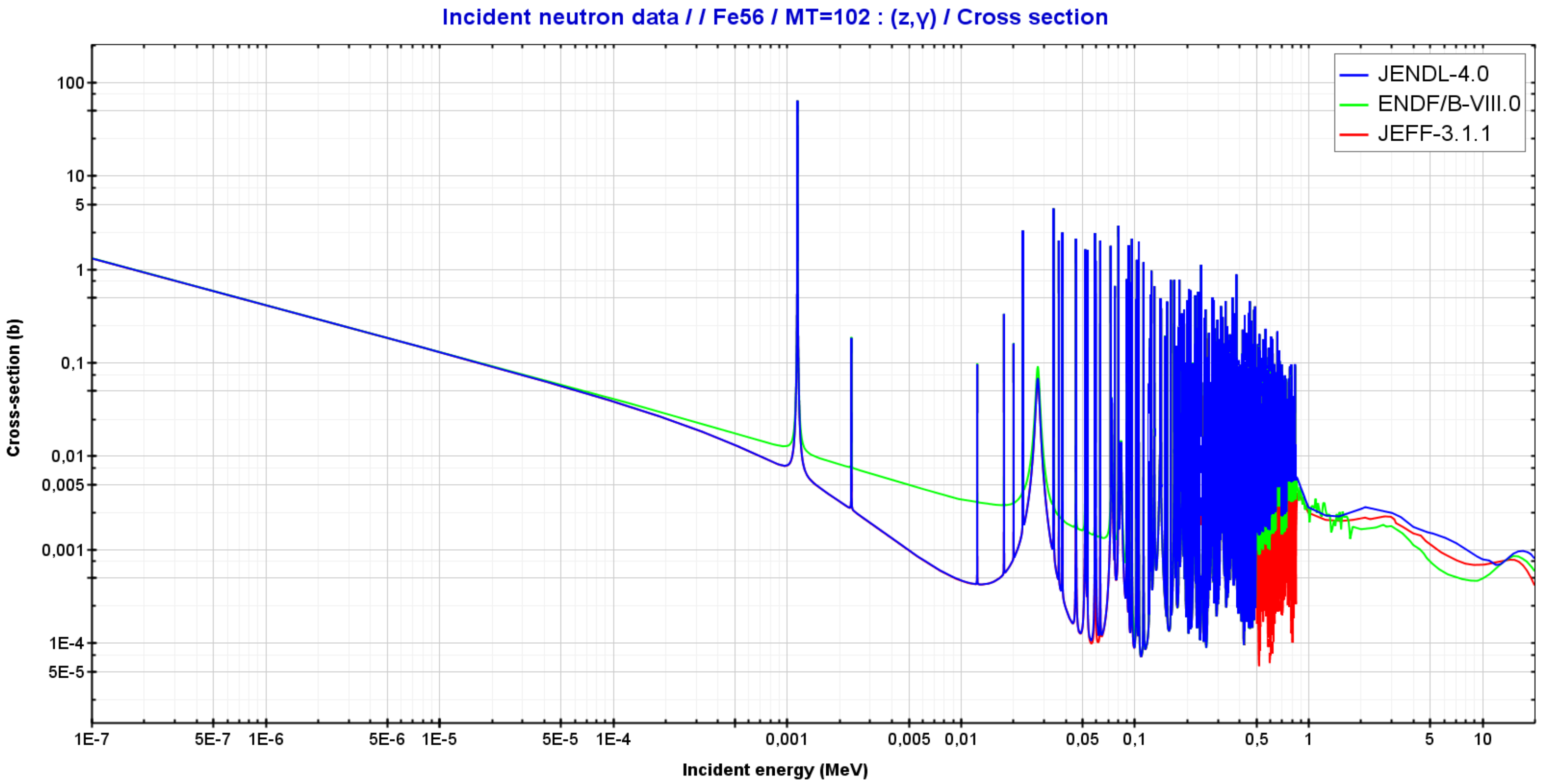
Impact of the activation evaluation

- Sulphur detector during the JANUS Phase 7 experiment



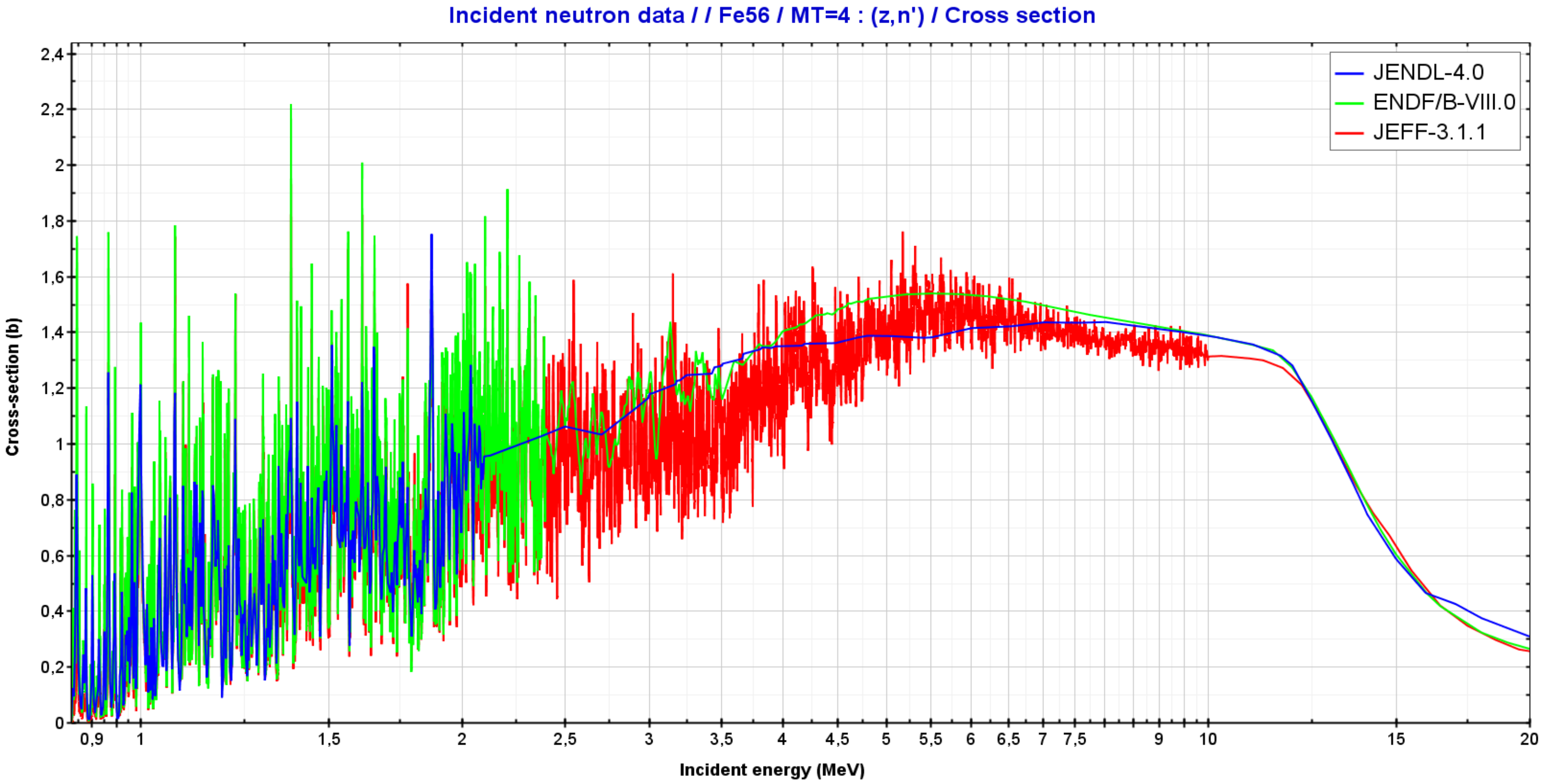
