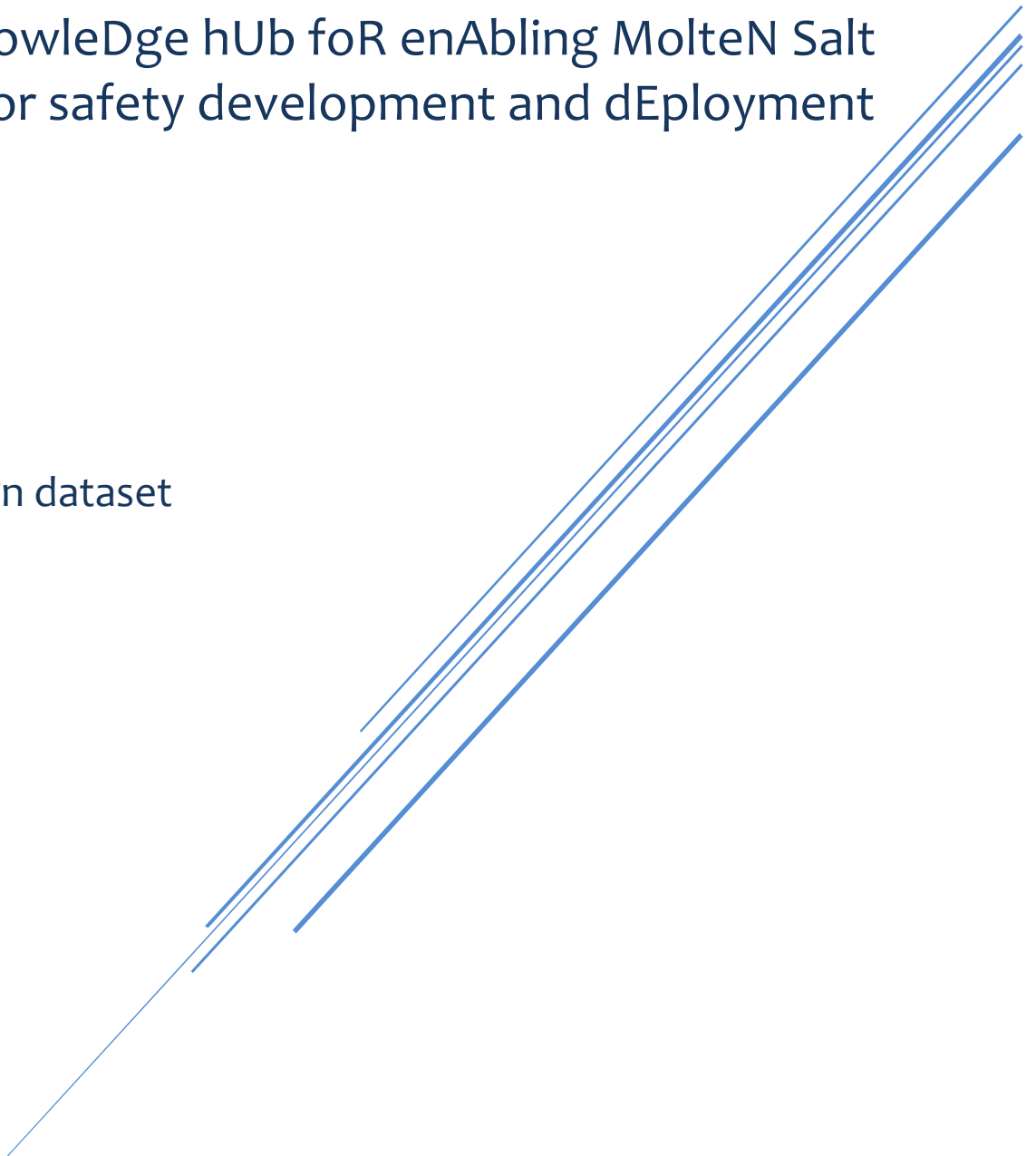




EU kNowleDge hUb foR enAbling MolteN Salt ReaCtor safety development and dEployment

D1.3 Design dataset





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Executive Summary

Based on the preparatory work performed in Deliverable 1.1 that reviews the EU MSR designs of interest for the project, Deliverable 1.3 contains the more detailed database gathering the data of interest to be made available for the studies and calculations of the project. This report thus corresponds to the definition of a design dataset related to the ENDURANCE project, more precisely aligned with the needs of the work-packages 4, 5 and 6.

Four MSR concepts have been selected: MSFR-F and ARAMIS-P, identified as the main case studies for the ongoing activities, and MSFR-CI and Stellarium, considered as additional configurations for the studies foreseen in the project. For these concepts, the report collects the main design characteristics, geometrical specifications, material compositions, thermophysical properties, operating conditions and fuel salt processing schemes, where applicable. The resulting dataset provides a common technical reference to support the modelling, simulation and assessment activities carried out in WP4, WP5 and WP6.

Keywords

Database, system description, Molten Salt Reactor characteristics



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1 Introduction

This report corresponds to the definition of a design dataset related to the ENDURANCE project, more precisely aligned with the needs of the work-packages 4, 5 and 6. The preparatory work has been led in two steps: a first step of identification of the data related to the concepts and the project tasks, and a second step of selection of the most representative concepts depending on the studies and calculations under working in ENDURANCE.

This report is based first on Milestone 3 “Preliminary list of design dataset” as a first step to identify the data required for the studies and calculations of the project on one side, and the data that may be available on the other side. This analysis has been led in coordination with the leaders of WP4 to WP6 and the task leaders of WP6 to identify which data are necessary for the calculations/studies related to their WP and task. This has been achieved by filling in two tables: a first one (see section 2.1) listing the data required for each type of studies foreseen on molten salt reactors in the Endurance project, and a second table (see section 2.2) listing which calculations/studies are or will be performed in each task of WP4, WP5 and WP6. In parallel, a work has been led in coordination with the project designers of the Endurance project to refine which data can be transmitted to the project for their concept (see section 2.3). A first iteration has been done between WP4 to WP6 and designers to check that all the data required are well listed in these tables. These analyses are presented in section 2 below.

The second step consisted in the selection of concepts representative as case studies, that depend on the studies and calculations to be led. This selection has been done by the leaders of the tasks and work packages 4 to 6. The selection is divided in two categories (see section 3):

- Two concepts, already used as case studies in WP4, 5 and 6, have been selected as main case studies with data already available: ARAMIS-P and MSFR-F;
- Two additional concepts may be considered in the following of the studies and analyses of the project: MSFR-CI and the Stellarium.



2 Identification of design dataset for the studies and calculations of WP4, WP5 and WP6

2.1 Categories of studies and calculations in each task of WP4, WP5 and WP6

As presented in Table 1, the following categories of studies and calculations to be done in WP4 to WP6 have been identified, the last category corresponding to some more global and system studies:

- Neutronic calculations
- Burnup calculations
- Deployment scenarios
- Thermalhydraulic calculations (CFD)
- Coupled calculations (neutronics and CFD)
- System code calculations
- Sensitivity studies / Uncertainty Quantification
- Other studies including global system studies (PIRT, cogeneration, processing units, safeguards...)

Table 1. Categories of studies and calculations in each task of WP4, WP5 and WP6.

Task / Type of studies	Neutronic calculations	Burnup calculations	Deployment scenarios	Thermalhydraulic calculations (CFD)	Coupled calculations (CFD)	System code calculations	Sensitivity studies / Uncertainty Quantification	Other studies including global system studies (PIRT, cogeneration, processing units, safeguards...)
Task 4.1 (PIRT)			X					X
Task 4.2 and 4.4	X	X		X	X	X	X	X
Task 4.3 (TAR)								X
Task 4.5				X				
Task 5.1 (fuel cycle sustainability)	X	X	X					
Task 5.2 (source term calc.)		X						
Task 5.3 (review of proc. schemes)								X
Task 5.4 (CFD calc. of droplets)								
Task 5.5 (processes safeguardability and wastes)								X
Task 6.1 TS Flexibility								X
Task 6.2 TS Cogeneration								X
Task 6.3 Flexibility requirements & simulations					X	X		
Task 6.4 Flexibility & safety issues					X	X		X

2.2 Type of data required for the various categories of studies foreseen in the WP4 to WP6 of the Endurance project

In a second step of the identification work, the data required for each category of study have been identified as presented in Table 2 below, leading to the following list of design data:

- Thermal power
- Fuel composition
- Intermediate coolant composition
- Fuel processing schemes
- Structural material composition and temperature
- Fuel temperature



- Flow rate in the different circuits
- Neutronic properties of the core
- Physico-chemical properties of the fuel salt
- Physico-chemical properties of the intermediate salt
- Core geometry
- Fuel circuit arrangement
- Other systems (decay heat removal system, conversion system...)
- Reactor operation strategy

Table 2. Type of data required for the various categories of studies foreseen in the WP4 to WP6 of the Endurance project.

Data / Type of studies	Neutronic calculations	Burnup calculations	Deployment scenarios	Thermalhydraulic calculations (CFD)	Coupled calculations (CFD)	System code calculations	Sensitivity studies / Uncertainty Quantification	Other studies including global system studies (PIRT, cogeneration, processing units, safeguards...)
Thermal power	X	X		X	X	X		X
Fuel composition	X	X		X	X	X	X (on nuclear data for 4.2)	X (for PIRT, actinide mass for safeguards)
Coolant composition	No if out of core	No if out of core		Yes if HX/intermediate system modeled	Yes if HX/intermediate system modeled	X		
Fuel processing schemes		X	X					X
Structural material composition and temperature	X	X			X	X		X (6.1 & 2 & 4 : T max value for safety)
Fuel temperature	X	X		X	X	X	X	X (6.1 & 2 & 4 : min & max value for safety)
Flow rate				X	X	X	X	X (6.1 & 2 & 4 : min & max value for safety)
Neutronic properties of the core						Neutronic calculation output		
Physico-chemical properties of the fuel salt	X	Density (1 mean temperature)		Density, viscosity, Cp, thermal conductivity (fonction of T)	Density, viscosity, Cp, thermal conductivity (fonction of T)	X		X (density for safeguards)
Physico-chemical properties of the intermediate salt				X	X	X		
Core geometry	Approximative shape	Approximative shape		CAD drawings	CAD drawings	Approximative shape		X (fuel volume for safeguards)
Fuel circuit arrangement				X	X	X		X (for PIRT, safeguards)
Other systems (DHR, conversion...)				X	X	X		X (for PIRT)
Reactor operation strategy								X (6.1)

2.3 Data available for each European MSR concept of the Endurance project

The last step of the identification work has been to refine which data can be transmitted to the project for each of the MSR concepts for which designers are partners of the Endurance project (ARAMIS-A, ARAMIS-P, CMSR, MSFR-F, MSFR-CI, Stellarium, XAMR), as presented in Table 3.



Table 3. Data potentially available for each European MSR concept of the Endurance project.

Data provided / Design	ARAMIS-A	ARAMIS-P	CMSR	MSFR-F	MSFR-CI	Stellaria	Thorizon One	XAMR
Thermal power	X	X	X	X	X	X		X
Fuel composition	X	X	X	X	X	X		X
Coolant composition	X	X		X	X	X		X
Fuel processing schemes			N/A	X	X			
Structural material composition	X	X	X	X	X	X		X
Fuel temperature	X	X	X	X	X	X		X
Flow rate	X	X		X	X	X		X
Neutronic properties of the core	X	X		X	X	X		X
Physico-chemical properties of the fuel salt	X	X	X	X	X	X		X
Physico-chemical properties of the intermediate salt	X	X	X					X
Core geometry		X		CAD drawings	CAD drawings	Dimensions table		Dimensions table
Fuel circuit arrangement		X		X		X		
Other systems (DHR, conversion...)				Conversion circuit and DHR system: yes Nothing on cogeneration	Not studied			
Reactor operation strategy		X		X				



3 Selection of Design dataset

As stated at the beginning of the present report, the selection of concepts representative as case studies, that depend on the studies and calculations to be led, has been done in collaboration with the leaders of the tasks and work packages 4 to 6. The selection is divided in two categories, whose data are detailed in the following sections:

- Two concepts, already used as case studies in WP4, 5 and 6, have been selected as main case studies with data already available: MSFR-F (section 3.2) and ARAMIS-P (section 3.5);
- Two additional concepts may be considered in the following of the studies and analyses of the project: MSFR-CI (section 3.3) and the Stellarium (section 3.4).

