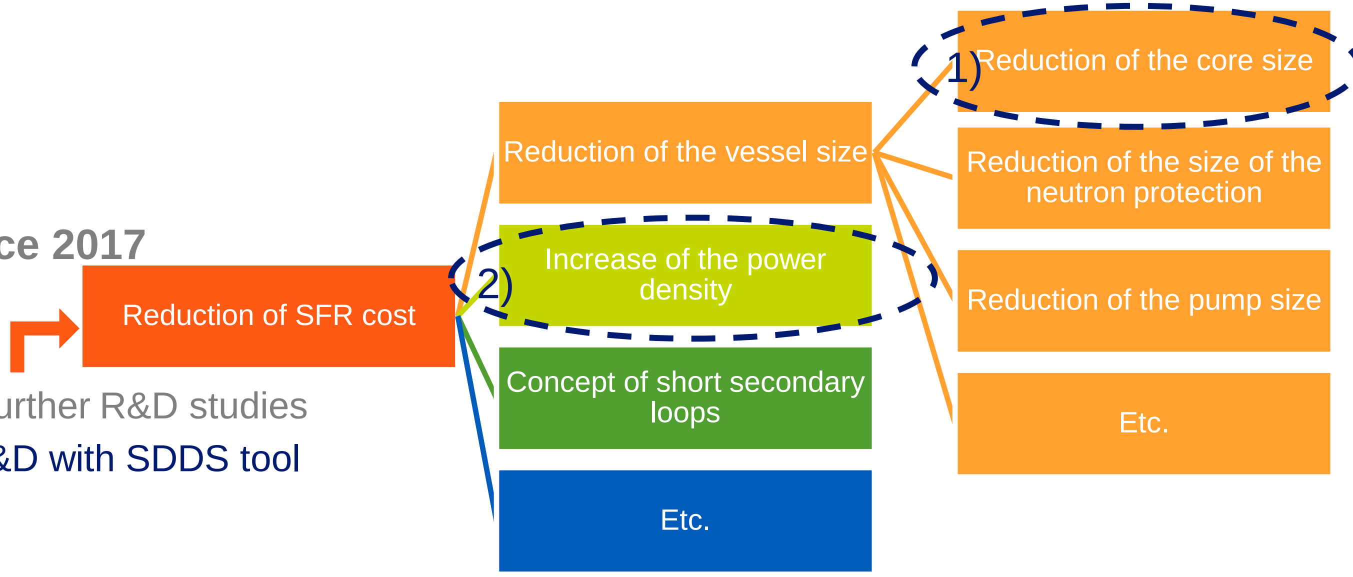
EVALUATION OF AN INCREASE OF THE POWER DENSITY FOR THE FRENCH COMMERCIAL SODIUM FAST REACTOR AND OPTIMIZATION STUDY AT 1100 MWE WITH THE SDDS TOOL

D GÉRARDIN, S. POUMEROULY, L. ANDRIOLO
EDF-R&D

International Conference on Fast Reactors and Related Fuel Cycles: Sustainable Energy for the Future
19-22 April 2022

I. CONTEXT

CONTEXT



- **French commercial SFR under definition at EDF since 2017**
  - Objective: Enhanced competitiveness with reduced construction costs
    - Several options identified to reduce SFR costs that needs further R&D studies

➡ Conception and optimisations studies performed at EDF-R&D with SDDS tool

1) Study performed in 2018 for a 1000 MWe SFR

- 2 designs (12 SA rings or 13 SA rings) pre-selected as they offered good compromise between safety performances and reduced core diameter

