Italian National Agency for New Technologies,
Energy and Sustainable Economic Development

# Sensitivity analyses on LFR concepts

## ALFRED case

*Meeting of the OECD/NEA-NSC-WPEC-SG46*

*15 March 2022*

**D.M. Castelluccio, F. Lodi, V.G. Peluso and G. Grasso – FSN-SICNUC-PSSN**

# Sensitivities on LFR concepts

## A contribution to a database of sensitivities

- Lead-cooled Fast Reactors are gathering increasing interest at international level

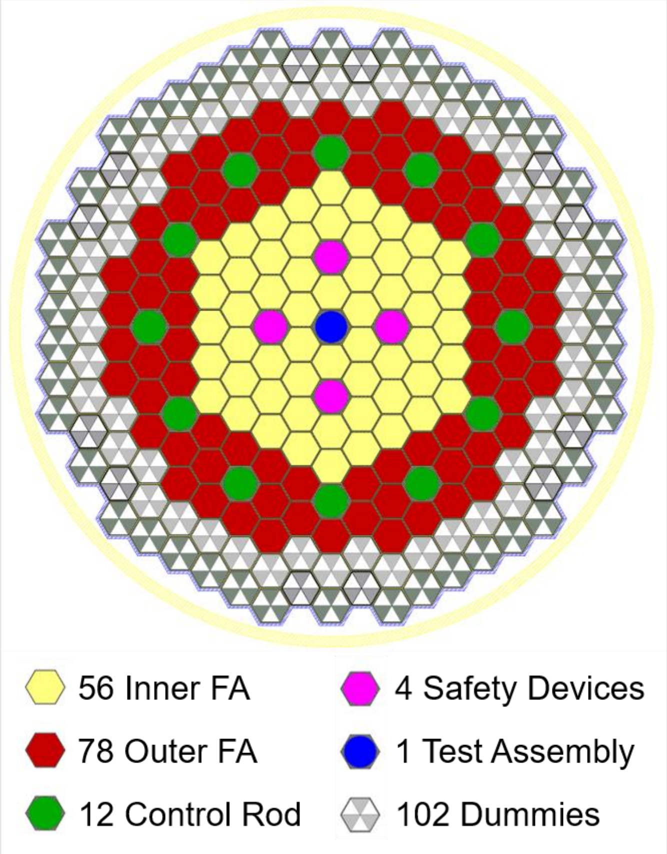
- In the perspective of establishing a NEA's database of sensitivities, for use in support of subsequent studies (e.g., target accuracy requirements, reactor physics, etc.), to include some cases referring to LFRs could be of worth for potential stakeholders

# Sensitivities on LFR concepts

## A first case study

### ALFRED

- As demonstrator, is based on features that are representative of follow-on units
- Thanks to its size (300 MWth), is prototypical of LFRs in the SMR range
- Is selected as reference for an international benchmark under the NEA's NSC/WPRS/EGPRS



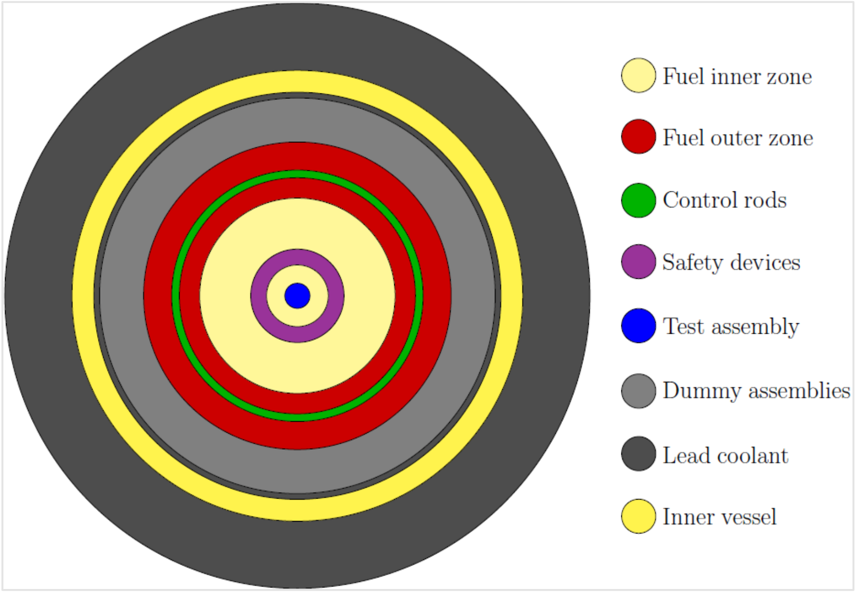
# Sensitivities on LFR concepts

## Core configuration – simulated model

### Core data

- R-Z model
- volumes of zones defined to preserve masses
- radii of zones tuned to be representative of direct / adjoint flux shapes