3.1 List of the selected concepts

The overall characteristics of the four concepts whose data are listed in the present deliverable are summarized in Table 4.

Table 4: List of molten salt reactor concepts detailed in the present database

Concept	Fuel carrier	Moderator	Neutron spectrum	Fissile matter / Fuel cycle	Power [MW _{th}]	Use
ARAMIS-P (CEA / Orano)	Chloride	None	Fast	Pu	300	Electricity production + Waste reduction
MSFR-F (CNRS + EU projects)	Fluoride	None	Fast	²³³ U – enrich U – Pu + MA / Th fuel cycle	3000	Electricity production
MSFR-CI (CNRS + SAMOSAFER)	Chloride	None	Fast	Pu + MA / U fuel cycle	100 to 3000	Electricity production + Waste reduction
Stellarium (Stellaria)	Chloride	None	Fast	U-based or Pu-based	544	Energy + Waste reduction



3.2 MSFR-F concept

Since 2004, the National Centre for Scientific Research (CNRS, France) has focused R&D efforts on the development of a new MSR concept called the Molten Salt Fast Reactor (MSFR) supported by the successive Euratom's projects: EVOL (Evaluation and Viability Of Liquid fuel fast reactor systems, 2009-2013), SAMOFAR (Safety Assessment of MOlten salt FAsT Reactor, 2015-2019) and SAMOSAfer (Severe Accident MOdeling and Safety Assessment for Fluid-fuel Energy Reactors, 2019-2023) Euratom projects of respectively the Framework Program 7 [Brovchenko et al., 2014a; Dulla et al., 2014, Merle et al., 2018] and the Horizon2020 program [Gerardin et al., 2017].

The MSFR does not employ any solid moderator (no graphite lifespan issues) which results in a fast spectrum breeder reactor with a large negative power coefficient. The initial version of the MSFR, named "reference MSFR" or MSFR-F, based on a fluoride LiF salt, can be operated in a Thorium fuel cycle. A new version named MSFR-Cl [Pitois, 2022] has been developed in the SAMOSAfer project, based on a chloride NaCl salt, can be operated in the Uranium fuel cycle (see section 3.3). Other advantages of an MSR as the MSFR include homogeneous fuel irradiation and the possibility of fuel reload and processing on-line or in batch mode, without requiring reactor shut-down and involving the transfer of small volumes of fuel. GIF forum selected the MSFR concept in 2008 as one of the GEN IV reference reactors. The MSFR concept is at a conceptual design phase.

The design studies on the MSFR have to be seen as a basis for interdisciplinary studies and not some plans to build a reactor directly. CNRS being not a vendor, the goal of the MSFR development and optimization is to identify the possible viable configurations of homogeneous breeder MSRs regarding physics, chemistry and material sciences and to propose a realistic working horse for various R&D studies and training of the European community.

3.2.1 General characteristics and system description

3.2.1.1 Plant overview

The system includes three circuits: the fuel circuit, the intermediate circuit and the power conversion circuit as illustrated in Figure 1.

The reference MSFR or MSFR-F, based on fluoride salts and the Th/²³³U fuel cycle, has with a total fuel salt volume of 18 m³, operated at a max fuel salt temperature of 750°C [Mathieu et al., 2009; Merle-Lucotte et al., 2012; Brovchenko et al., 2019].

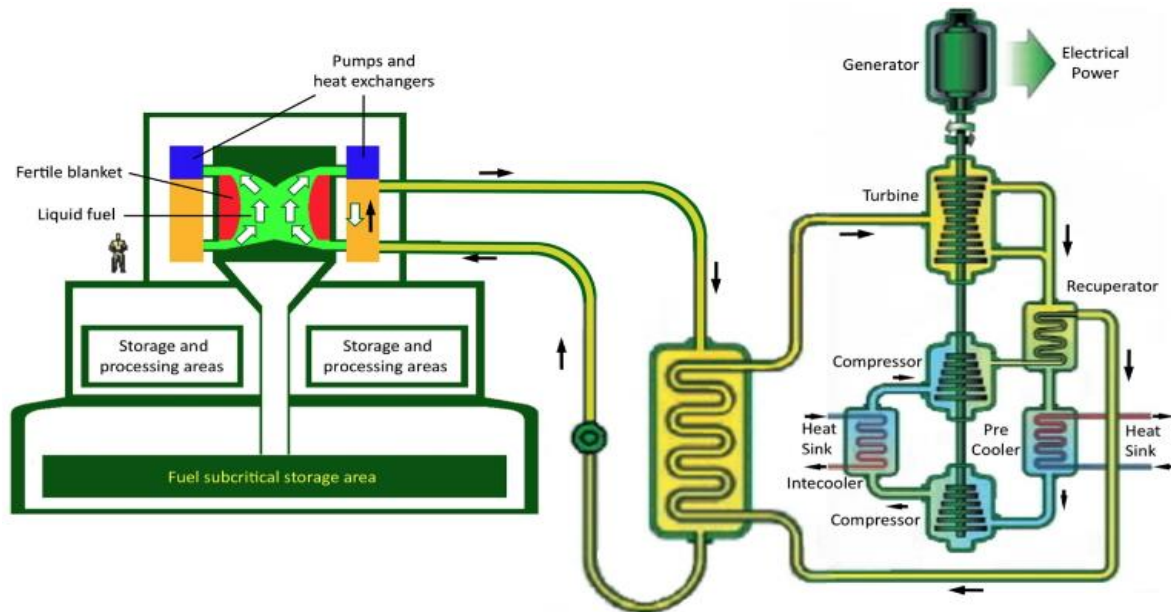


Figure 1: Overview of the MSFR concept

3.2.1.2 Fuel circuit

The fuel circuit, displayed in Figure 2, is defined as the circuit that contains the fuel salt during power generation, includes the core cavity and the recirculation-cooling loops or sectors (16 in the MSFR-F), which are mainly comprised by the inlet and outlet pipes, pumps, and fuel heat exchangers.

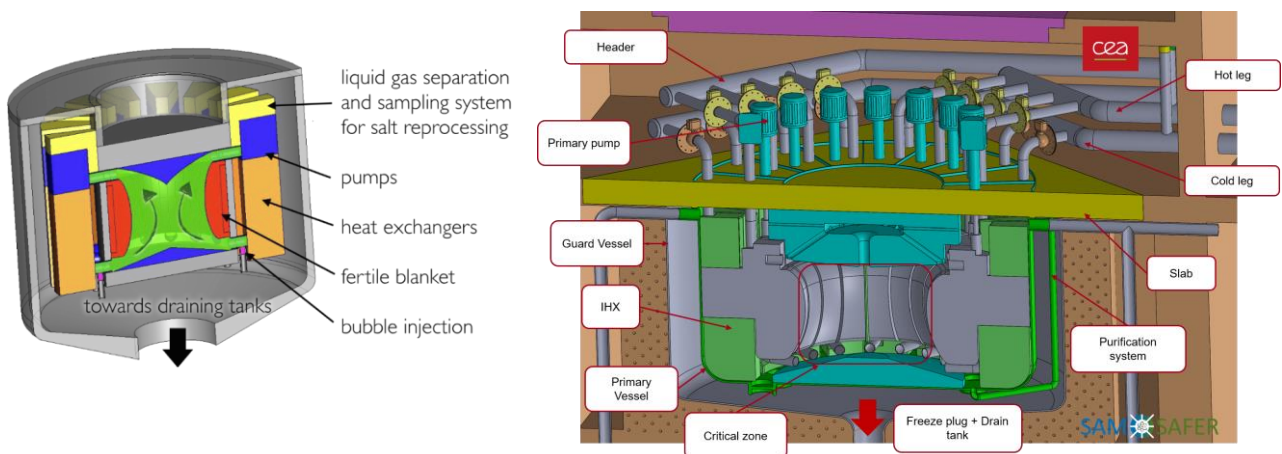


Figure 2: Schematic representation (left – CNRS studies) and CAD drawings (right – SAMOSAFER project) of the reference MSFR fuel circuit

The fuel circuit is connected to a salt draining system which can be used for a planned shut down or in case of any incident/accident resulting in an excessive temperature being reached in the core. In such situations the fuel salt geometry can be passively reconfigured by gravity driven draining



of the fuel salt into tanks located under the reactor and where a passive cooling and adequate reactivity margin can be implemented.

The characteristics of the MSFR-F fuel circuit are listed in Table 5. The external core structures and the fuel heat exchangers are protected by thick reflectors made of nickel-based alloys, which are designed to absorb more than 99% of the escaping neutron flux. These reflectors are themselves surrounded by a 20cm thick layer of B_4C , which provides protection from the remaining neutrons. The radial reflector includes a fertile blanket (50 cm thick - red area in Figure 2 left) to increase the breeding ratio. This blanket is filled with a LiF-based fertile salt with initially 22.5mol % $^{232}ThF_4$. Due to the neutron inelastic scattering on fluorine nuclei, the MSFR spectrum is a bit less fast than that of solid-fueled fast reactors. This fact, combined to the absence of solid material in the core, results in reduced irradiation damages of the materials surrounding the core.

Table 5. General characteristics of the MSFR-F 3000 MW_{th} fuel circuit

Parameters	Units	Values
Ternary salt		LiF – ThF ₄ – ²³³ UF ₄
Fuel salt	%mol	76.3245 – 20.9636 – 2.7119
Fertile blanket salt		76.602 – 23.398 – 0
Fuel loop design		16 loops design
Thermal power	MW _{th}	3000.0
Fuel salt volume	m ³	18 (50% in the core)
Blanket salt volume	m ³	7.33
Fuel salt power density	MW/m ³	166.7
Fuel salt density	g/cm ³	$4.2128 - 8.94 \cdot 10^{-4} \cdot (T(K)-973)$
Blanket salt density	g/cm ³	$4.1835 - 8.90 \cdot 10^{-4} \cdot (T(K)-973)$
Salt viscosity	m ² /s	$5.54 \cdot 10^{-8} \exp(3689/T(K))$
Thermal conductivity	W/m/K	$0.928 + 8.397 \cdot 10^{-5} \cdot T(K)$
Calorific capacity	J/kg/K	$(-1.111 + 0.00278 \cdot T(K)) \cdot 10^3$
Input/output temperature	K	923 / 1023

The criticality enrichment is adjusted using JEFF4.0 on the eutectic line from Figure 3 and corresponds to a U/(U+Th) of $(11.455 \pm 0.001)\%$, corresponding to a multiplication factor of $1 \pm$



4pcm (considering the statistical uncertainty only) at 973K. The density is extrapolated using the salt mixture densities and atom masse and volume [Ignatiev et al, 2012] [Janz et al, 1974]. The viscosity, the thermal conductivity and the calorific capacity are coming from [Ignatiev et al, 2012] and assumed to be identical for both salts.