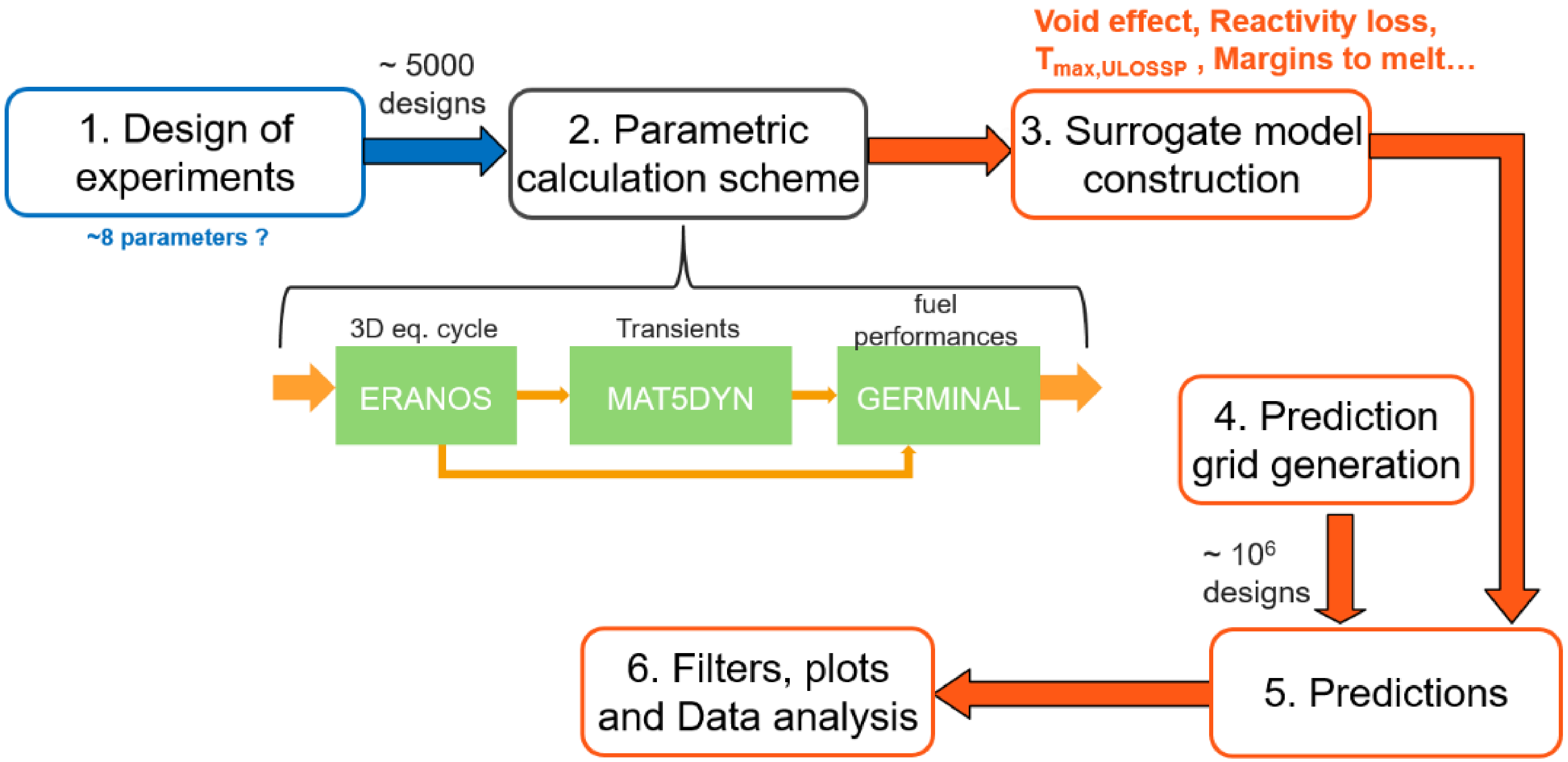
2) Study performed in 2020 considering a 10% increase of nominal power

- 1000 MWe (2400 MWth) →1100 MWe (2640 MWth)
- Questions to be answered:
  - *Are the trends of the study at 1000 MWe still the same at 1100 MWe?*
  - *Is it possible to find a design at 1100 MWe that meet the safety criteria and the limited core diameter objective ?*
- Complementary studies to test some evolutions of the variable parameters or selection criteria

