PSI Center for Nuclear Engineering and Sciences

MSR Workshop

BALDER project

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10.12.2025

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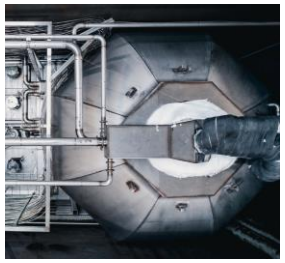
copenhagen atomics

Who is **Copenhagen Atomics?**

swiss safety center ISO 9001 certified system

Copenhagen Atomics has the technical expertise!

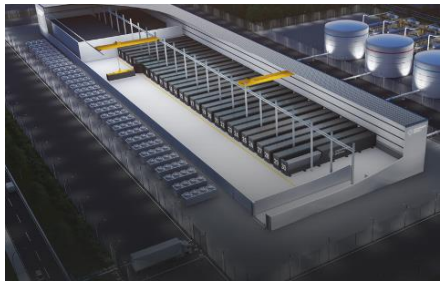
The products: Salt and molten salt circuits



Inactive prototype

The production facility

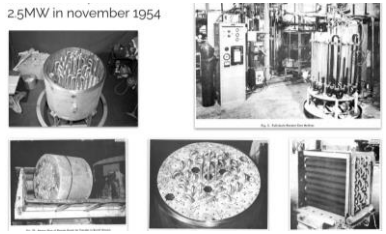
CA Founder



The vision

A young team

CA CTO



Inspired by the MSR of 1954

An experiment

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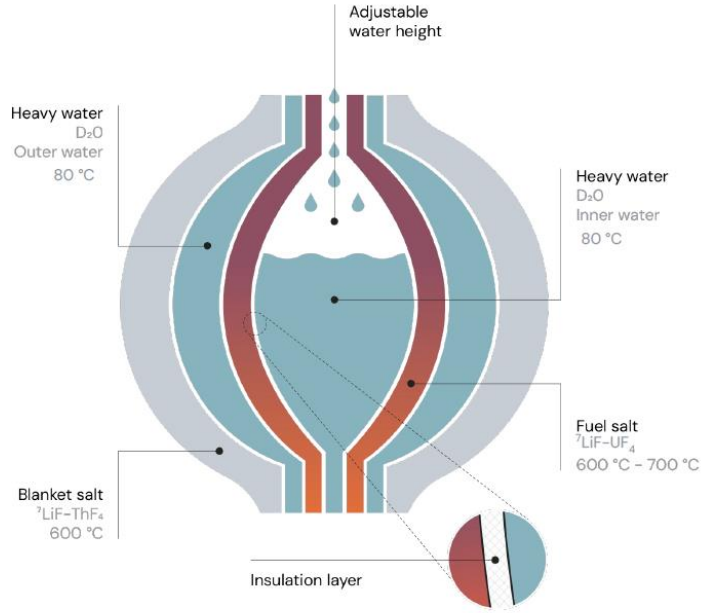
Technical information on the **Molten Salt Experiment (MSE)**

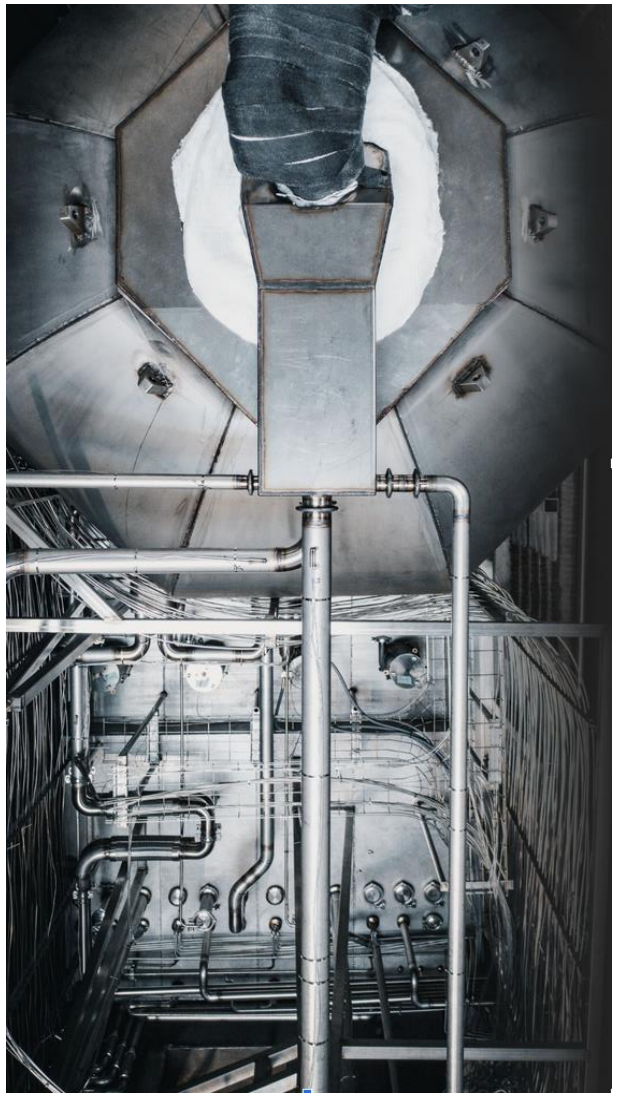
swiss safety center ISO 9001 certified system