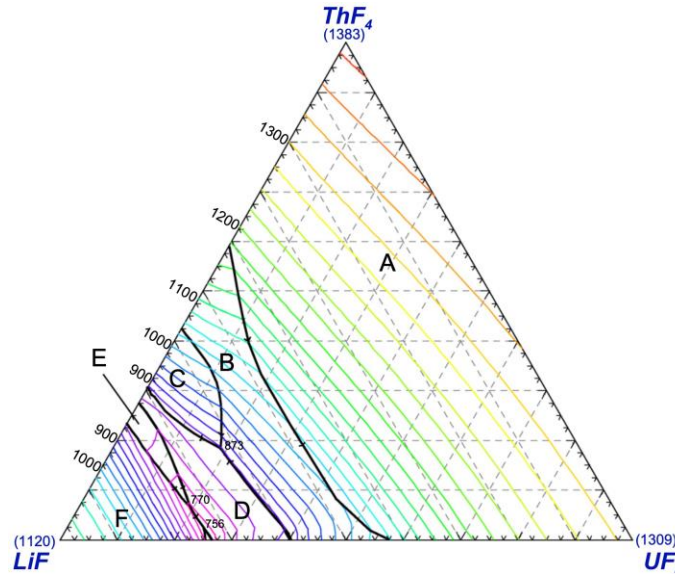


Figure 3: LiF–UF₄–ThF₄ ternary diagram [Beneš et al, 2010]

3.2.1.3 Energy conversion circuit

Regarding the energy conversion systems, PoliMi identified a Helium Joule-Brayton cycle as a potential candidate to take advantage from the high temperatures of the MSFR concept while complying with the potential risk of salt freezing in the intermediate circuit [Di Ronco et al., 2020]. Supercritical steam cycle options may offer higher efficiency but can be more prone to salt freezing in the conversion heat exchanger.

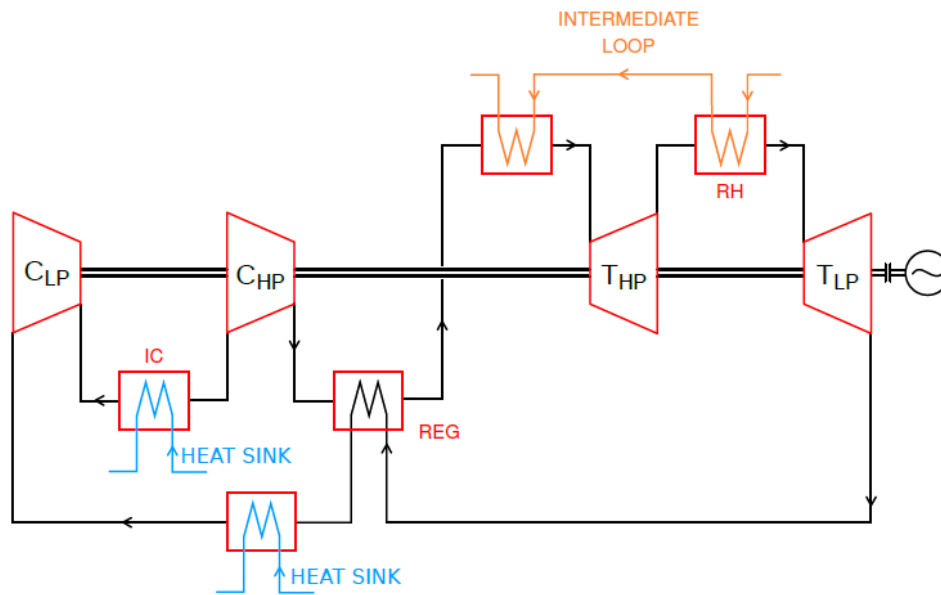


Figure 4: Simplified scheme of a closed gas cycle plant: RH = reheater, IC = intercooler, REG =regenerator, HP/LP = high/low pressure [Di Ronco et al., 2020]

The general layout is depicted in Figure 4. The optimization of the layout led to consider three intercooling stages and three reheating stages. The static optimization has been implemented in a Modelica-based model of the Energy conversion system (Figure 5). Table 6 provides the main parameters of the cycle while additional details can be found in [Di Ronco et al., 2020].

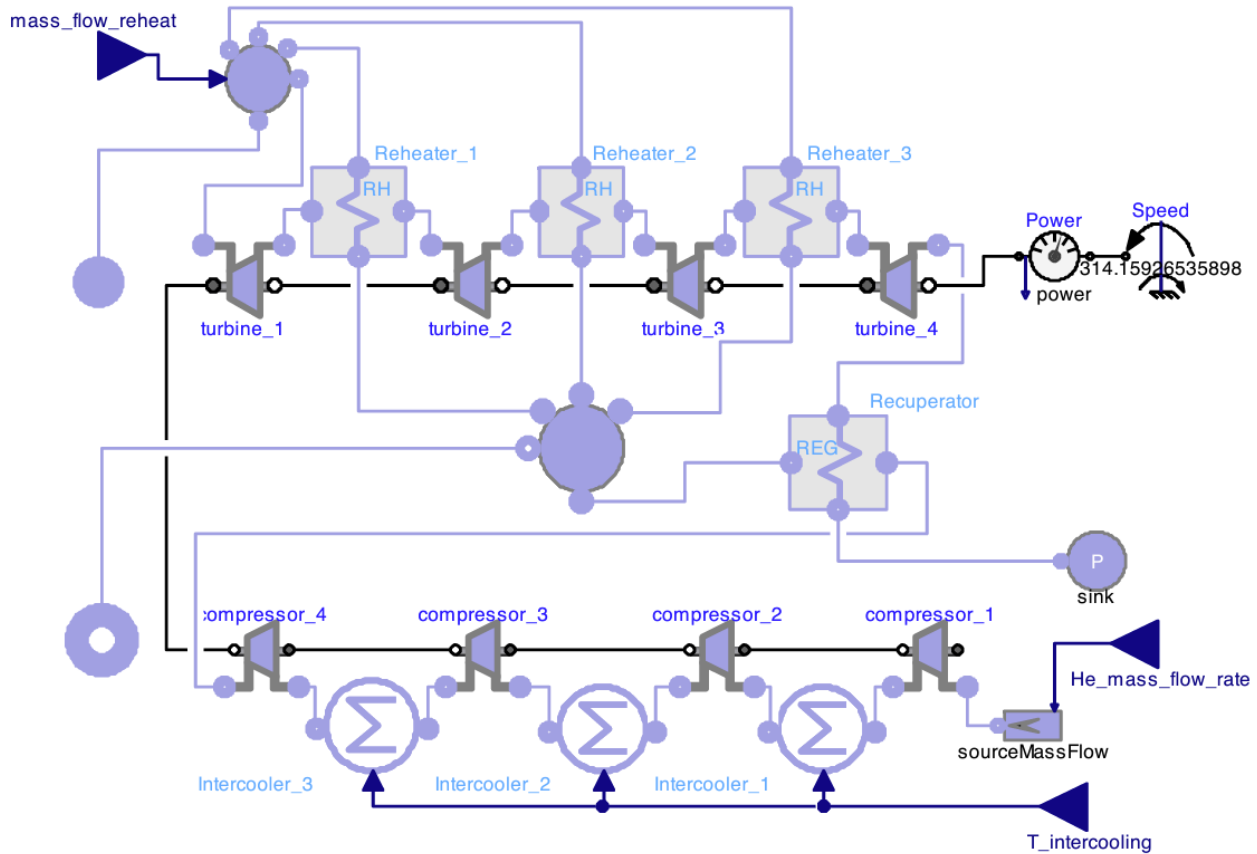


Figure 5: Energy conversion system (Helium Joule-Brayton cycle) model developed in Modelica [Tripodo et al., 2019]

Table 6: Main parameters of the Energy conversion system (He Joule-Brayton cycle)

Parameter	Value
Outlet He gas temperature	625 °C
Inlet He gas temperature	462 °C
Cycle efficiency	~40%
Gas mass flow rate (total mass flow rate for 3000 MW MSFR)	1211 kg/s

3.2.2 Detailed geometry related characteristics

As shown in the sketch of Figure 2, the fuel salt flows from the bottom to the top of the core cavity (note the absence of in core solid matter). In preliminary designs developed in relation to calculations, the core of the MSFR is a single compact cylinder (2.25 m high per 2.25 m diameter for the MSFR-F version), where the nuclear reactions occur within the liquid salt acting both as fuel and as coolant.

Thermal-hydraulic studies using RANS modeling performed in the frame of the EVOL project have shown that a torus shaped core (see Figure 6 on the left) improves thermal flow [Laureau et al., 2013; Rouch et al., 2014], while more recent optimization studies based on DES CFD calculations led to a new optimized core geometry to reduce temperature and thus power fluctuations (Figure 6 right). For the thermalhydraulic and the coupled calculations, the CAD drawings of both geometries of Figure 6 are available on the sharepoint: the *msfr_f_evol.step* and the *msfr_f_optim.step* files.

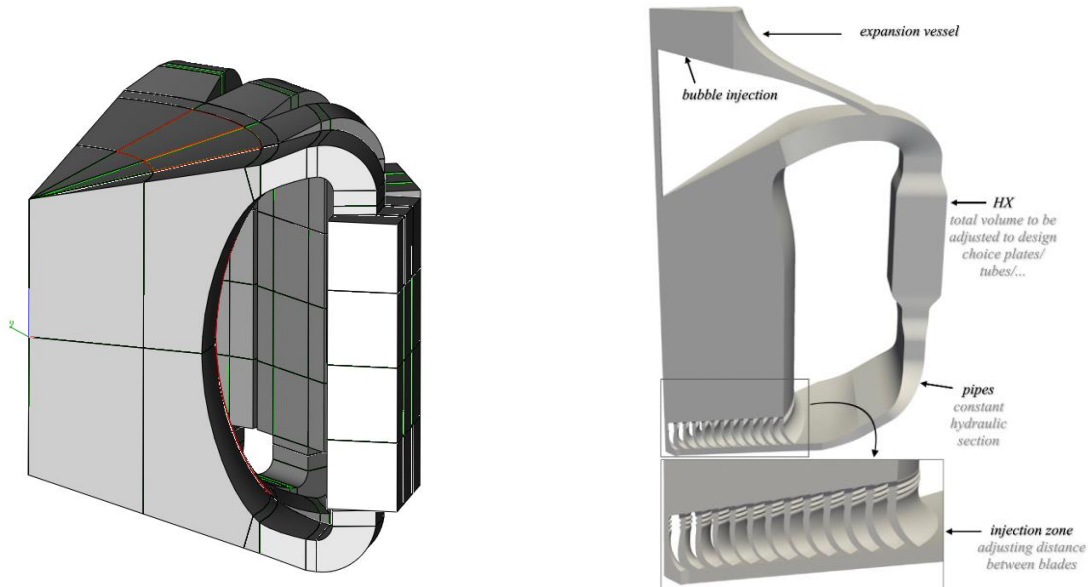


Figure 6: MSFR fuel circuit geometries optimized through CFD RANS modelling ('EVOL shape' – left) and CFD DES modelling ('optimized shape' – right)

Two geometries are provided for neutronics calculations, the cylindrical (see Figure 7) and the CAD (see Figure 6 right). The cylindrical one is more likely to be used pure neutronics computation (e.g. depletion, uncertainty propagation...) or system code calculation, and the CAD geometry is more likely to be used for coupled calculation using 3D high fidelity model.