II. METHOD

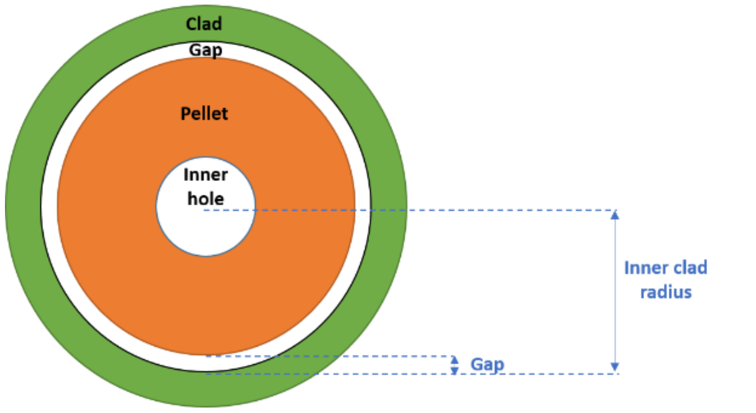
SDDS

- Tool to help the conception and the optimisation of SFR cores
- Developed at EDF since 2009



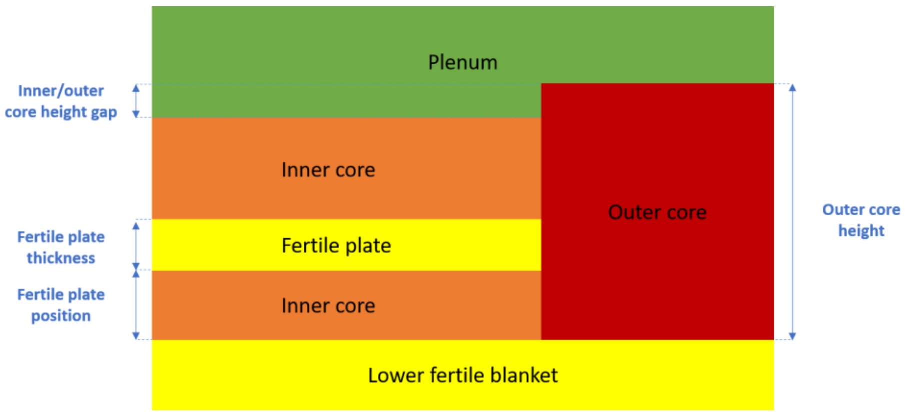
SPECIFICATION OF THE STUDY

Parameter	Range
Number of fuel sub-assembly rings	12 or 13
Number of pins per sub-assembly	217 or 271
Pellet/cladding (radial) gap (mm)	[0 ; 0.11]
Inner clad radius (cm)	[0.35 ; 0.5]
Outer core height (cm)	[90 ; 110]
Outer/inner core height gap (cm)	[0 ; 20]
Fertile plate position (% of inner core height)	[0 ; 50]
Fertile plate thickness (cm)	[0 ; 20]



- **Low sodium void effect core geometries**
  - Heterogenous core with fertile plate, height gap between inner and outer core and plenum
  - Variation range allows to go up to homogeneous core geometry

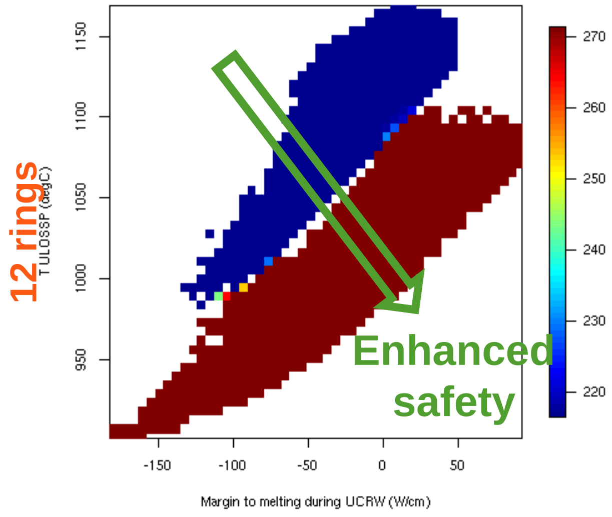
- **Additional constraints/filters before creating the surrogate models**
  - French commercial SFR specifications: **power density in [250 ; 375] W/cm^3**
  - Core viability: **Margin to fuel melting in nominal conditions > 0**