Interesting cross sections

- Radiative capture of iron 56



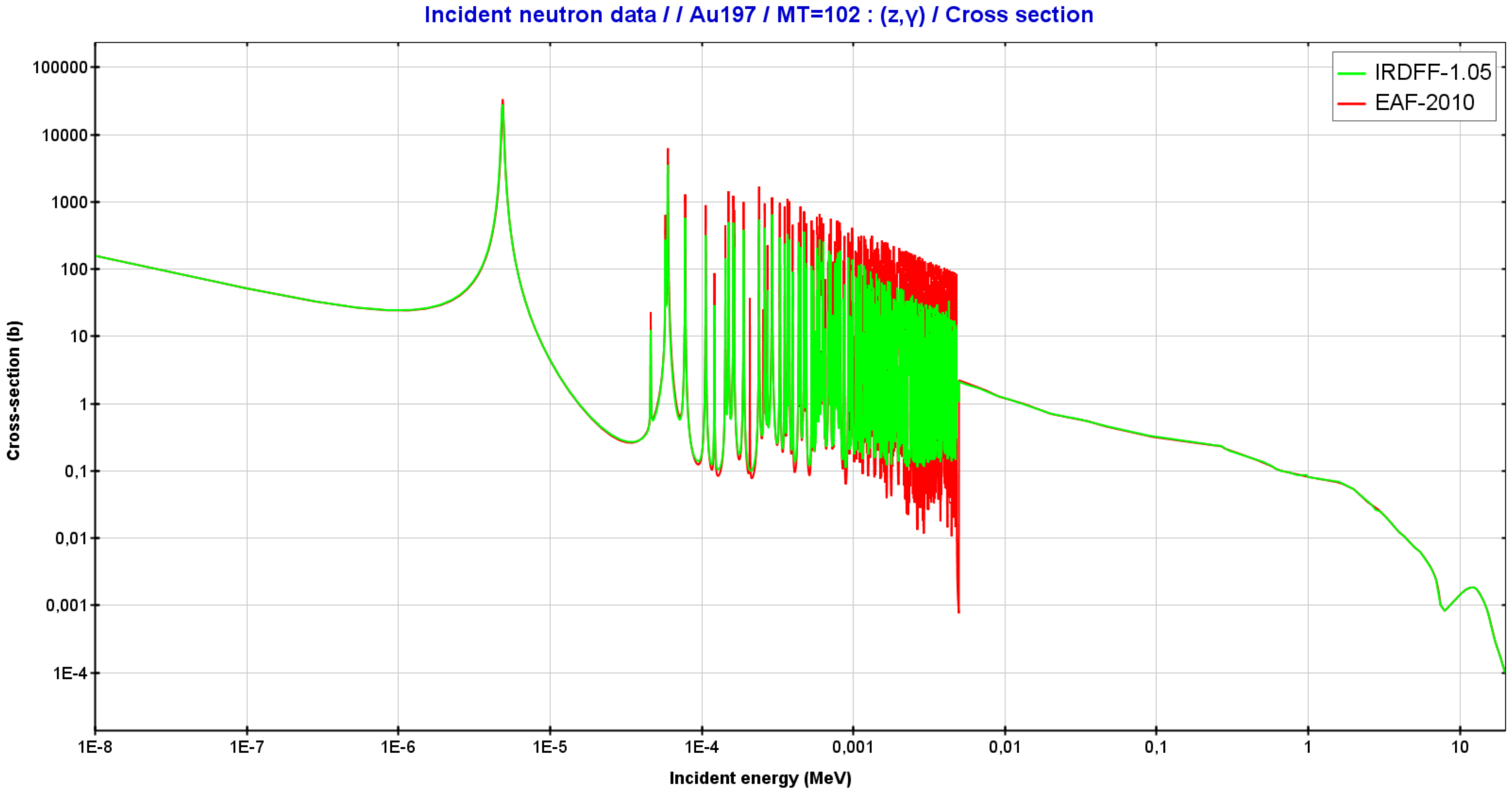
Interesting cross sections

- Inelastic scattering of iron 56



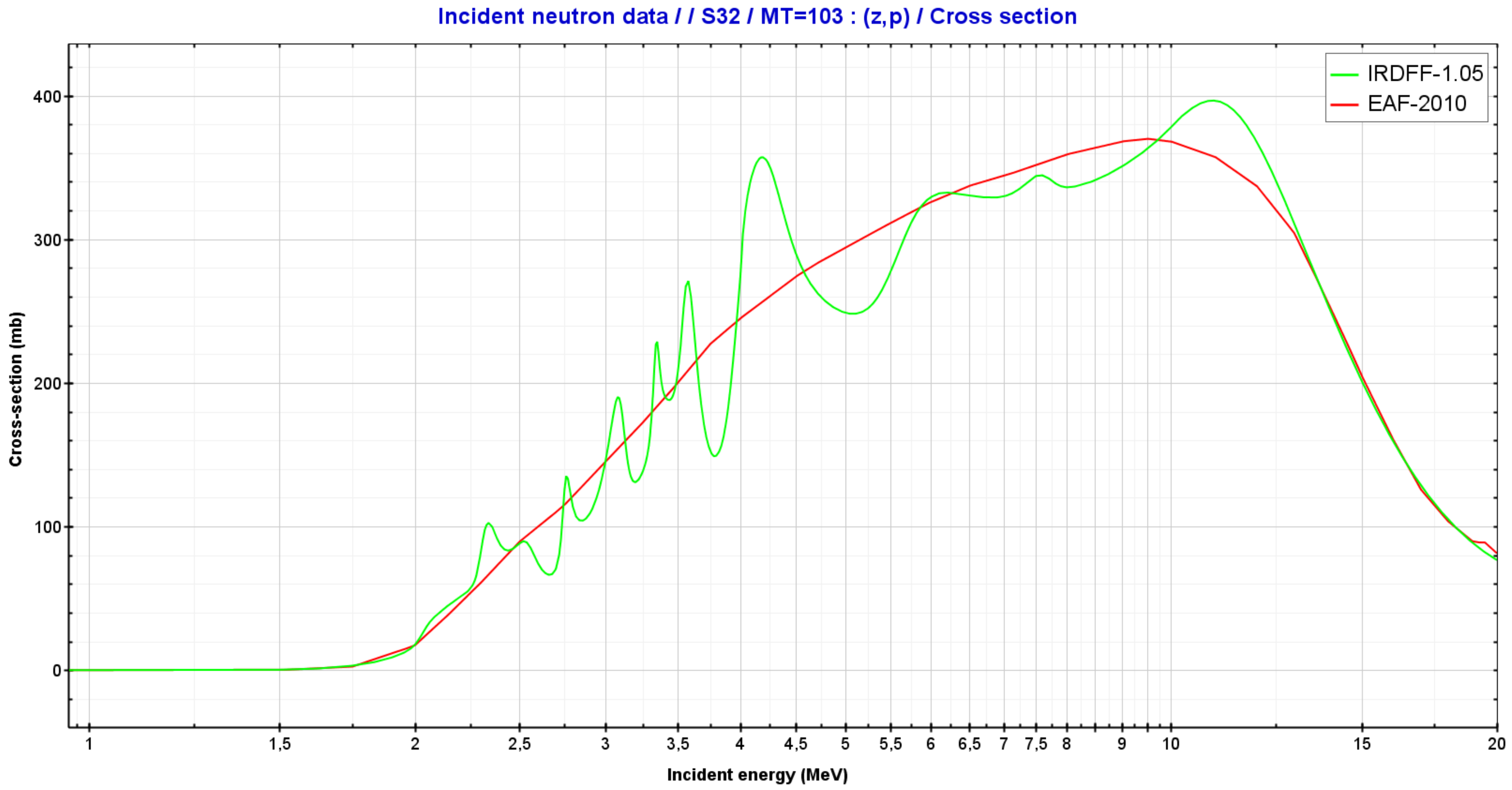