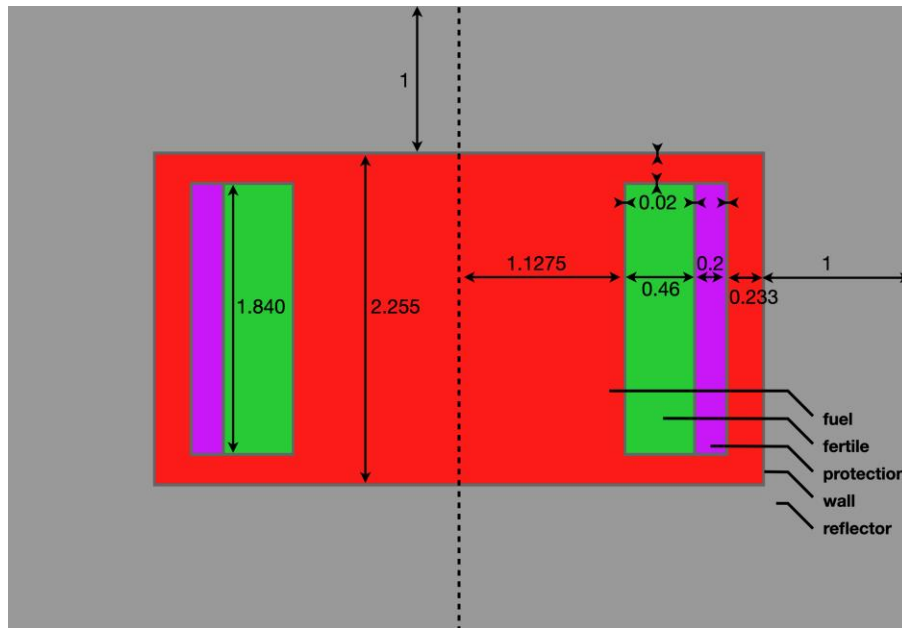


Figure 7: Neutronics cylindrical geometry, dimensions are given in m

The corresponding EVOL cylindrical geometry for the OpenMC definition is provided for verification purpose in Appendix 1.

3.2.3 Material composition

The material compositions adopted for the MSFR-F neutronic model are summarized in Table 7. The fuel salt and fertile blanket compositions correspond to the ^{233}U fuel cycle configuration. Lithium is enriched to 99.95% in ^7Li . The structural walls and reflector are modelled using a Ni–Cr–W alloy, while boron carbide (B_4C) is used for neutron shielding. The OpenMC material definition is provided in Appendix 2

Table 7: Material compositions and densities adopted in the MSFR-F OpenMC model.

Material	Composition	Density (g/cm ³)
Fuel salt	$\text{LiF-ThF}_4\text{-}^{233}\text{UF}_4$ (76.3245–20.9636–2.7119 mol%)	4.2128
Fertile blanket	LiF-ThF_4 (76.602–23.398 mol%)	4.1835
Neutron shielding	B_4C , natural isotopic composition	2.5
Structural walls and reflector	Ni–Cr–W (81.54–8.22–10.24 at%)	10



3.2.4 Fuel salt processing scheme

The fuel salt undergoes two types of treatment: on-line neutral gas bubbling in the core and delayed mini-batch on-site reprocessing [Delpech et al., 2009]. This is displayed in Figure 8 for the MSFR-F. These salt treatments aim at removing most of the fission products without stopping the reactor and thus securing a rather small fissile inventory outside the core compared to present day LWRs. The reprocessing rate itself is assumed equivalent to the present LWR rate, although it could be possible to reprocess the fuel salt every ten years but to the detriment of economical yield.

The gas bubbling has two objectives: removing metallic particles by capillarity (floating) and extracting gaseous fission product before their decay in the salt. The second part of the processing is a semi-continuous salt reprocessing at a rate of some tens (10-40) liters per day for the MSFR-F, in order to limit the lanthanide and Zr concentration in the fuel salt. The salt sample is returned to the reactor after purification and after addition of ^{233}U and Th as needed to adjust the fuel composition and the redox potential of the salt by controlling the U^{4+} to U^{3+} ratio.

These two processes aim at keeping the liquid fuel salt in an efficient physical and chemical state for long time periods (decades).

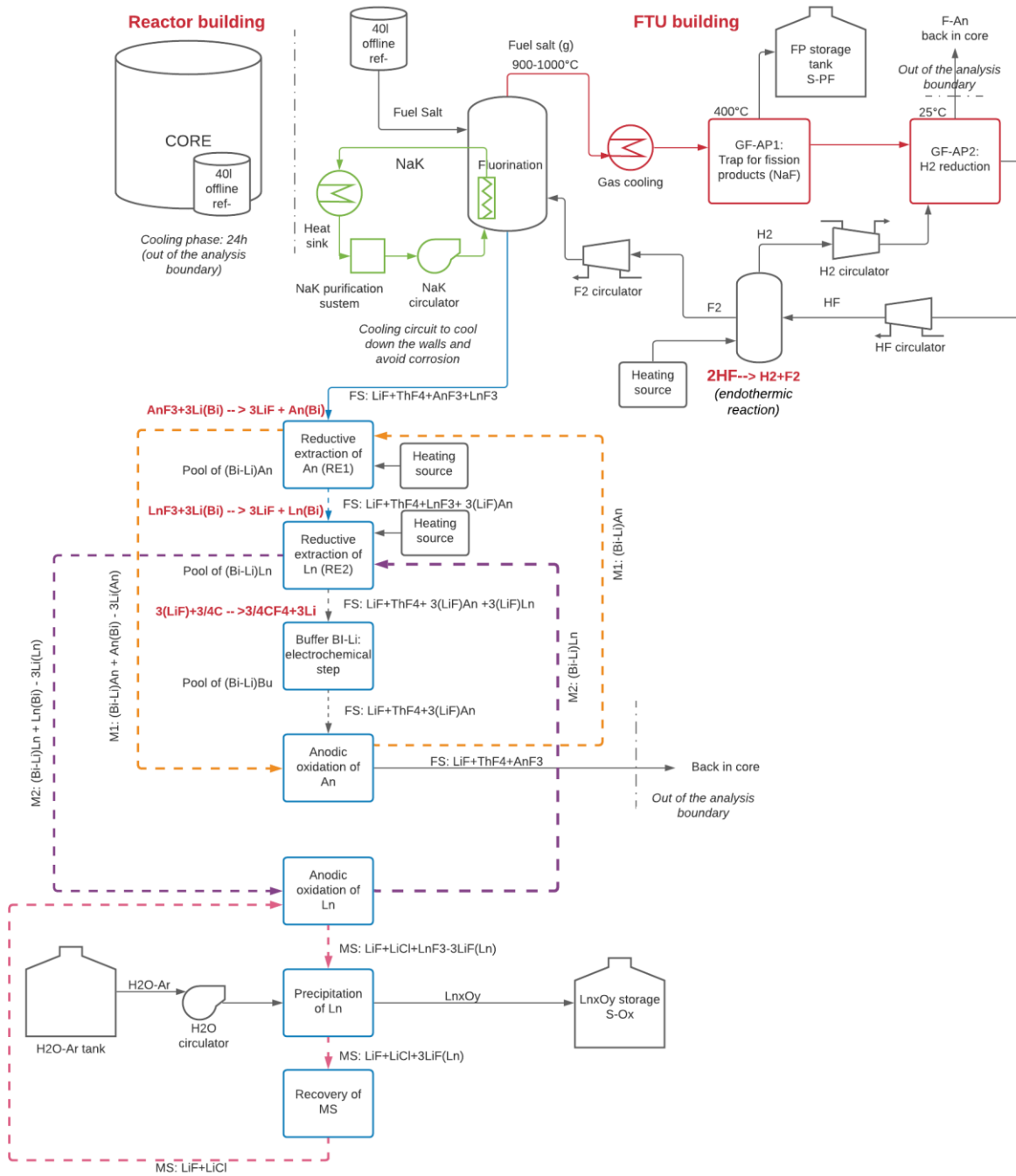


Figure 8: Schematic representation of the fuel salt treatment units of the MSFR-F [SAMOSAfer D1.3, 2023]



3.3 MSFR-CI concept

The chloride MSFR concept, initially developed at CNRS during the SAMOSAfer European project, is divided into two design categories, the specifications for which are provided in this section: a ‘large’ reactor of 3 GW_{th} (named in the following “MSFR-CI 3000 MW_{th}”) equivalent to the MSFR-F, mainly studied in terms of evolutive neutronics and reprocessing in the frame of the PhD thesis of Hugo Pitois [Pitois, 2023][Pitois et al, 2022] funded by Samosafer; and SMR versions (named in the following “SMSFR-CI”) mainly studied at CNRS, Framatome and Orano in coupled neutronic thermalhydraulic calculations, design optimisations and noise studies in the frame of the PhD theses of Thomas Sornay [Sornay, 2024][Sornay et al, 2023] and Max Begue [Begue et al, 2025].

3.3.1 General characteristics and fuel circuit

The MSFR-CI – 3000MW_{th} version, based on chloride salts and the U/Pu fuel cycle, has a total fuel salt volume of 45 m³. The MSFR-CI-3000M_{th} configuration listed in Table 8 comes from [Pitois, 2023] for used UOX fuel.

Table 8: General characteristics of the MSFR-CI 3000 MW_{th} concept

Parameters	Units	Values
Ternary salt		NaCl–UCl ₃ –PuCl ₃
Fuel salt	% _{mol}	65.7-28.4-5.9
Fuel loop design		24 loops design
Thermal power	MW _{th}	3000.0
Fuel salt volume	m ³	45 (44.4% in the core)
Blanket salt volume	m ³	23.4
Reflector volume	m ³	7.4
Fuel salt density	g/cm ³	$3.19 - 0.002 \cdot (T(K) - 925)$
Blanket salt density	g/cm ³	$3.86 - 0.0008371 \cdot T(K)$
Heat capacity	J/kg/K	627
Input/output temperature	K	850 / 1000

The fuel composition corresponds to the eutectic line from Figure 9.

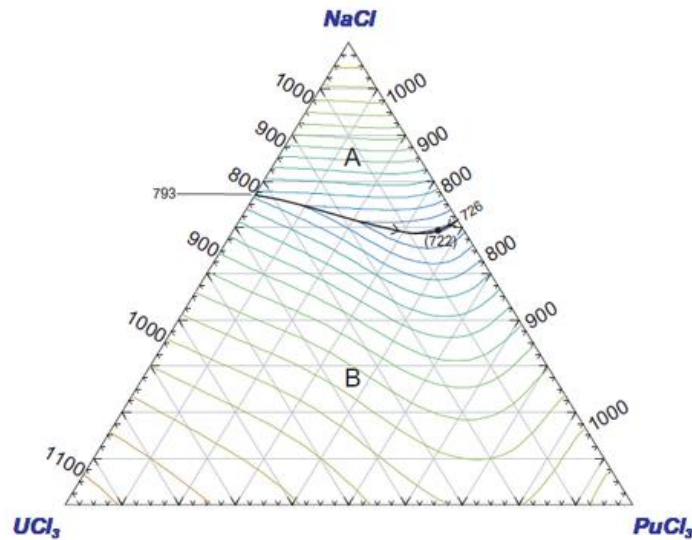


Figure 9: NaCl- UCl_3 - PuCl_3 ternary diagram [Beneš et al, 2008]

3.3.2 Geometry

The fuel circuit, defined as the circuit that contains the fuel salt during power generation, includes the core cavity and the recirculation-cooling loops or sectors (24 in the MSFR-Cl – 300MW_{th} and less, for example here 8 for the SMSFR-Cl), which are mainly comprised by the inlet and outlet pipes, pumps, and fuel heat exchangers.

Scaling effects of the MSFR-Cl have been studied in the frame of the PhD thesis of Thomas Sornay [Sornay, 2024] in collaboration between CNRS and Framatome, by varying the fuel salt volume and the number of circulation/cooling loops, with a particular focus on smaller and lower-power reactors, akin to Small Modular Reactor (SMR) designs. These studies involved coupled neutronic thermal-hydraulic calculations and multicriteria design optimization.

No official CAD description is associated to the MSFR-Cl geometry coming from a previous project (such as EVOL for the MSFR-F). The *msfr_cl.stp* on the sharepoint (see Figure 10) can be used for coupled high fidelity calculation code, note that the system volume have to be adjusted accordingly.