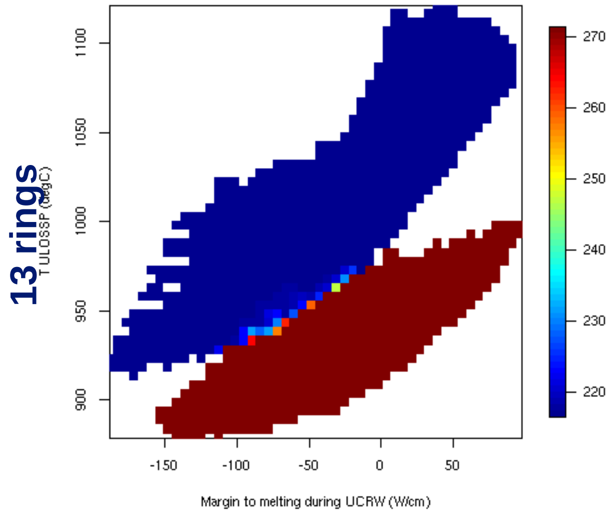


III. RESULTS OF THE SDDS METHOD AT 1100 MWE

RESULTS OF THE SDDS STUDY AT 1100 MWE

Colour : number of pins per assembly



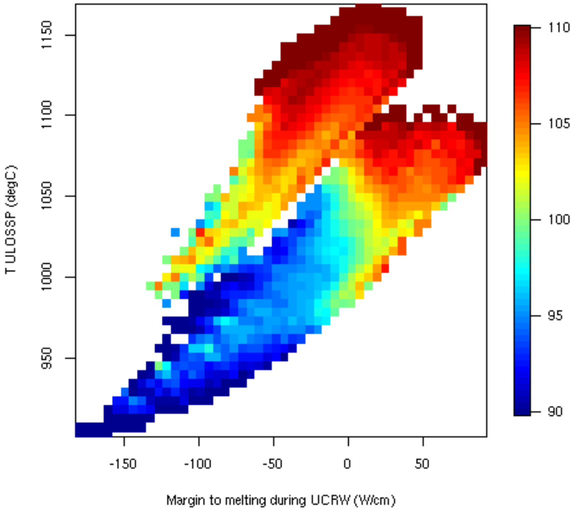


- **Results presented in (Margin to fuel melting during UCRW, sodium temperature in ULOSSP)**
  - Degradation of the safety performances compared to previous study at 1000 MWe
  - 12 assembly rings
    - TULOSSP in [901 ; 1170] °C & Margin to fuel melting in UCRW [-189 ; 98] W/cm
    - No design avoiding boiling in ULOSSP in the studied space
  - 13 assembly rings
    - TULOSSP in [878 ; 1122] °C & Margin to fuel melting in UCRW [-189 ; 98] W/cm
    - Designs avoiding fuel melting in UCRW and designs avoiding boiling in ULOSSP but not both simultaneously
- **Best designs on the safety point of view located on the Pareto front**
- **Colour of each point indexed on the mean value of the studied parameter**
- **Number of pins**
  - Designs on Pareto front with a **high number of pins** per assembly (271 rather than 217)

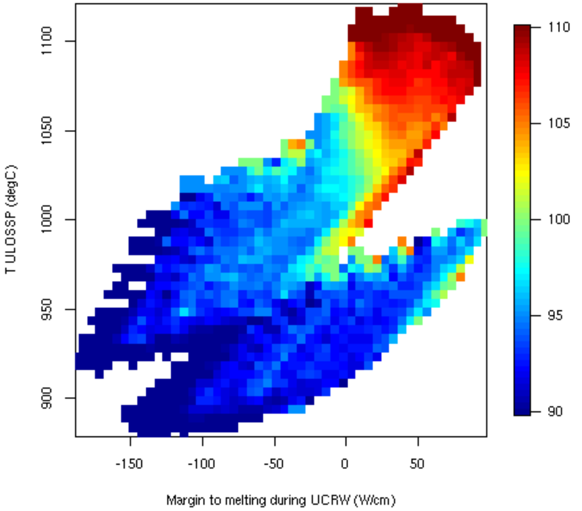
RESULTS OF THE SDDS STUDY AT 1100 MWE

Colour : outer core height

12 rings



13 rings



- **Outer core height**
  - Gradient colinear to Pareto front → either small outer core to enhance ULOSSP or a large outer core to enhance UCRW
- **For other parameters, designs on the Pareto front with**
  - **Thin pins** ~8 mm diameter → due to the filtering of the low power density cores
  - **Relatively small inner/outer core height gap**
  - **Large fertile plate** (15-20 cm) either located at the bottom of the core to enhance ULOSSP or at the middle of the core to enhance UCRW