Interesting cross sections

- Radiative capture of gold 197



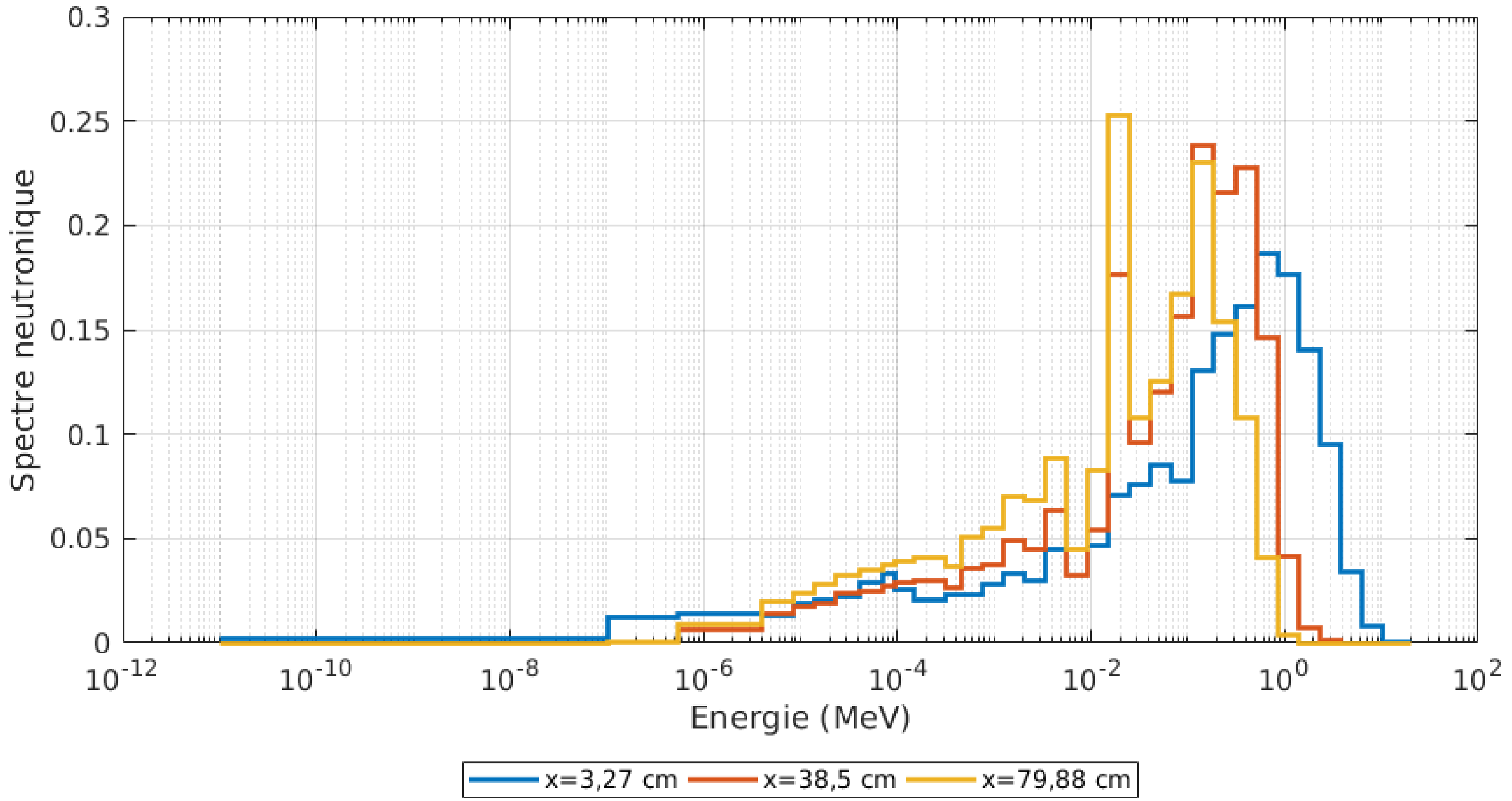
Interesting cross sections

- (n,p) reaction of sulphur 32