Molten Salt Experiment (Core structure)

- Onion-shaped, multi-layer rotational ellipsoidal container with vertical, concentric, welded channels
  - Fuel and shielding salt channels made of 316 stainless steel
  - Heavy water channels (D_2O) Zirconium alloy channels
  - Size of onion-shaped container L x W x H: 2.3 m x 2.3 m x 2.8 m
- Fluid flow is controlled by pumps and associated control system (speed of D_2O internal channel pump is main parameter for reactivity control [T,dN/dt])



Cross section illustrative view of MSE core



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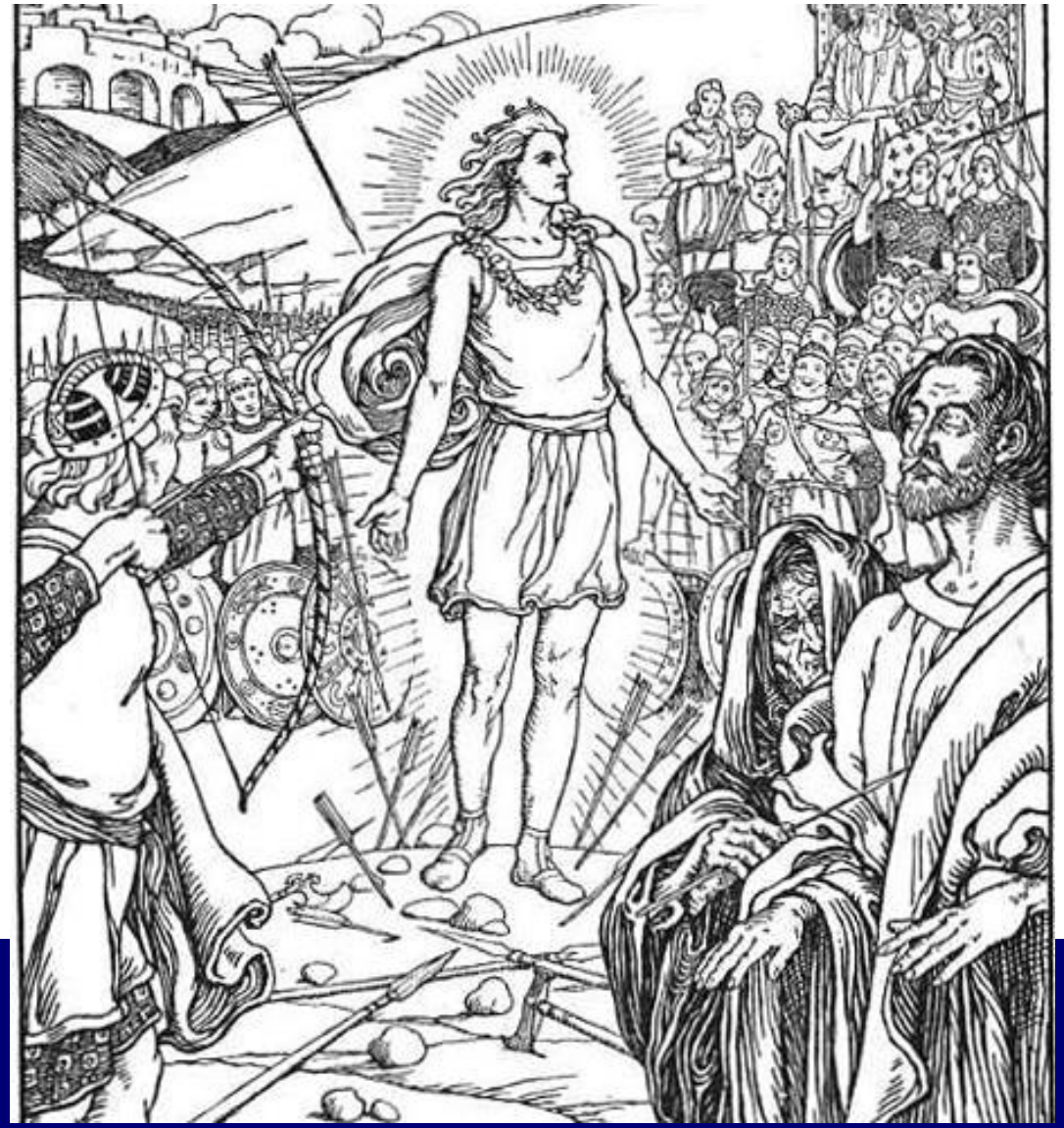
Bereitstellung der **A**uslegungs- und **L**izensierungs-**D**okumente für das **E**rste MS-**R**eaktor-Experiment