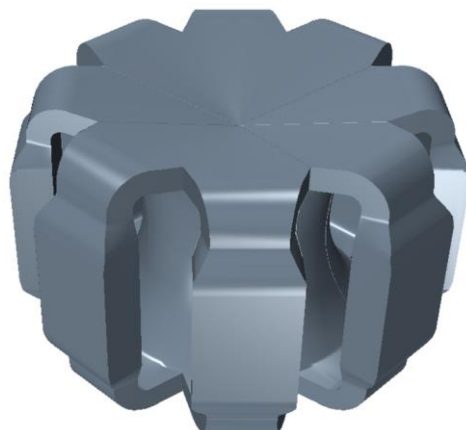


Figure 10: eight recirculation loops configuration *msfr_cl.stp* [Sornay, 2024]



3.3.3 Material composition

The uranium in UCl_3 is depleted uranium (0.2% enrichment) and the plutonium in PuCl_3 composition is indicated in Table 9 along with transuranic elements.

Table 9 : Transuranic elements from ex-UOX fuel [Mesthiviers, 2022]

Nuclide	Isotopic ratio
^{238}Pu	2.76E-2
^{239}Pu	4.64E-1
^{240}Pu	2.24E-1
^{241}Pu	1.05E-1
^{242}Pu	6.90E-2
^{237}Np	5.41E-2
^{241}Am	3.31E-2
$^{242\text{m}}\text{Am}$	9.00E-5
^{243}Am	1.62E-2
^{243}Cm	5.00E-5
^{244}Cm	6.00E-3
^{245}Cm	5.00E-4
^{246}Cm	6.00E-5

3.3.4 Fuel salt processing

As for the MSFR-F, the fuel salt of the MSFR-Cl-3000MW_{th} undergoes two types of treatment: on-line neutral gas bubbling in the core and delayed mini-batch on-site reprocessing. The processing scheme developed for the MSFR-F has been adapted in the frame of the PhD thesis of Hugo Pitois [Pitois, 2023] for the chloride fuel salt or the MSFR-Cl-3000MW_{th}, as displayed in Figure 11.

The main steps of the processing scheme are the following:

- Gas swipe and fuel tapping are performed in the expansion vessel in order to avoid in-core gas injection.
- Gases and volatile species are first sent towards cold traps to isolate the latter, then a part of the formers is processed with advanced techniques.



- Metallic particles are adsorbed on solid metallic traps. It is possible assuming that the fuel circuit is coated in a non-metallic material. Otherwise they are likely to be adsorbed in heat exchangers that present a significant area, ultimately leading to clogging and/or damages.
- Lanthanides can be extracted by electrolysis with separate compartments, but actinides must be extracted first because of the respective electrochemical potentials. Formers are then oxidized, they precipitate and are filtrated out. The latter are reinjected in the core.
- Advanced processing of fission products can be performed off-site, using aqueous chemistry. On-site chemical treatment can only use pyrochemical processes due to the high temperature and radiolysis risks for compounds at low temperature.

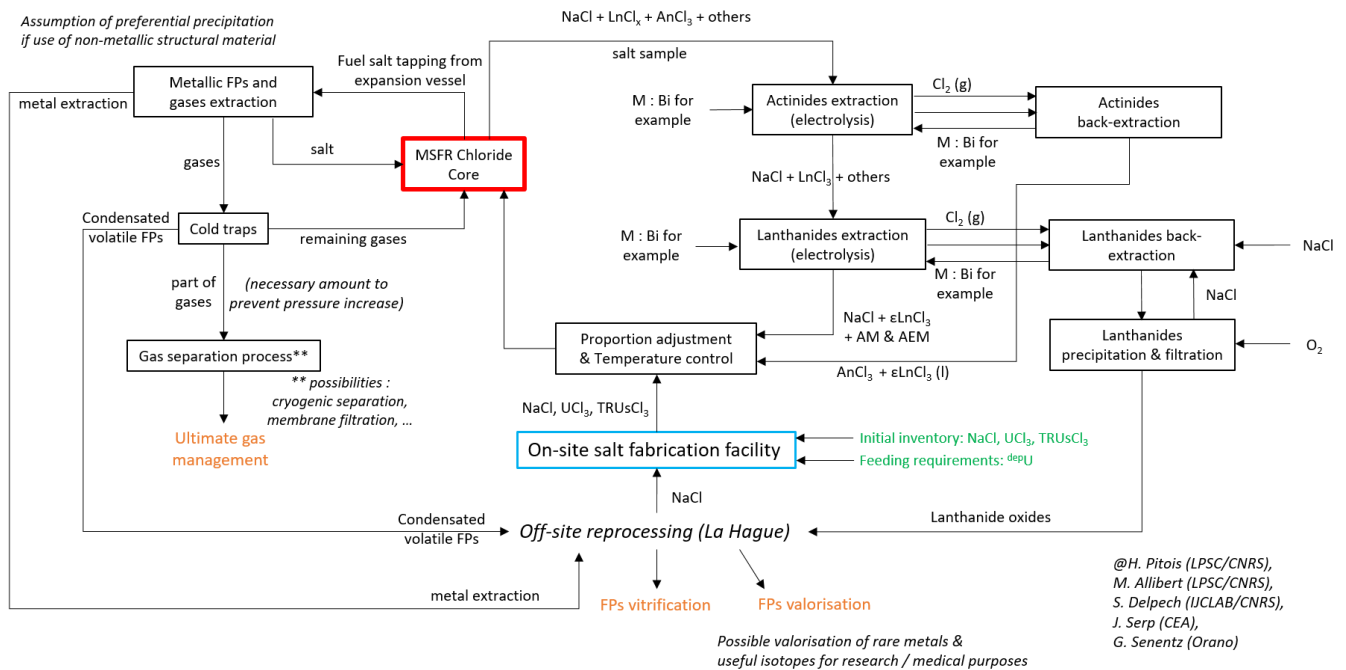


Figure 11: Principle diagram for the MSFR-Cl reprocessing scheme [Pitois et al., 2023]



3.4 Stellarium concept

3.4.1 General characteristics

Stellarium is a fast molten chloride reactor designed to operate in natural circulation at a nominal thermal power of 544 MW_{th}. This document compiles its geometric and physical data, including the overall dimensions, material and fluid compositions and properties. The heat exchanger is represented by two radial zones with specified porosity and hydraulic-diameter profiles; pressure losses use a Darcy friction factor, and convective heat transfer is modelled with a Nusselt correlation.

3.4.2 Geometry

3.4.2.1 Vessel and geometric envelope

The parametric dimensions define the overall reactor envelope and the material volumes described in the following sub-sections. Figure 12 shows a schematic cross-section with the overall dimensions; Figure 13 provides a simplified representation. The associated dimensions are provided in Table 10.

3.4.2.2 Heat exchanger: geometry and flow characteristics

The precise description and technological details of the heat exchanger are not provided here. The heat exchanger is represented by two radial zones. Table 11 gives their dimensions, volume fractions, porosity, hydraulic diameters, friction factor and Nusselt correlations. The pressure drop follows Darcy–Weisbach:

$$\Delta p = f \frac{L}{D_h} \frac{\rho u^2}{2}$$

with f and D_h defined in Table 11. The convective heat-transfer coefficient is $h = \text{Nu} \cdot \lambda / D_h$, where λ denotes the thermal conductivity of the fluid considered.

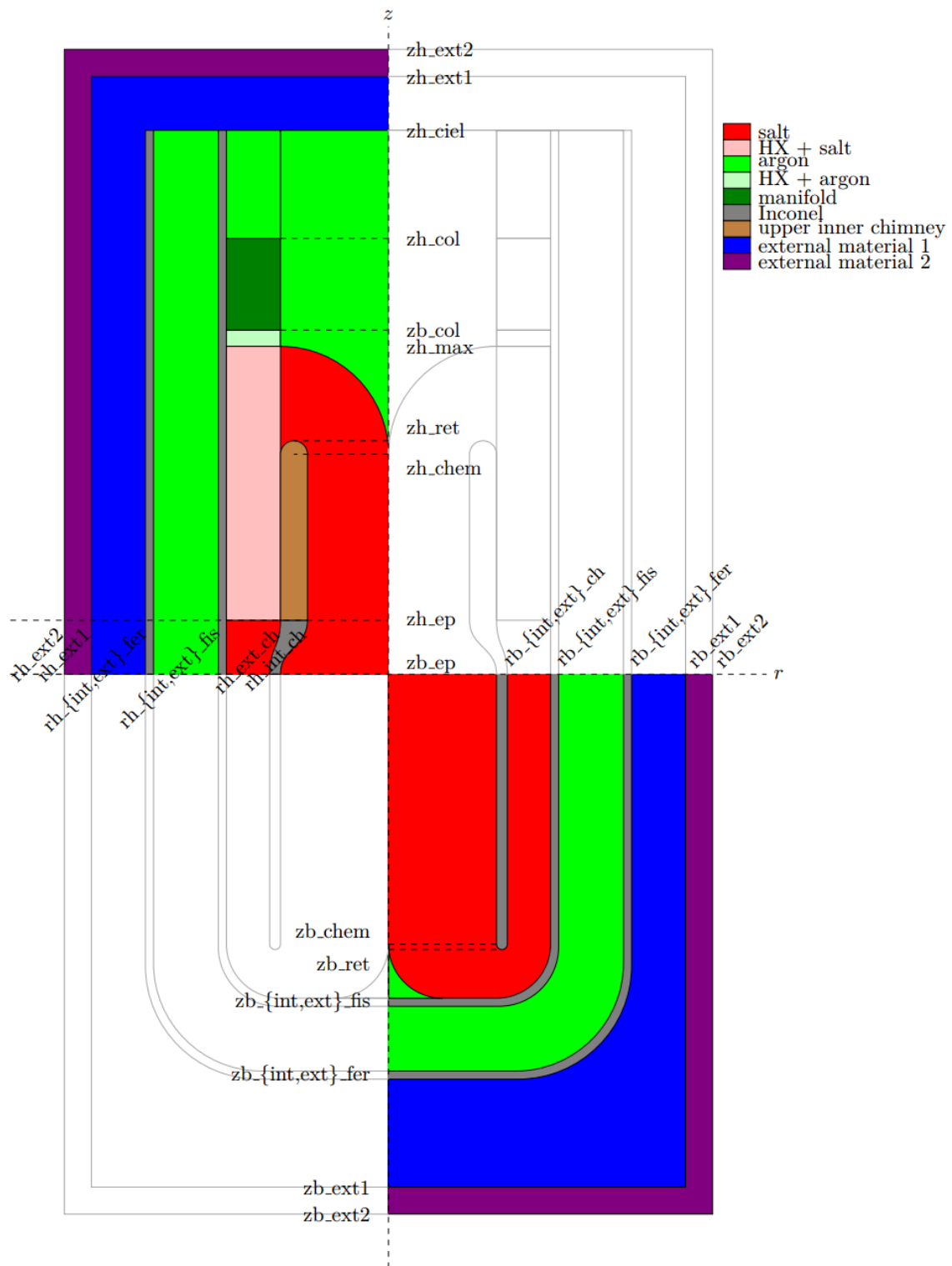


Figure 12: Dimensioned overview of Stellarium, with dimensions identified in Table 10.