### Core map



# Sensitivity analysis

## Objective

To retrieve sensitivities to the key isotopes-cross sections-energy ranges for the following integral parameters of interest:

| system | $k_{eff}$ | $\beta_{eff}$ | $\Delta k_{eff}$ | | | Power peak |
|---|---|---|---|---|---|---|
| | | | *Doppler* | *CR worth* | $\Delta\rho_{coolant}$ | |
| ALFRED | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |

# Sensitivity analysis

## Methodology

- GPT ($k_{eff}$, $\beta_{eff}$)

- EGPT ($\Delta k_{eff}$ {Doppler, CR worth, $\Delta\rho_{coolant}$}, power peak)

- code: ERANOS v. 2.2N
- cross-sections: ENDF/B-VIII.0
- covariances: ENDF/B-VIII.0
- number of groups: 7, 15, 33, 80

# Sensitivity analysis

## List of isotopes

- O16
- U234
- U235
- U236
- U238
- Pu238
- Pu239
- Pu240
- Pu241
- Pu242
- Am241
- Zr91
- Zr92
- Zr94
- Zr96
- Mo95
  Mo97
- Mo98
- Mo100
- Ag109
- Sb121
- B10
- B11
- C12
- C13
- Al27
- N14
- N15
- Si28
- Si29
- Si30
- Ca40
- Ca42
- Ca43
- Ca44
- Ca46
- Ca48
- V50
- V51
- Ti46
- Ti47
- Ti48
- Ti49
- Ti50
- Cr50
- Cr52
- Cr53
- Cr54
- Mn55
- Fe54
- Fe56
- Fe57
- Fe58
- Ni58
- Ni60
- Ni61
- Ni62
- Ni64
- Zr90
- Nb93
- Mo92
- Mo94
- Mo96
- W180
- W182
- W183
- W184
- W186
- P31
- S32
- S33
- S34
- S36
- Co59
- Cu63
- Cu65
- Sn112
- Sn114
- Sn115
- Sn116
- Sn117
- Sn118
- Sn119
- Sn120
- Sn122
- Sn124
- Sb123
- Ta181
- Mg24
- Na23
- Mg25
- Mg26
- Pb204
- Pb206
- Pb207
- Pb208
  Bi209
- Zn64
- Zn66
- Zn67
- Zn68
- Zn70
- As75
- Ag107

# Preliminary results (example)

$k_{eff}$

| Isotope | capture | fission | ν | elastic | inelastic | (n,xn) | SUM |
|---|---|---|---|---|---|---|---|
| O16 | -2.50E-03 | 0.00E+00 | 0.00E+00 | -3.64E-02 | -1.75E-04 | 3.32E-10 | -3.90E-02 |
| Pu239 | -5.08E-02 | 4.88E-01 | 6.89E-01 | 9.18E-04 | -3.30E-03 | 2.70E-05 | 1.12E+00 |
| Pu241 | -4.80E-03 | 7.41E-02 | 1.03E-01 | 7.69E-05 | -5.45E-04 | 1.53E-05 | 1.72E-01 |
| Pu240 | -2.39E-02 | 4.87E-02 | 7.21E-02 | 5.09E-04 | -2.02E-03 | 1.04E-05 | 9.54E-02 |
| Pu238 | -2.75E-03 | 1.24E-02 | 1.77E-02 | 3.99E-05 | -1.16E-04 | 9.38E-08 | 2.73E-02 |
| U235 | -1.40E-03 | 1.01E-02 | 1.52E-02 | 2.11E-05 | -1.38E-04 | 2.16E-06 | 2.38E-02 |
| Pb208 | -8.85E-04 | 0.00E+00 | 0.00E+00 | 2.79E-02 | -4.15E-03 | 2.77E-04 | 2.31E-02 |
| Pu242 | -5.81E-03 | 9.87E-03 | 1.47E-02 | 1.58E-04 | -5.71E-04 | 5.74E-06 | 1.84E-02 |
| Pb207 | -3.24E-03 | 0.00E+00 | 0.00E+00 | 1.02E-02 | -5.93E-03 | 1.86E-04 | 1.26E-03 |
| Zr90 | -7.84E-04 | 0.00E+00 | 0.00E+00 | 2.03E-03 | -1.54E-04 | 2.41E-07 | 1.09E-03 |