Graded Approach according to IAEA

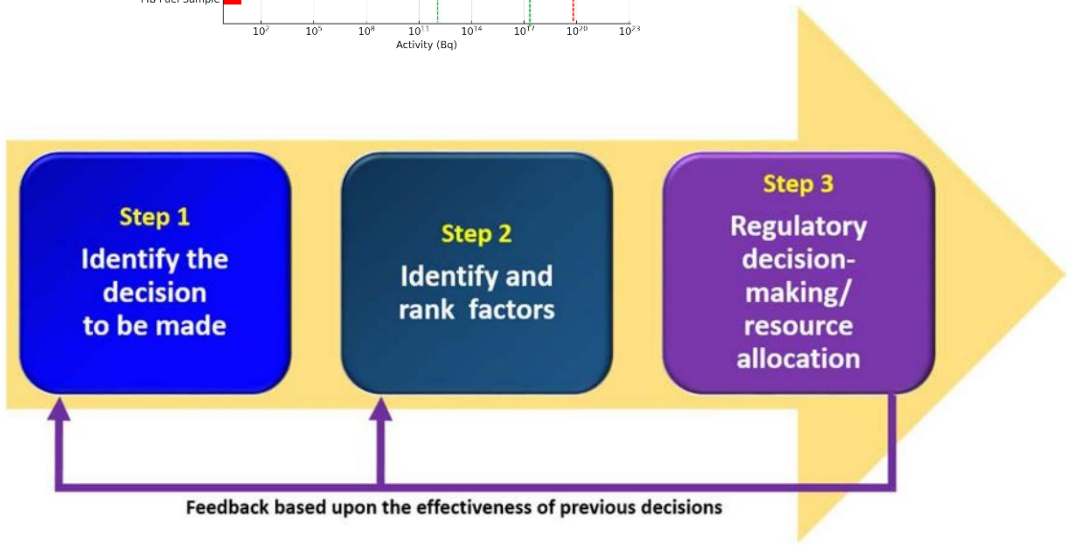


FIG. 2. Generic three-step methodology for applying graded approach to regulate nuclear installations

TABLE 1. KEY QUESTIONS WHEN APPLYING A GRADED APPROACH TO CORE REGULATORY FUNCTIONS

Regulatory Function	Key Questions when Applying a Graded Approach
Regulations and guides	• Are regulations and guidance adequate or commensurate with the risk associated with the nuclear installation?
Authorization	• Is the level of authorization (approval, consent) commensurate with the risk associated with the nuclear installation? • Is the licence/conditions established for an installation adequate to control the risk associated with the nuclear installation?
Review and assessment	• Is regulatory effort allocated for the review/assessment commensurate with the risk (potential safety significance) associated with the item being assessed? • Is there a systematic way of determining safety significance of review issues from a review and assessment?
Inspection	• Is regulatory effort allocated for the inspection programme commensurate with the risk associated with the item being assessed?
Enforcement	• Is there a systematic way of determining safety significance of findings resulting from an inspection? • Is the enforcement action commensurate with the safety significance of the non-compliance?
Communication and consultation with interested parties	• Are resources allocated for communication activities commensurate with the safety significance and level of stakeholder interest?

Graded Approach in Switzerland

Federal Constitution, Article 5, Paragraph 2:

Government action in the public interest AND appropriate

NEA, in particular Art. 72:

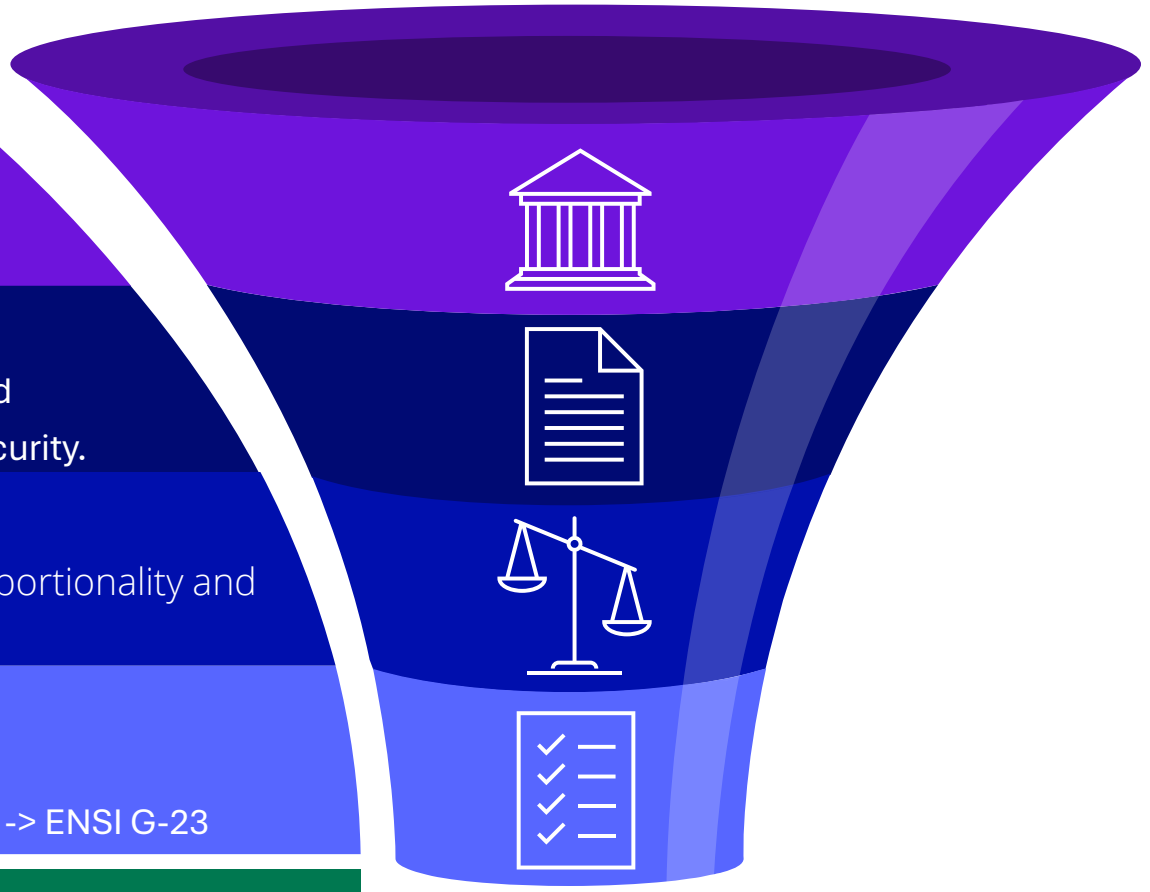
The regulatory authorities shall order all measures necessary and **proportionate to** ensure compliance with nuclear safety and security.