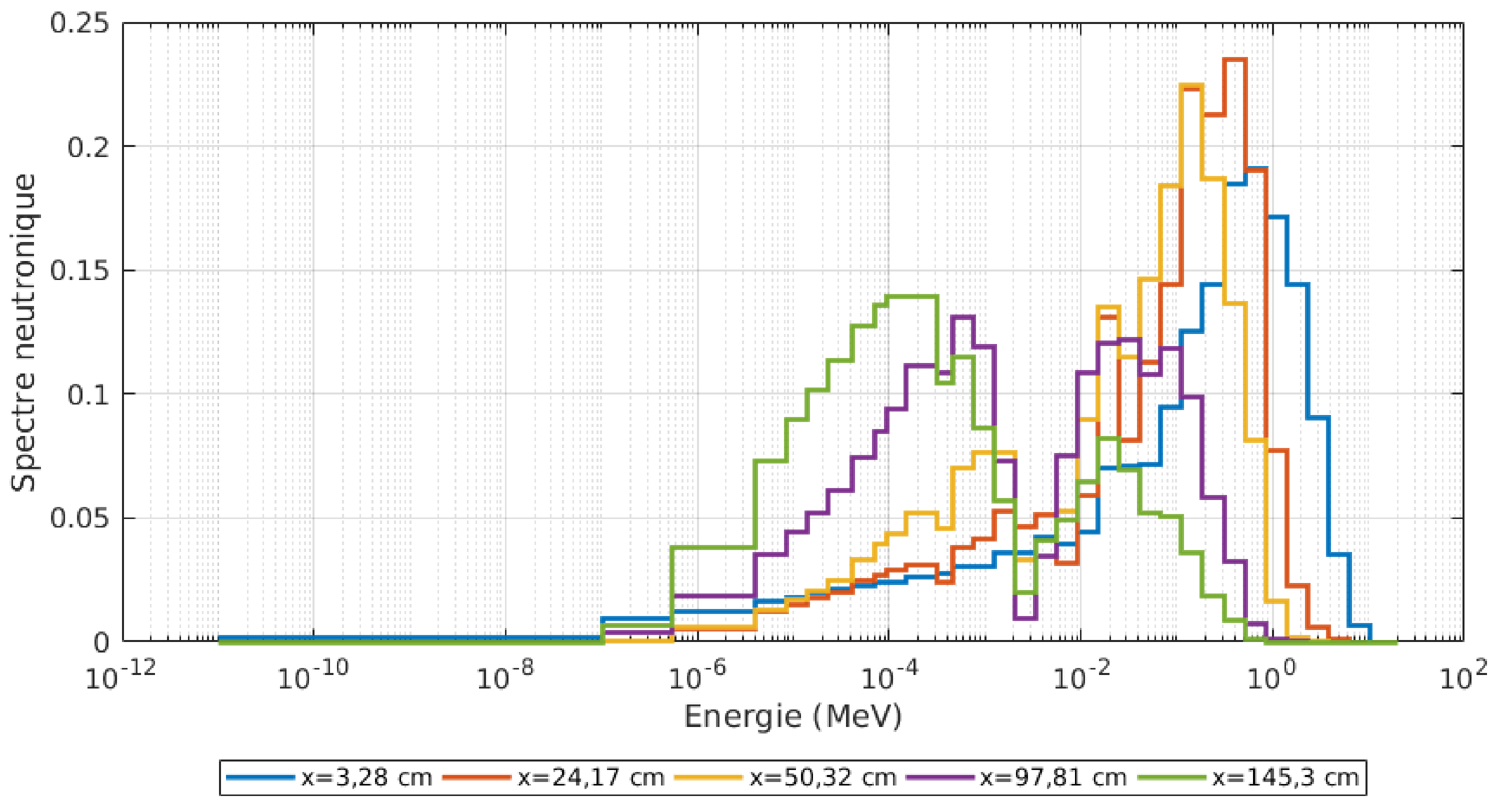
Evolution of neutron spectrum

- ASPIS Iron 88 experiment



Evolution of neutron spectrum

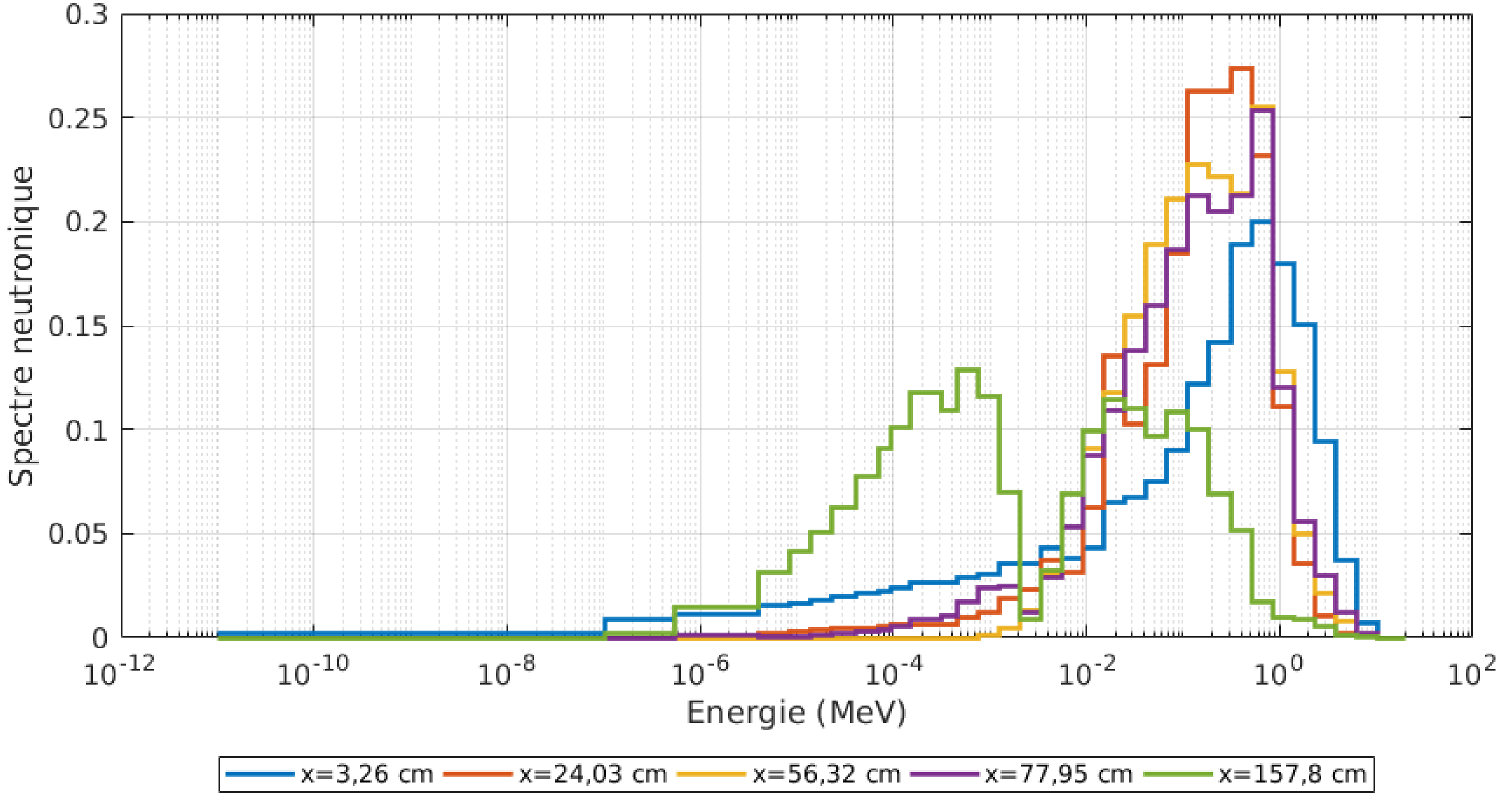
- JANUS Phase 2 experiment



X=3.28 cm: mild steel beginning
X=24.17 cm: between mild steel and stainless steel
X=50,32 cm: between stainless steel and sodium
X=97,81 cm: middle of sodium
X=145,3 cm: end of sodium