# Preliminary results (example)

## $k_{eff}$ - Detailed breakdown of sensitivity contributions

| Group | capture | fission | $\nu$ | elastic | inelastic | (n,xn) | SUM |
|---|---|---|---|---|---|---|---|
| 1 | -1.8552E-04 | 4.3598E-04 | 7.0132E-04 | -2.9414E-05 | -2.9976E-04 | 2.7828E-04 | 9.0089E-04 |
| 2 | -1.5585E-03 | 5.6819E-03 | 8.5546E-03 | 3.4578E-05 | -2.7461E-03 | 9.6051E-04 | 1.0927E-02 |
| 3 | -2.9389E-03 | 1.6070E-02 | 2.4363E-02 | 1.9094E-03 | -6.7402E-03 | 2.3915E-06 | 3.2665E-02 |
| 4 | -2.3118E-03 | 4.0100E-02 | 6.4616E-02 | 4.9982E-03 | -2.1098E-02 | -2.3664E-06 | 8.6301E-02 |
| 5 | -3.4812E-03 | 5.5655E-02 | 8.8967E-02 | 3.2154E-03 | -2.6299E-02 | -9.4843E-07 | 1.1806E-01 |
| 6 | -6.6374E-03 | 4.3781E-02 | 6.5534E-02 | 6.5032E-03 | -1.3800E-02 | -2.1125E-07 | 9.5380E-02 |
| 7 | -1.6362E-02 | 7.1114E-02 | 1.0528E-01 | 9.3701E-03 | -5.2410E-03 | -1.0620E-07 | 1.6416E-01 |
| 8 | -1.3495E-02 | 4.7379E-02 | 6.8715E-02 | 2.0279E-03 | -1.6757E-03 | -6.6153E-09 | 1.0295E-01 |
| 9 | -1.8103E-02 | 5.6622E-02 | 8.1013E-02 | 7.6142E-04 | -2.0943E-03 | -2.0363E-09 | 1.1820E-01 |
| 10 | -2.2122E-02 | 5.6814E-02 | 7.9962E-02 | -1.3893E-03 | -2.5419E-03 | -1.3931E-09 | 1.1072E-01 |
| 11 | -2.2208E-02 | 4.9553E-02 | 6.8543E-02 | -4.6283E-03 | -1.9975E-03 | -5.9987E-10 | 8.9262E-02 |
| 12 | -2.6479E-02 | 4.5146E-02 | 6.1347E-02 | -1.8206E-03 | -4.7909E-04 | -3.5356E-10 | 7.7715E-02 |
| 13 | -2.6195E-02 | 3.5465E-02 | 4.7590E-02 | 1.5465E-03 | -1.4004E-04 | -2.3154E-10 | 5.8266E-02 |
| … | | | | | | | |
| 33 | -3.1129E-06 | 1.0093E-06 | 2.0395E-06 | -4.1543E-08 | -2.1136E-22 | -2.9568E-14 | -1.0563E-07 |
| ***PART >0*** | **0.0000E+00** | **6.9593E-01** | **1.0000E+00** | **4.7628E-02** | **6.9280E-05** | **1.2412E-03** | **1.7449E+00** |
| ***PART <0*** | **-3.3340E-01** | **0.0000E+00** | **0.0000E+00** | **-1.3240E-02** | **-8.5155E-02** | **-3.6447E-06** | **-4.3180E-01** |
| **SUM** | **-3.3340E-01** | **6.9593E-01** | **1.0000E+00** | **3.4388E-02** | **-8.5086E-02** | **1.2375E-03** | **1.3131E+00** |

# Usability of the results

## Past applications

1. The sensitivities were complemented by uncertainty propagation to integral parameters, to both
    - capture the confidence on the design studies
    - compare the current status against the assumed Target Accuracy Requirements established for ALFRED (even though, being ALFRED a demonstrator, this could not be directly relevant for follow-on LFRs!)

2. The sensitivities were also used for an exercise of adjustment of ENDF/B-VIII.0 nuclear data, to obtain an ad-hoc library for use for ALFRED (and other LFRs to which ALFRED is representative)

# Way forward

## Establish a database of sensitivities

- A sensitivity (and uncertainty) study was performed on ALFRED, as European demonstrator of LFRs and prototype of LFR-SMR, limited to the needs of the project at the present stage
- Information was obtained on the sensitivity to the main core parameters, using state-of-the-art nuclear data
- ENEA is available – and willing! – to share these results to populate the database with an LFR-relevant case
- An agreement should be found on the structure of the database for the collection of data (e.g., number of groups, number of isotopes/reactions, etc.)

Giacomo Grasso
giacomo.grasso@enea.it