ENSI-AN-8526 Interpretation:

The Federal Constitution and KEG require the principle of proportionality and appropriateness.

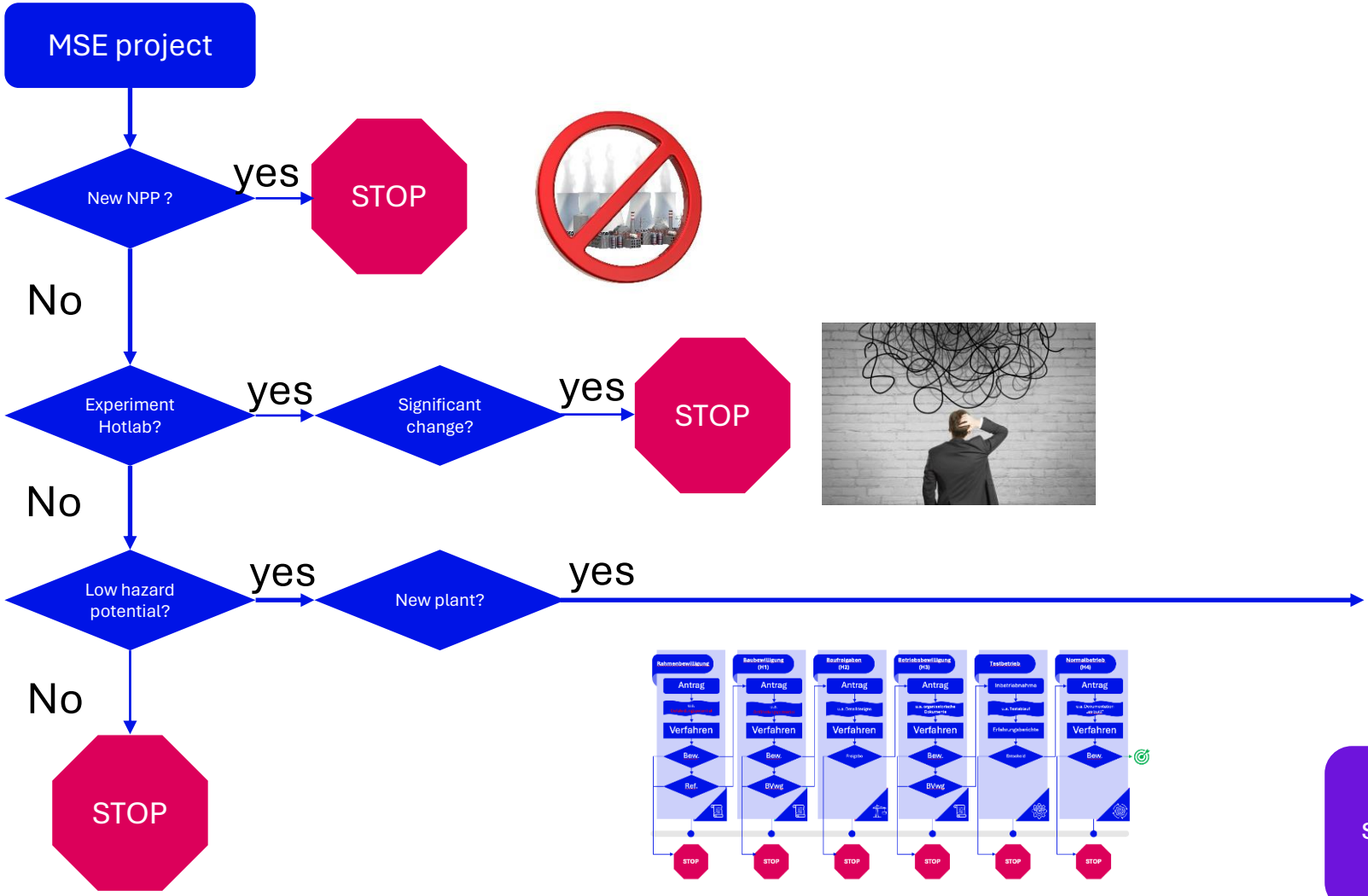
Mandatory security measures should be proportional to the actual security relevance.