Table 10: Radial and axial dimensions of the Stellarium envelope

Dimension (mm)	Stellarium
rh_int_ch	495.3
rh_ext_ch	535.3
rb_int_ch	878.1
rb_ext_ch	883.1
rb_int_fis	1184.0
rh_int_fis	1184.0
rb_ext_fis	1200.0
rh_ext_fis	1200.0
rb_int_fer	1230.0
rh_int_fer	1230.0
rb_ext_fer	1246.0
rh_ext_fer	1246.0
rb_ext1	1256.0
rh_ext1	1256.0
rb_ext2	1956.0
rh_ext2	1956.0
rb_ext3	1966.0
rh_ext3	1966.0
rb_ext4	1976.0
rh_ext4	1976.0
rb_ext5	1986.0
rh_ext5	1986.0
rb_ext6	2586.0
rh_ext6	2586.0
rb_ext7	2596.0
rh_ext7	2596.0

Dimension (mm)	Stellarium
zh_ext7	940.0
zh_ext6	930.0
zh_ext5	330.0
zh_ext4	320.0
zh_ext3	310.0
zh_ext2	300.0
zh_ciel	0.0
zh_ext1	0.0
zh_col	-795.0
zb_col	-1145.0
zh_max	-1395.0
zh_ret	-2023.7
zh_ref	-3050.0
zh_ep	-3150.0
zh_int	-3190.0
zb_ref	-3250.0
zb_ext	-3630.0
zb_ep	-3670.0
zb_ret	-4937.1
zb_int_fis	-5500.0
zb_int_br	-5500.0
zb_ext_fis	-5516.0
zb_int_fer	-5546.0
zb_ext_fer	-5562.0
zb_ext1	-5572.0
zb_ext2	-6272.0
zb_ext3	-6282.0
zb_ext4	-6292.0
zb_ext5	-6302.0
zb_ext6	-6902.0
zb_ext7	-6912.0

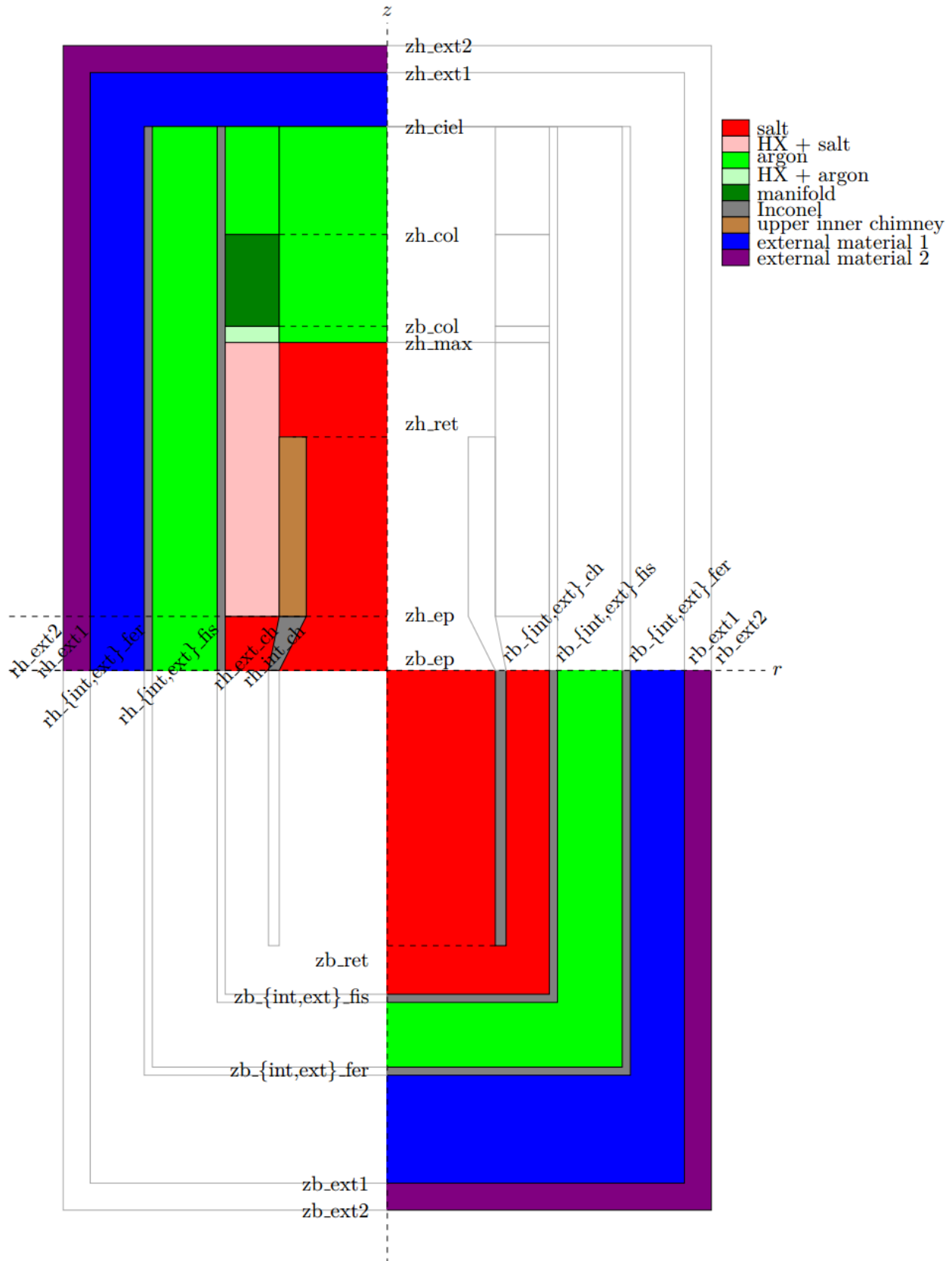


Figure 13: Simplified representation of the Stellarium envelope and overall dimensions



Table 11: Geometry, volume fractions, flow and heat-transfer characteristics of the heat exchanger

Parameter	Inner zone	Outer zone
Height within the salt	1755 mm	
Height above the salt	250 mm	
Fuel salt volume fraction	68.12%	24.72%
Inconel volume fraction	15.94%	11.50%
Primary salt volume fraction	15.94%	63.78%
Inner radius	0.5353 m	1.1439 m
Outer radius	1.1439 m	1.1840 m
Porosity ϕ	$\phi_{fi}(r) = 1 - \frac{0.26770}{r}$	$\phi_{fe}(r) = 1 - \frac{0.87619}{r}$
Hydraulic diameter D_h	$D_{h,fi}(r) = 0.014942 r - 0.004000$ m	$D_{h,fe}(r) = 0.014942 r - 0.013092$ m
Darcy friction factor for pressure-loss calculation	$f = \max\left(\frac{48}{Re}, \frac{0.264}{Re^{0.25}}\right)$	
Primary-side hydraulic diameter $D_{h,p}$	1.997 mm	9.745 mm
Nusselt correlation	$Nu = \max\left(4.36, \left[8.235^6 + (0.032 Re^{0.8} Pr^{0.43})^6\right]^{1/6}\right)$	

3.4.3 Material compositions

The available compositions and physical properties of the materials and fluids are presented below.

3.4.3.1 Fuel salt

The fuel salt selected for Stellarium is NaCl-KCl-UCl₃-PuCl₃, with the following composition in mol%:

Reactor	NaCl	KCl	UCl ₃	PuCl ₃
Stellarium	37.9	22.8	33.2	6.1

The isotopic compositions of these elements are as follows:

- sodium consists of 100% ²³Na;
- potassium and chlorine have their natural isotopic compositions;
- uranium is depleted, with a ²³⁵U fraction of 0.3%;
- plutonium has the following isotopic composition by mass (mass%):

Reactor	²³⁸ Pu	²³⁹ Pu	²⁴⁰ Pu	²⁴¹ Pu	²⁴² Pu
Stellarium	3.1	53.4	26.3	8.5	8.7

The plutonium isotopic vector is the one provided by ORANO for this configuration.

The plutonium and ²³⁵U masses in the reference configuration are 4325 kg and 69 kg, respectively.

The physical properties of the salt are estimated using the molar-volume additivity rule, the Dulong & Petit method, and the ideal-mixture method:

$$\rho(T) = \frac{\sum_i M_i x_i}{\sum_i \frac{M_i}{\rho_i(T)} x_i}, C_p = \frac{\sum_i N_i x_i}{\sum_i M_i x_i} \times 33.49 \text{ J mol}^{-1} \text{ K}^{-1}, \mu = \left(\sum_i \mu_i(T)^{1/3} x_i\right)^3 \quad (1)$$

where x_i , M_i , $\rho_i(T)$, N_i , and $\mu_i(T)$ denote the mole fraction, molar mass in kg/mol, density, number of atoms per formula unit, and viscosity of each constituent, respectively.



The available properties are summarized in Table 12. Thermal conductivity is taken as $\lambda = 0.5 \text{ W/(m.K)}$.

Table 12: Physical properties of the Stellarium fuel salt

	$T(^{\circ}\text{C})$	400	450	500	550	600	650	700	750	800
Stellarium	$\rho \text{ [kg/m}^3\text{]}$	3736	3680	3624	3568	3512	3456	3400	3343	3287
	$C_p \text{ [J/kg.K]}$	526	526	526	526	526	526	526	526	526
	$\mu \text{ [10}^{-3}\text{Pa.s]}$	3.79	3.10	2.60	2.23	1.95	1.74	1.56	1.42	1.31
	$\lambda \text{ [W.m}^{-1}\text{.K}^{-1}\text{]}$	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50

3.4.3.2 Inconel

The material used for the inner and outer fuel vessels, the inner chimney, and the heat exchanger is Inconel 625. Its composition is given by mass:

Element	Ni	Cr	Mo	Nb	Fe
% (mass)	58	23	10	4.15	4.85

Each of these elements is assumed to have its natural isotopic composition. Its density is taken as 8440 kg/m^3 ; thermal expansion and the resulting geometric changes are not taken into account. Its thermal conductivity is taken as 20 W/m.K .

3.4.3.3 Argon

The inter-vessel space and the reactor headspace (for $z > z_{h_max}$) are filled with argon, assumed to have its natural isotopic composition. Its density is taken as 1.783 kg/m^3 ; its variation with temperature is not taken into account.

3.4.3.4 Primary salt

The primary salt has a molar composition of 20.5% NaCl-41.3% KCl-38.2% MgCl_2 . Its physical properties are given in Table 13.

Table 13: Physical properties of the primary salt [Wang et al, 2021]

	$T(^{\circ}\text{C})$	400	450	500	550	600	650	700	750	800
Stellarium	$\rho \text{ [kg/m}^3\text{]}$	1733	1705	1677	1649	1621	1593	1564	1536	1508
	$C_p \text{ [J/kg.K]}$	1101	1076	1051	1026	1001	976	951	926	901
	$\mu \text{ [10}^{-3}\text{Pa.s]}$	4.23	3.73	3.35	3.05	2.81	2.60	2.43	2.29	2.17
	$\lambda \text{ [W.m}^{-1}\text{.K}^{-1}\text{]}$	0.48	0.47	0.45	0.44	0.43	0.41	0.40	0.39	0.37



3.4.3.5 External materials

Stellarium has seven concentric layers of external materials around the vessel. External material i extends to radial dimensions rb_exti/rh_exti , from axial dimension zb_exti to axial dimension zh_exti . These materials are:

- an argon gap around the outer vessel;
- followed by a lead reflector, optionally clad with a SiC layer;
- then a B₄C layer, a steel (316L) layer, and another B₄C layer;
- followed by water neutron shielding;
- and finally an outer 316L steel wall.

The thicknesses and densities of these materials are detailed in Table 14. Their variation with temperature is not taken into account.

Table 14. Properties of the external materials

Stellarium		
Material	Thickness [mm]	ρ [kg/m ³]
Argon	10	1.783
Pb	700	10580
B ₄ C	10	2500
316L	10	7900
B ₄ C	10	2500
H ₂ O	600	998
316L	10	7900

3.4.3.6 Material in the upper section

The upper section of the inner chimney contains gadolinium with its natural isotopic composition and a density of 7890 kg/m³, clad with Inconel 625. This cladding is not represented in the current model.

3.4.4 Power and nominal conditions

The nominal temperatures and flow rate of the primary circuit, together with the power deposited in each zone, are reported in Tables 15 and 16.