Evolution of neutron spectrum

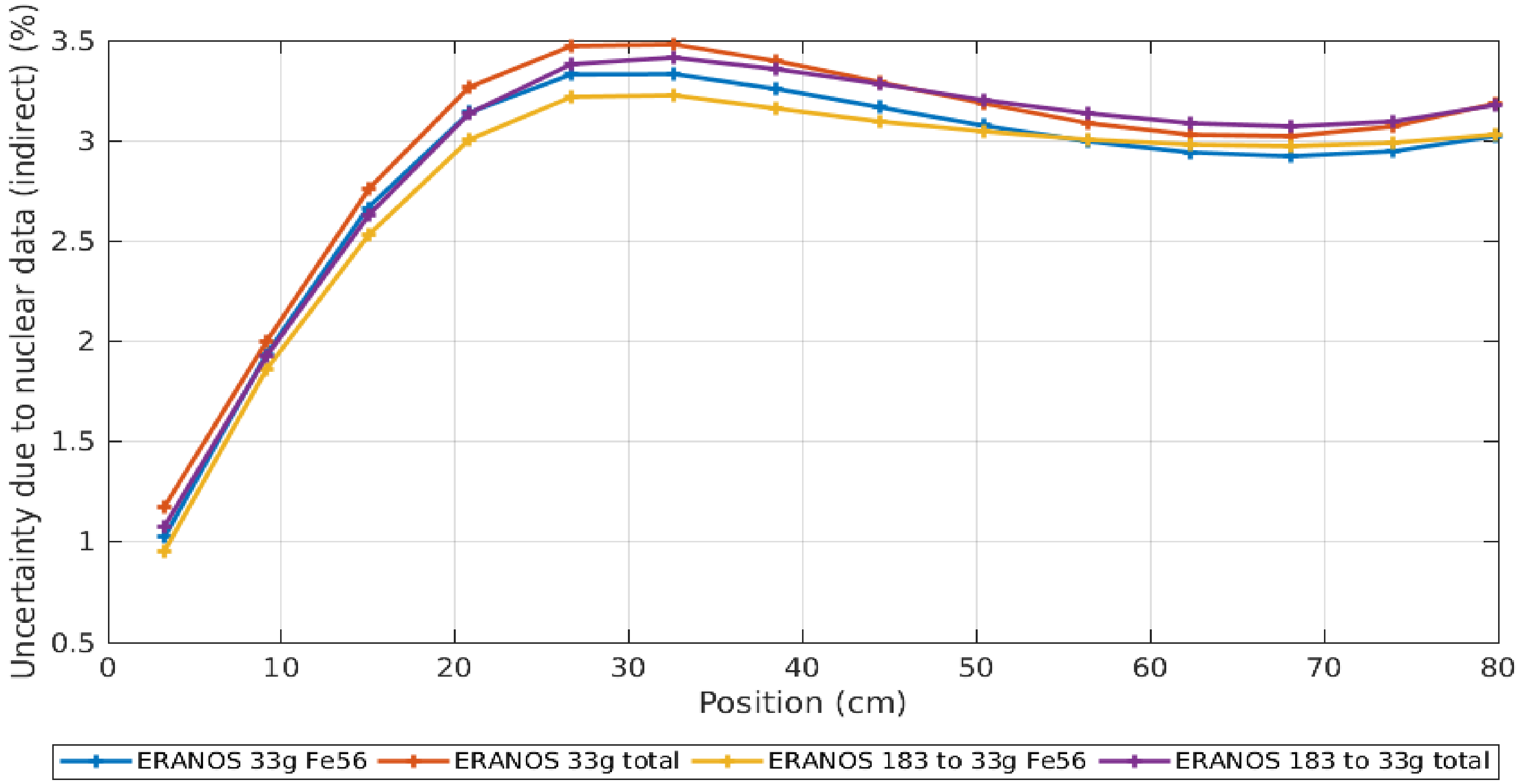
- JANUS Phase 7 experiment



X=3.26 cm: mild steel beginning
X=24.03 cm: between mild steel and B4C
X=56,32 cm: middle of B4C
X=77,95 cm: between B4C and sodium