KEG Art. 12, Art. 22 KEV Art. 12 Abs.1, Art. 22 Abs.1, Art. 24 Abs. 1-> ENSI G-23



- **Overall system safety design**
- **SSC classification / SSC qualification**
- **H1-H4 documentation and depth**
- **Joint construction and operating permit**
- **…**

Authorization procedure (based on NEA, NEO & ENSI-A04)



Due to the experimental nature: additional safety through conservatively designed nuclear test facility (NT)

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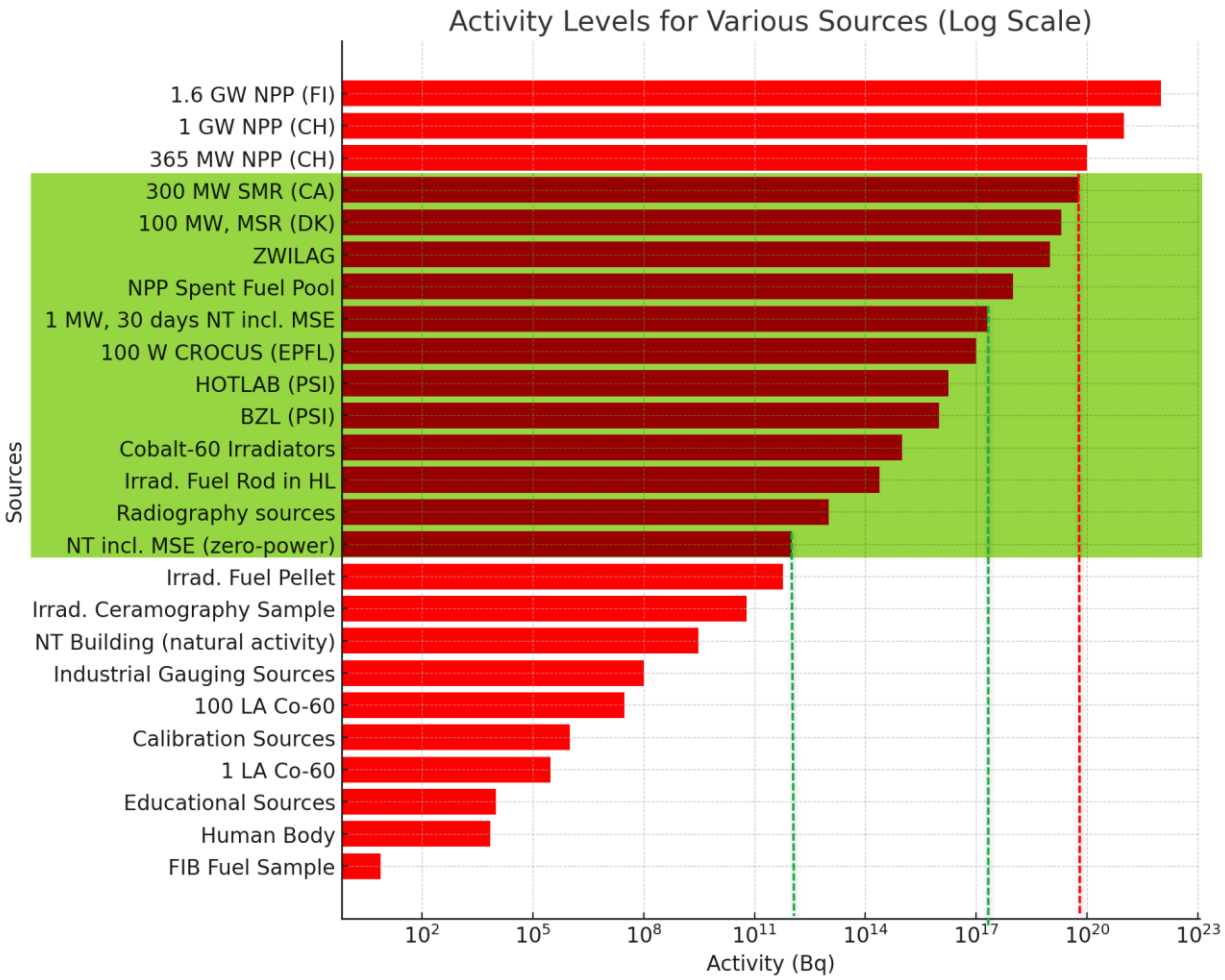
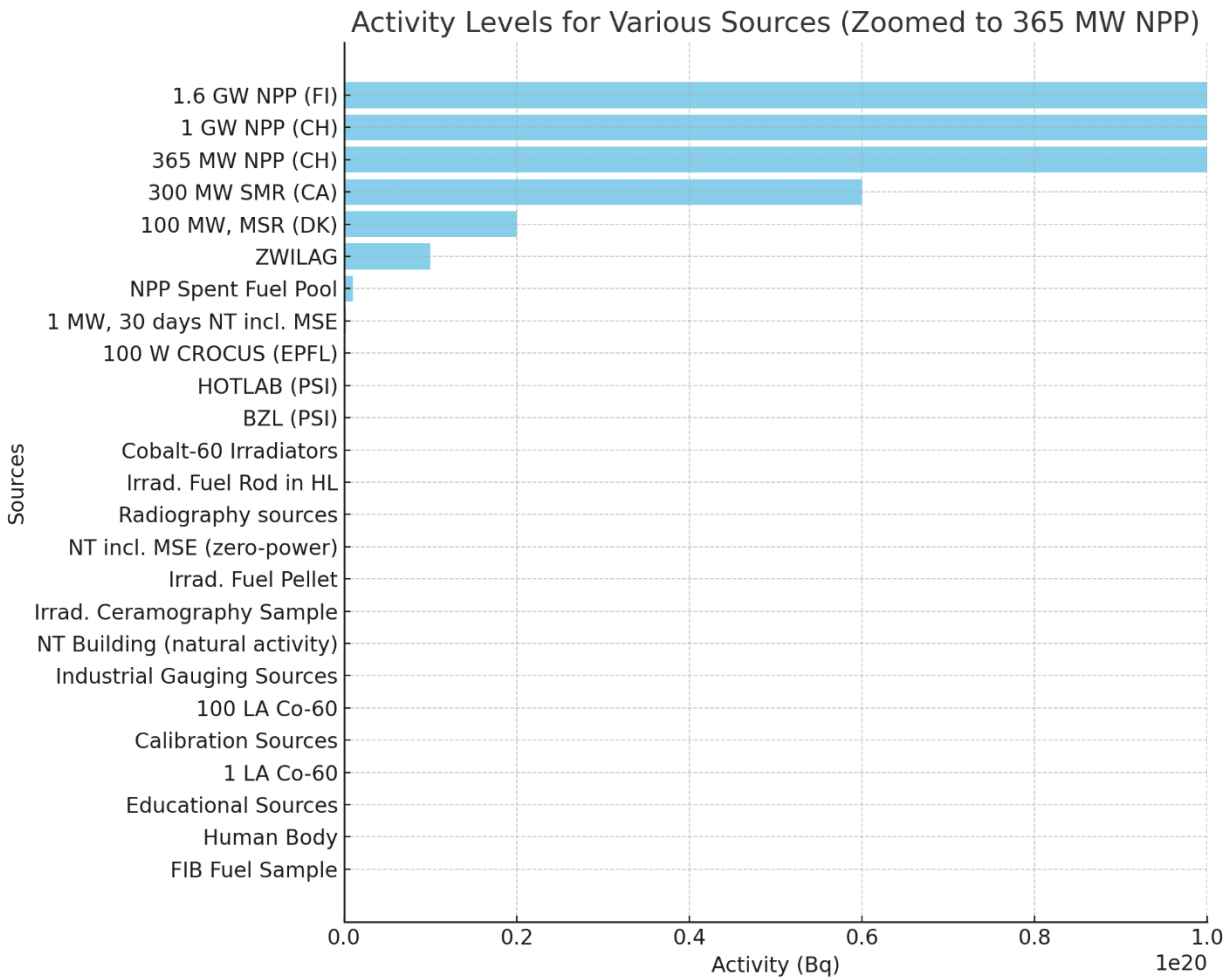
Low hazard potential