Table 15. Nominal conditions for the primary circuit in Stellarium

Parameter	Stellarium
Cold primary temperature	399.8 °C
Hot primary temperature	562.2 °C
Primary mass flow rate	3160.5 kg/s



Table 16. Power values by zone from OpenMC tallies

Case	Fuel	Heat exchanger	Reflector	Wall	Absorber
Stellarium	544.7 MW	69.1 MW	3.7 MW	2.0 MW	391.5 kW

The heat-exchanger power is included in the fuel tally. Power deposited in the reflector, wall and absorber is outside the fuel balance and is extracted by means other than the primary heat exchanger.



3.5 ARAMIS-P concept

The ARAMIS (Advanced Reactor for Actinides Management In Salt) concept has been developed initially through a collaboration between CEA and ORANO to convert plutonium in the first version called ARAMIS-P [Pascal et al., 2026]. The reactor power was fixed to 300 MW_{th} in the power range of Advanced Modular Reactors (AMR). The design process was driven by the desire to make maximum use of proven technologies when available, as well as to implement a maintenance by design approach. For the ARAMIS-P concept the choice was made to select a chloride salt as fuel. This choice had some impact on the design, especially for the heat exchanger design.

All the information related to Aramis-P, including the present descriptions and data completed by the CEA benchmark of WP4, are available in [Pascal and Martinet, 2026].

3.5.1 General characteristics

The general characteristics of the ARAMIS-P 300 MW_{th} concept as provided in task 4.4 are summarized in Table 17. A pdf document has been provided by CEA in this frame, containing all the elements necessary to achieve the system code benchmark of the ARAMIS-P concept.

Table 17: General characteristics of the ARAMIS-P 300 MW_{th} concept

Parameters	Units	Values
Fuel salt		NaCl-MgCl ₂ -AcCl ₃
Coolant salt		NaCl-MgCl ₂ (58-42 mol%)
Power conversion fluid		Nitrogen
Fuel loop design		6 loops design
Coolant loop design		3 loops design
Thermal power	MW _{th}	300.0
Electrical power	MW _e	124.0
Thermal efficiency	%	41.3
Core power density (Power / fuel volume in core)	MW/m ³	250.0
Fuel power density (Power / overall fuel volume)	MW/m ³	55.0
Fuel volume in fuel loop	m ³	5.45

The global architecture of the reactor is a 4-loops design. The intermediate coolant loop cools down the fuel loop and transfer the extracted power to the power conversion loop, where the thermal power is converted in electrical power. The last loop corresponds to the fatal heat sink.

The architecture of the fuel circuit is a loop type design as shown in Figure 14. Even if the loop designs with connecting pipes are subjected to fuel salt leakage, the maintenance operations of the internal components were deemed more favorable than in an integrated design, at the start of the project.

The core internal tank, where the fission reaction occurs, is surrounded by neutron shields, which act both as neutron reflector and neutron absorber to lower the flux in the out-core components. The reactivity control is performed using rotating control drums, while fast shutdown is achieved using additional vertically moving control rods. Control devices are outside of the fuel salt.

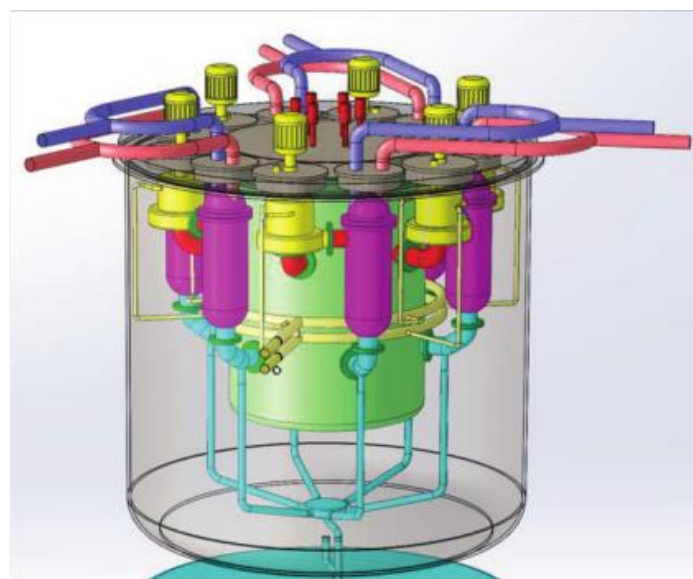


Figure 14: Schematic CAD of the ARAMIS-P fuel loop [Pascal et al. 2026]

Nominal operating point

The nominal operating point has been defined using the temperature limits listed in Table 18.

Table 18: Nominal operating point of the ARAMIS-P concept

Parameters	Units	Values
Temperature upper limit for materials	°C	700.0
Temperature lower limit for fuel salt	°C	495.0
Temperature lower limit for coolant salt	°C	445.0
Fuel salt core inlet temperature ($T_{core\ in}^{fuel}$)	°C	570.0



Fuel salt core outlet temperature ($T_{core\ out}^{fuel}$)	°C	650.0
Coolant salt HX inlet temperature ($T_{IH\ X\ in}^{coolant}$)	°C	550.0
Coolant salt HX outlet temperature ($T_{IH\ X\ out}^{coolant}$)	°C	490.0
PCS fluid HX inlet temperature ($T_{SGHX\ in}^{gas}$)	°C	411.0
PCS fluid HX outlet temperature ($T_{SGHX\ out}^{gas}$)	°C	535.0

3.5.2 Detailed system description

Fuel circuit

The fuel circuit (see Figure 14) is composed of six loops as a preliminary trade-off between component size and overall complexity. Each fuel loop is made of one pump connected to one expansion tank, one heat exchanger and pipes. Pumps are located in the hot branch of the pipes at the highest point of the fuel circuit, which means that a gas-tight seal should be provided for the pump shaft. Off-gas systems, as well as salt extraction and feeding systems, are connected to the pump bowl. Out-core components are located around the neutron shields with a light axial shift to enhance natural convection in case of fuel pump loss.

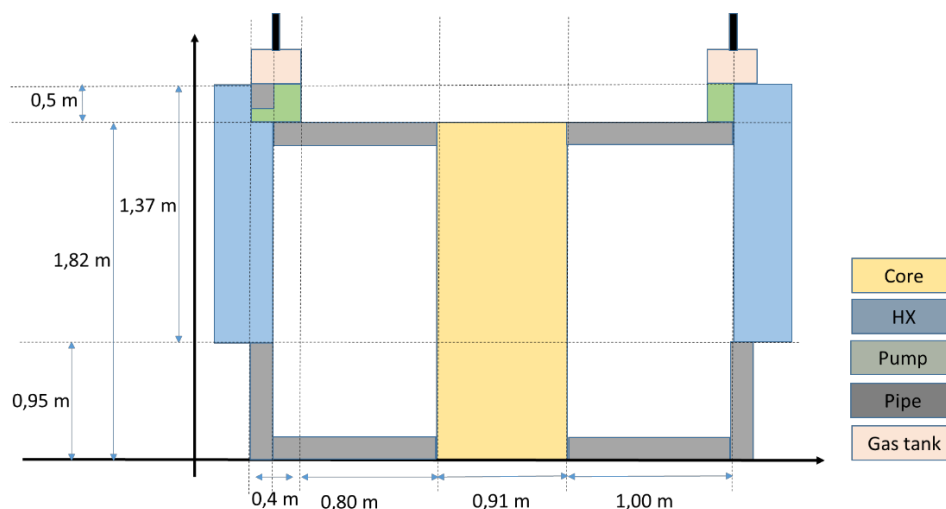


Figure 15: Schematic representations of the fuel circuit

Table 19: Design parameters of the fuel circuit

Parameters	Units	Values
Number of branches		6
Free surface pressure (absolute)	bars	1.5



Fuel volume in the core	m ³	1.18
Fuel volume in the heat exchangers	m ³	1.90
Fuel volume in the pumps	m ³	1.20
Fuel volume in the pipes	m ³	1.17
Fuel volume in the fuel loop	m ³	5.45
Fuel volume ratio ($V_{fuel\ salt}^{core}/V_{fuel\ salt}^{tot}$)	%	22.0
Fuel mass flowrate	kg/s	4190.0
Fuel volume flowrate	m ³ /s	2.054
Fuel circulation time (in core) τ_1	s	0.6
Fuel circulation time (total)	s	2.7
Fuel circulation time (outside the core) τ_2	s	2.1

All the fuel components are located inside a guard external vessel, which can drain the salt to the external draining tanks in case of fuel leakage. Finally, three intermediate loops transfer the energy produced by the fuel loop to the energy conversion system, which is based on a Brayton cycle. Table 19 gives the main design parameters of the fuel circuit.

Core

The core volume corresponds to the critical zone of the reactor where the nuclear fission occurs (see Figure 16). The height/diameter ratio (H/D) was chosen as a trade-off between neutron performance and overall reactor dimensions and was assumed to be 2. The core area is free of any structure, so the salt flow is unconstrained inside the core volume. The neutron shields, which surround the critical area, combines an MgO reflector with a B₄C absorber. Some provisions with respect to their theoretical density are assumed. Table 20 gives the main parameters of the core vessel. Figure 16 illustrates the dimensions of the core cavity and its surrounding media using a schematic representation extracted from the CAD geometry.

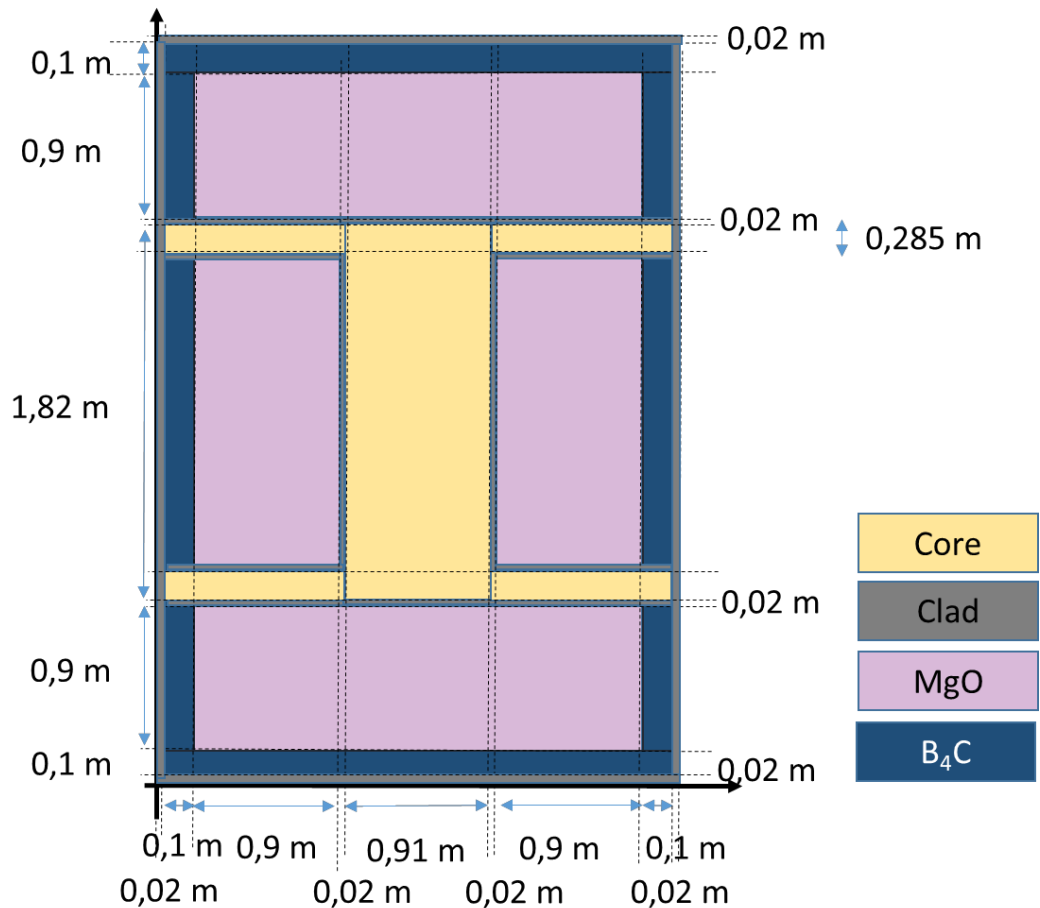


Figure 16: Schematic representation of the reactor core (RZ Cut)

Table 20: Design parameters of the core vessel

Parameters	Units	Values
Critical cylindric zone diameter	m	0.91
Critical cylindric zone height	m	1.82
Nickel alloy shell	m	0.02
Magnesia (MgO) thickness	m	0.9
Natural boron carbide (B ₄ C) thickness	m	0.1
Overall diameter of the core vessel	m	2.99
Overall height of the core vessel	m	3.90



Pipes

Table 21 gives the main parameters of the fuel salt pipes.