X=157,8 cm: end of sodium

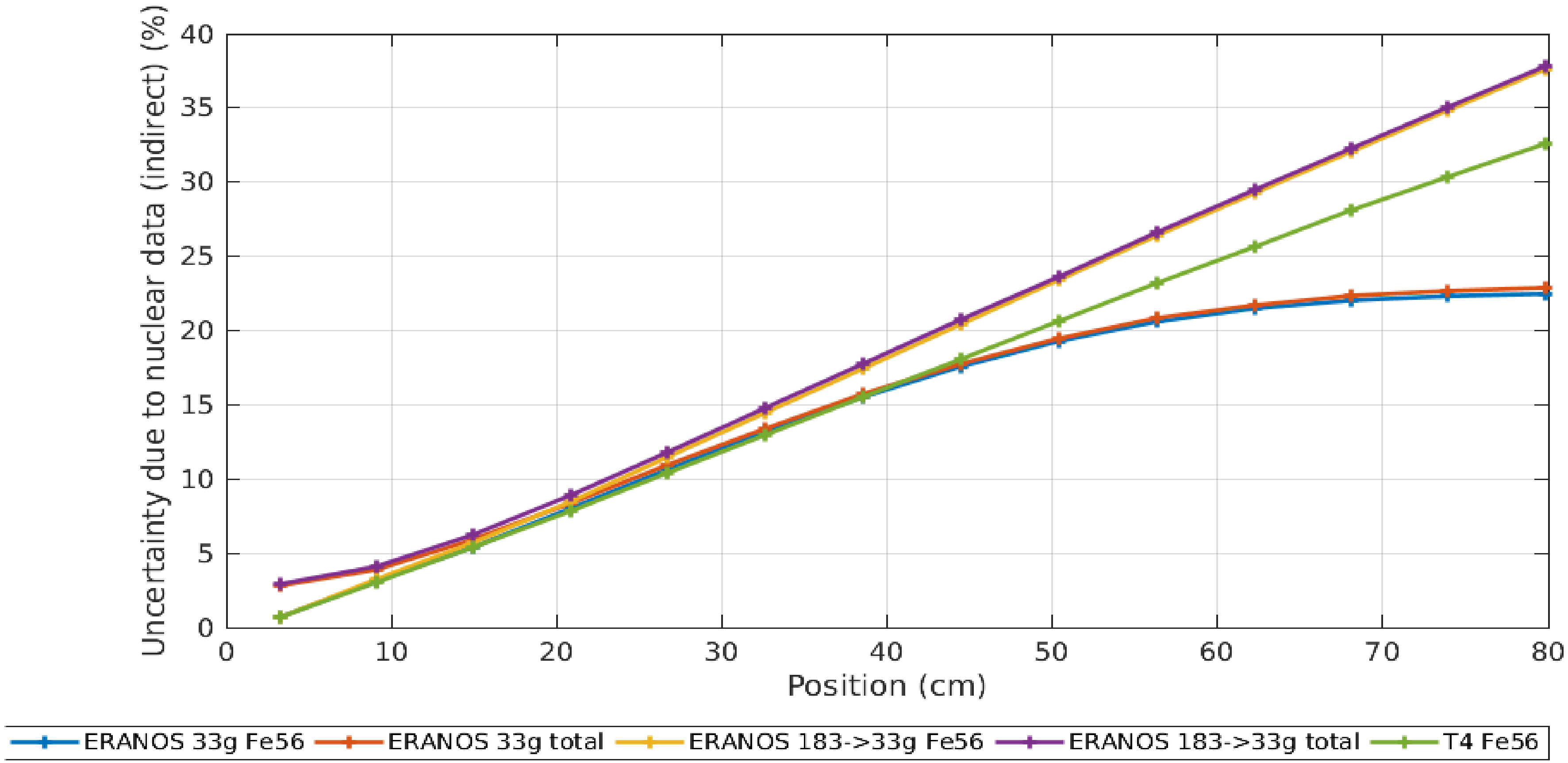
Uncertainties to nuclear data

- Gold detector during the ASPIS Iron 88 experiment, indirect effect, COMAC-v2.0 covariance matrix