swiss safety center ISO 9001 certified system

Comparison of hazard potentials





Outstanding safety features of the MSE

Drain tank for molten salt (gravity)when pump is switched off (fail-safe)
SZ1

Low inventory or thermal power level MSE max 1 MW for 30 days (compared to CA commercial MSR 100 MW for 1800 days)
SZ4

Natural convection for heat dissipation in the event of pump failure
SZ2

Strong Doppler effect and significant thermal salt expansion
SZ1

Additional cocoon encloses radiological material
SZ3

Molten salt stable against overheating (high heat capacity)
SZ2

High retention of fission products in liquid salt
SZ4

Drain tank for D2O moderator (gravity)
SZ1

Low pressure to protect the reactor loop
SZ3

Protection objectives (SZ)

SZ1:	**Rapid stable criticality shutdown (reactor shutdown)**
SZ2:	**Uninterrupted and long-term: Cooling the reactor circuit**
SZ3:	**Safe containment of radioactivity**
Total SZ4:	**No impermissible radiation exposure to humans and the environment**

Due to the experimental nature:additional safety through conservatively designed nuclear test facility (NT)

Legal information - Low risk potential

NEA

Art. 12 Licensing obligation

[1] Anyone intending to construct or operate a nuclear installation requires a general licence issued by the Federal Council. Article 12*a* is reserved.[9]

[2] No legal entitlement exists with respect to the granting of a general licence.