Table 21: Design parameters of the pipes

Parameters	Units	Values
Pipe internal diameter	m	0.285
Upper pipe length	m	1.00
Lower pipe length	m	1.95
Pump discharge pipe length	m	0.10

Heat exchangers

Table 22 gives the main parameters of the HX smooth plate heat exchangers in counter-current mode. The correlation used for the computation of the smooth plate heat exchangers is the Gnielinski correlation [Dostal et al, 2022].

Table 22: Design parameters of the HX fuel heat exchangers

Parameters	Units	Values
Power	MWth	50.0
Exchange surface	m ²	253.0
Exchange length	m	1.37
LMDT	°C	89.6
Plate width	m	0.95
Plate thickness	m	0.001
Number of canal (cold/hot)		98 / 97
Channel thickness (cold/hot)	m	0.0025
Hydraulic diameter (cold/hot)	mm	4.99 / 4.99
Crossflow surface (cold/hot)	m ²	0.2328 / 0.2304
Fuel salt velocity	m.s ⁻¹	1.5
Coolant salt velocity	m.s ⁻¹	2.9



Fuel salt volume	m ³	0.32
Power density	MW.m ⁻³	158.0

Pumps

Table 23 gives the main parameters of the fuel salt pumps.

Table 23: Design parameters of the pumps

Parameters	Units	Values
Design motor pressure drop	bars	2.0
Design volume flow rate	m ³ .s ⁻¹	2.1
Pump impeller diameter	m	0.4
Fuel salt volume	m ³	0.2
Pump internal diameter	m	1.20
Pump fuel salt level	m	0.18
Pump internal height	m	0.36
Cover plug gas volume	m ³	0.20

Coolant (intermediate) circuit

Table 24 gives the main parameters of the coolant salt circuit. The circuit is composed of 3 branches. Each branch contains 1 salt to gas heat exchanger (SGHX), one pump and pipes. The SGHX was designed and its main parameters are listed in Table 25. The SGHX are smooth plate heat exchangers in counter-current mode. The pumps are not yet designed and do not appear in the following description. Figure 17 gives the elevation of the various component of the coolant circuit.

Table 24: Design parameters of the coolant circuit

Parameters	Units	Values
Number of branches		3
Free surface pressure (absolute)	bars	1.5



Coolant mass flowrate	kg.s ⁻¹	4629.6
Coolant volume flowrate	m ³ .s ⁻¹	2.7
Coolant volume in HX	m ³	1.9
Coolant volume in SGHX	m ³	7.6
Coolant volume in pipes (+pumps)	m ³	17.7
Coolant pipe internal diameter	m	0.58
Coolant upper pipe length	m	12.27
Coolant lower pipe length	m	10.07
Total coolant volume	m ³	27.2
Circulation time (loop)	s	10.1
Ratio fuel volume / coolant volume	%	20.0

Table 25: Design parameters of the SGHX heat exchangers

Parameters	Units	Values
Power	MWth	100.0
Exchange surface	m ²	2021.0
Exchange length	m	3.57
LMDT	°C	38.6
Plate width	m	1.5
Plate thickness	m	0.0025
Number of channels (cold/hot)		189 / 189
Channel thickness (cold/hot)	m	0.0025
Coolant salt velocity	m.s ⁻¹	1.24
Nitrogen velocity	m.s ⁻¹	13.1
Volume of coolant salt	m ³	2.53

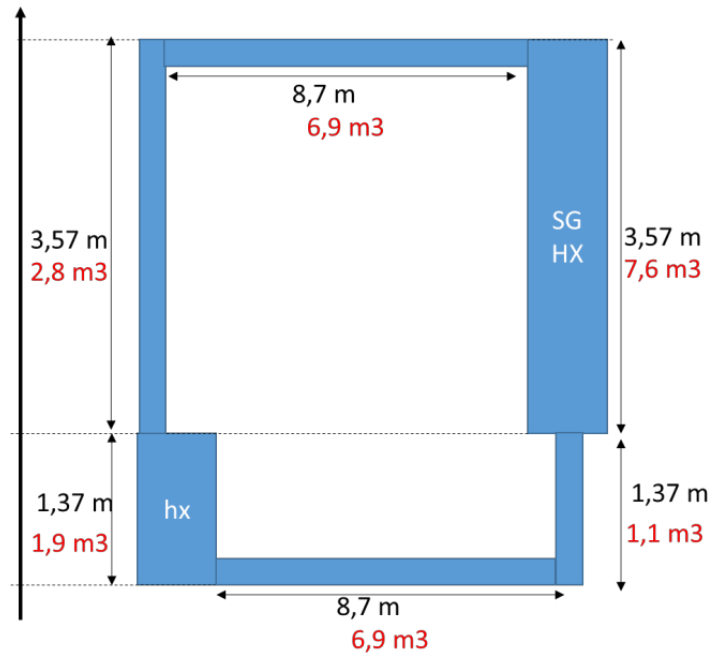


Figure 17: Schematic of the coolant (intermediate) circuit

3.5.3 Material compositions

Fuel coolant and energy conversion fluids

The fuel loop fluid is a molten chloride ($\text{NaCl-MgCl}_2\text{-PuCl}_3$). The coolant fluid is the NaCl-MgCl_2 and the energy conversion fluid is the nitrogen. The isotopic composition of the chlorine considered is 1% mass of ^{35}Cl and 99% mass of ^{37}Cl .

The main thermal properties as well as the compositions are given in Table 26. However, experimental data on the properties of chlorides salts with plutonium are very limited [Karlsson et al., 2023]. For this reason, approximations and assumptions were used to predict fuel salt properties. The following approximate methods, described in reference [ORNL, 2018], were used:

- The additive molar volume method for densities;
- The “Dulong & Petit” method for heat capacities;
- The ideal mixing method for viscosities;
- A constant value for the thermal conductivity.

Properties for unitary chloride fuel salts (density, viscosity) came from references [Desyatnik et al., 1975] and [Karlsson et al., 2023]. According to these references, the uncertainties for the density, the viscosity, the specific heat and the thermal conductivity could be assumed at 7%, 7%, 20% and 50%, respectively. The coolant salt properties come from measurements given in the reference [Williams et al., 2006] and [Janz, 1988]. Table 26 gives the thermal properties of the fluids. Table 27 gives the isotopic vector of the plutonium considered.


Table 26: Fluid thermal properties for nominal operation state

Properties	Units	Fresh fuel salt (NaCl-MgCl ₂ -PuCl ₃)			Coolant salt NaCl-MgCl ₂	Nitrogen (180 bar)
Composition	Mol%	62.0	31.2	6.8	58-42 [Williams et al, 2006]	-
Melting temperature	°C	467			450 [Williams et al, 2006]	-
Nominal temperature	°C	610			520	473
Density (ρ)	kg.m ⁻³	$\rho_l(T(^{\circ}C)) = (2359 - 0.52 \cdot T)$			$\rho_l(T(^{\circ}C)) = (1929 - 0.4 \cdot T)$ [Janz, 1988]	76
		2040 at 610°C			1721 at 520°C	
Heat mass capacity (C_p)	J.kg ⁻¹ .K ⁻¹	895			1080 [Williams et al, 2006]	1139
Viscosity (μ)	Pa.s	$\mu_l(T(K)) = \frac{0.2272 \cdot e^{\frac{1930}{T}}}{1000}$			$\mu_l(T(K)) = \frac{0.0823 \cdot e^{\frac{2614.8}{T}}}{1000}$ [Janz, 1988]	3.5*10 ⁻⁵
		2.1*10 ⁻³ at 610 °C			2.2*10 ⁻³ at 520 °C	
Thermal conductivity (λ)	W.m ⁻¹ .K ⁻¹	0.5			0.5	0.055

Table 27: Isotopic vector of the plutonium (% mass)

Isotope	Pu ²³⁸	Pu ²³⁹	Pu ²⁴⁰	Pu ²⁴¹	Pu ²⁴²	Am ²⁴¹
% mass	3.6	47.4	29.7	8.2	10.4	0.8

Magnesia

The properties of the MgO (see Table 28), located in neutron protection come from reference [Azom, 2025-1].

Table 28: MgO properties

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Parameters	Units	Values
Theoretical density (at 20°C)	kg.m ³	3600.0
Isotopic content	at%	²⁴ Mg - 79% ²⁵ Mg - 10% ²⁶ Mg - 11% ¹⁶ O - 100%
Melting point	°C	2807.0
Heat capacity	J.Kg ⁻¹ .K ⁻¹	880.0
Thermal conductivity	W.m ⁻¹ .K ⁻¹	30.0
Thermal expansion	K ⁻¹	9.0*10 ⁻⁶
Porosity	%	20

Boron carbide

The properties of the B₄C given in Table 29 come from reference [Azom, 2025-2].

Table 29: B₄C properties

Parameters	Units	Values
Theoretical density (at 20°C)	kg.m ³	2510.0
Isotopic content	at%	¹⁰ B – 19.9 % ¹¹ B – 80.1% ¹² C – 100%
Melting point	°C	2372.0
Heat capacity	J.kg ⁻¹ .K ⁻¹	840.0
Thermal conductivity	W.m ⁻¹ .K ⁻¹	17.0
Thermal expansion	K ⁻¹	3.2*10 ⁻⁶
Porosity	%	30



Metallic alloy

The properties of the metallic alloy given in Table 30 come from references [Azom, 2025-3] and [Watson and Robinson, 1963].

Table 30: Metallic alloy properties

Parameters	Units	Values
Theoretical density (at 20°C)	kg.m ⁻³	7870.0
Mass content	mass%	Fe – 65.8 % Cr – 18.0 % Ni – 12.0 % Mo – 2.4 % Mn – 1.8 %
Melting point	°C	1405.0
Heat capacity	J.Kg ⁻¹ .K ⁻¹	490.0
Thermal conductivity (450°C)	W.m ⁻¹ .K ⁻¹	20.0
Thermal expansion	K ⁻¹	15.9*10 ⁻⁶



4 Conclusion

This deliverable presents the design dataset developed within WP1 of the ENDURANCE project to support the studies and calculations performed in WP4, WP5 and WP6. Based on the identification of the data requirements of the different work packages and the information collected from the European MSR concepts, four main cases studies have been selected: MSFR-F, MSFR-CI, Stellarium and ARAMIS-P. Among these, MSFR-F and ARAMIS-P have been identified as the main case studies for the activities currently performed within ENDURANCE, while MSFR-CI and Stellarium provide additional configurations for the studies foreseen in the project.

The dataset includes the main design characteristics, geometrical specifications, material compositions, thermophysical properties, operating conditions and fuel salt processing schemes of the selected concepts. It provides a common reference for the modelling, simulation and assessment activities carried out in the different work packages, facilitating the exchange of information and ensuring consistency between the studies. Overall, the work performed provides the design information required to support the ongoing and future technical activities of ENDURANCE, contributing to the alignment between the research activities and the characteristics of European MSR concepts.



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Appendix 1 – OpenMC Geometry Definition of the EVOL Reference MSFR-F

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Appendix 2 – OpenMC Material Definition of the EVOL Reference MSFR-F

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