➡ **Similar trends than the ones observed in the study at 1000 MWe**

IV. SELECTION OF A 1100 MWE CORE

SELECTION OF A 1100 MWE CORE
CRITERIA AND OPTIMISATION OBJECTIVES

- **Criteria (safety related criteria)**
  - **Margin to fuel melting in nominal conditions > 300 °C** (Standard conception criteria)
  - **Margin to fuel melting in case of UCRW > 20 W/cm** (to take into account the surrogate models' uncertainties)

- **Optimisation objectives**
  - Safety objectives: **Sodium temperature in ULOSSP** at core outlet **as low as possible**
  - Economical objective: **Core diameter as small as possible**

- **12 SA rings configurations : no core configuration selected at 1100MWe because of poor safety performances (in the studied space)**

SELECTION OF A 1100 MWE CORE

- **13 SA rings configurations**
  - Core selected in 2018 re-evaluated at 1100 MWe does not meet the non-melting criteria in UCRW
  - Core selected with the new optimisation at 1100 MWe
    - Meet the safety criteria regarding non fuel melting
    - Same core radius as the core selected in 2018

Parameter	13-Ref (Core selected in 2018 re-evaluated at 1100 MWe)	13-C5 (Core on the Pareto front of the SDDS study at 1100 MWe)
Outer pellet radius [cm]	0.346	0.3455
Inner clad radius [cm]	0.35	0.35
Outer core height [cm]	94	92
Outer/inner core height gap [cm]	5	0
Inner fertile zone position (% of inner core height)	5	18
Inner fertile zone height [cm]	20	15
Number of pins per SA	271	271
Fissile core radius [cm]	**203**	**203**
Power density [W/cm3]	304	**302**
Margin to fuel melting in nominal conditions [°C]	356	**431**
Margin to fuel melting in UCWR [W/cm]	**-3**	**29**
Asymptotic temperature in ULOSSP [°C]	915	**922**

Does not avoid sodium boiling in ULOSSP

- SDDS models : Simplified thermohydraulic, natural convection but no passive protection system
- Need more precise modelling and additional protection system

V. COMPLEMENTARY STUDIES AT 1100MWE

COMPLEMENTARY STUDIES

- **Test of some evolutions of the variable parameters or selection criteria**

- **Increase of the number of pin per assembly**
  - Variation range shifted from {217 ; 271} to {271 ; 331} to access core configurations with better behaviour in ULOSSP and in UCRW
  - Significative **improvement of the safety performances** (particularly in ULOSSP) but :
    - Designs with 13 SA rings and 331 pins : **too large core radius** (too low power density) do not meet the French commercial SFR specifications
    - Designs with 12 SA rings and 331 pins : lower safety performances than the 13 SA rings and 271 pin designs and equivalent core radius

- **Addition of technical and economical criteria**
  - Campaign length > 1500 JEPN
  - Maximal damage on the cladding < 150 dpa
  - **Increased number of designs are eliminated** (some of them being on the Pareto front and with a low sodium temperature in ULOSS)

VI. CONCLUSIONS & PERSPECTIVES

CONCLUSIONS & PERSPECTIVES

- **Several constraints**
  - Safety performances : some of the geometrical characteristics that enhance ULOSSP tend to degrade UCWR (and vice versa)
  - Economical objectives (reduction of the core radius and high power density) opposed to safety objectives

- **10% increase of the power**
  - Similar trends at 1000 MWe and 1100 MWe (core on Pareto front with similar characteristics)
  - Degradation of the safety performances for ULOSSP and for UCRW
  - One 13 assembly rings design with 271 pins per assembly pre-selected

- **Further studies of the selected design**
  - Selected design does not avoid sodium boiling in ULOSSP with the models of SDDS
  - Implementation of passive safety rods and more precise modelling => CATHARE study
  - Evaluate the severe accident behaviour and the need for mitigation devices implementation => SIMMER study
  - No fixed design
    - More precises studies of the pre-selected design foreseen => feedback on the design => iterative procedure
    - Possible future evolution of the criteria and optimisation objectives of the French commercial SFR

THANK YOU!