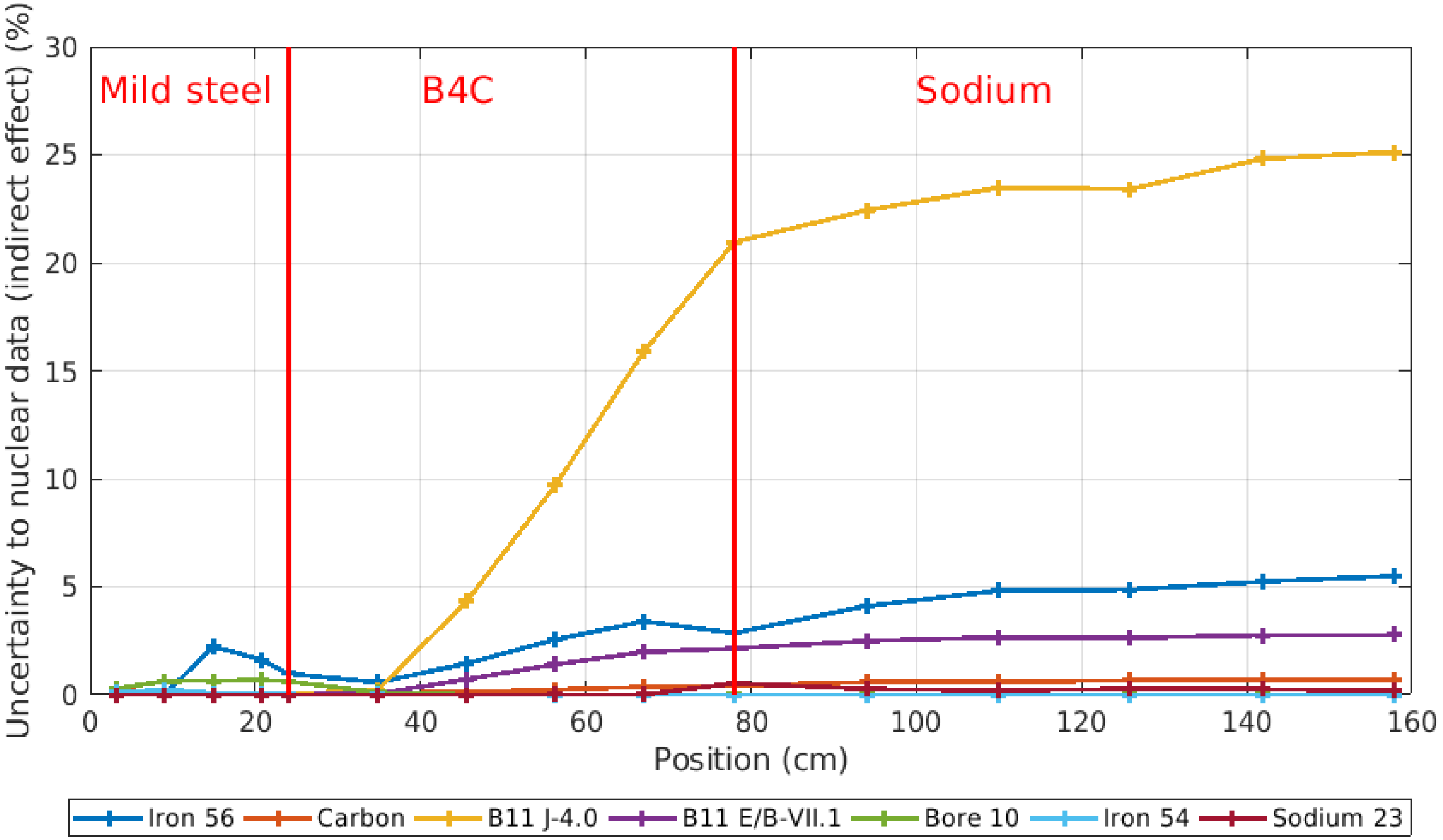
Uncertainties to nuclear data

- Sulphur detector during the ASPIS Iron 88 experiment, indirect effect, COMAC-v2.0 covariance matrix



Uncertainties to nuclear data

- Gold detector during the JANUS Phase 7 experiment, indirect effect, COMAC-v2.0 covariance matrix except B11



Uncertainties to nuclear data

- Sulphur detector during the JANUS Phase 7 experiment, indirect effect, COMAC-v2.0 covariance matrix except B11