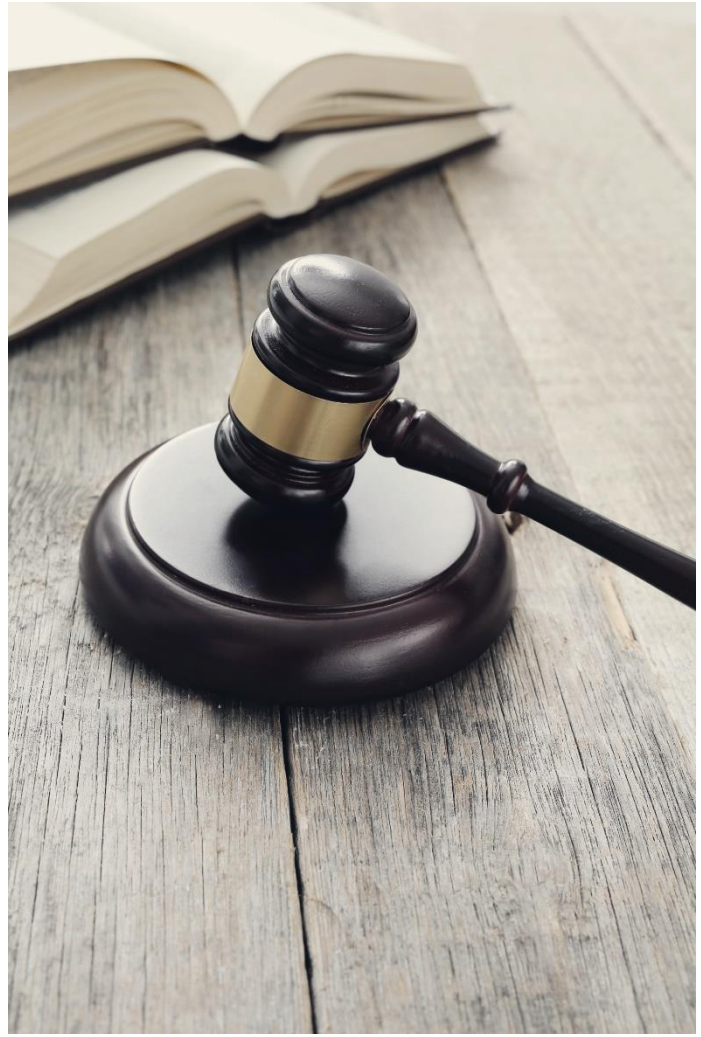
[3] Nuclear installations with a low hazard potential do not require a general licence. The Federal Council shall specify the installations concerned.

NEO

Art. 22 Nuclear installations with low hazard potential

[1] Nuclear installations do not require a general licence if the frequency of all accidents in accordance with Article 8 paragraphs 2 and 3 with a resulting dose of more than 1 mSv for members of the public does not exceed 10^{-6} per annum. In the case of interim storage installations and deep geological repositories, the total of activities of all nuclides to be emplaced must not exceed 10^{16} g LL in accordance with Annex 3 column 9 RPO[26].[27]

[2] ENSI shall specify the methodology and boundary conditions for the accident analysis called for in paragraph 1 in guidelines.[28]



– Section 3 Operation

– Art. 19 Licensing obligation

Anyone intending to operate a nuclear installation requires an operating licence granted by the Department.

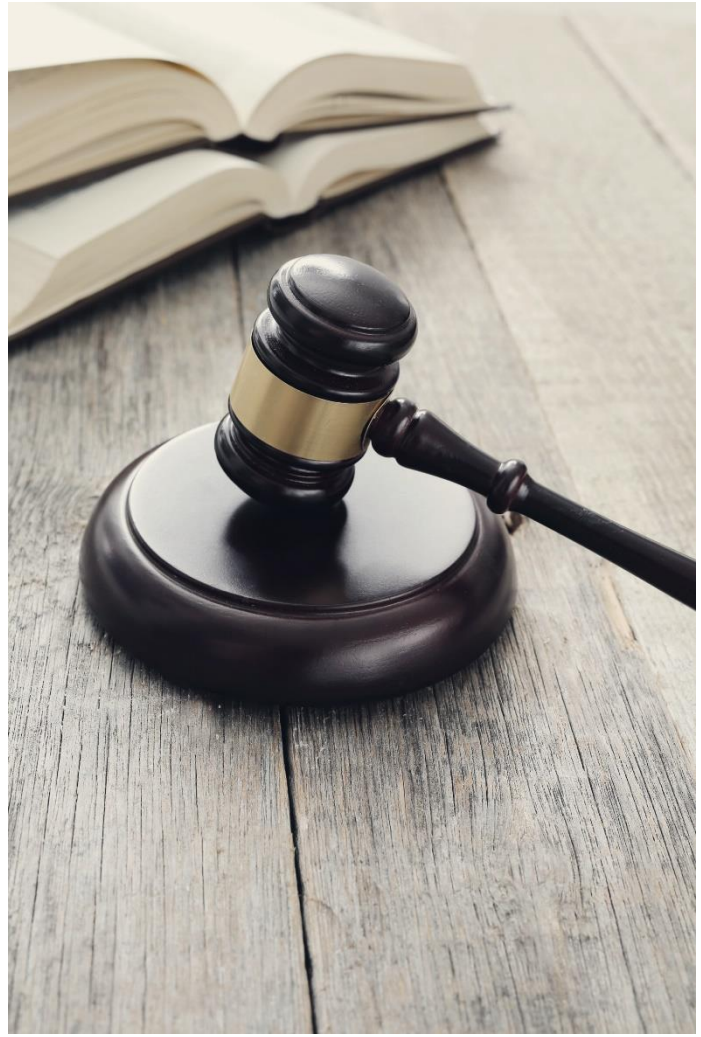
– Art. 20 Conditions governing the granting of an operating licence

[1] An operating licence is granted if the following conditions are met:

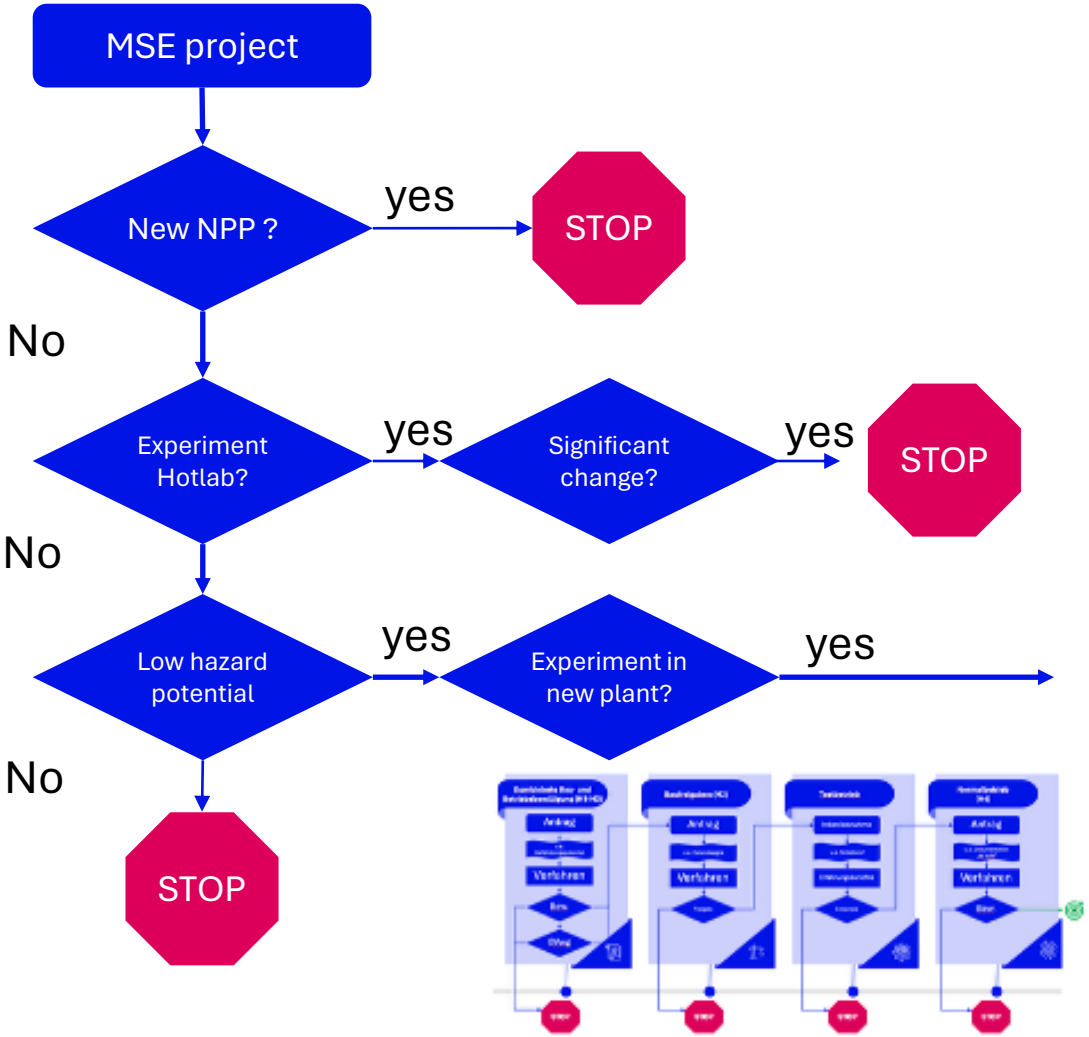
a. the applicant is the owner of the nuclear installation in question;
b. all provisions pertaining to the general licence and construction licence have been met;
c. protection of humans and the environment is ensured;
d. the installation and planned type of operation meet the relevant nuclear safety and security requirements;
e. the requirements on personnel and organisation can be met;
f. appropriate measures have been prepared to secure quality assurance for all activities to be carried out within the installation;
g. appropriate measures for dealing with emergencies have been prepared;
h. the prescribed insurance cover exists in accordance with the Nuclear Energy Liability Act of 18 March 1983[11].

[2] The operating licence may be granted at the same time as the construction licence if the requirements for safe operation can be assessed conclusively at the time of application.

[3] The owner of a nuclear reactor may store nuclear materials in its installation before an operating licence has been granted, as long as it obtains a licence for this purpose from the Department. Articles 20 to 24 apply analogously to this licence.



Approval process from the perspective of PSI (based on NEA & ENSI-A04)



Parallel submission (NEA, Art. 20 (2) Low risk potential)

H1 Buidling permit
- Concept
- Process description
- Safety assessment
- …

H2 Construction (in stages)
- •Detailed design, plant description
- (Revised) process
- (Revised) safety assessment
- …

H3 Operating license
- Construction documents, technical specifications
- (Revised) process
- (Revised) safety assessment
- …

H4 Continuous operation
- Update plant description, technical specifications (as built)
- Revised process, operating instructions, operating regulations
- Revised safety assessment
- …

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Technical information on **the nuclear test facility (NT)**

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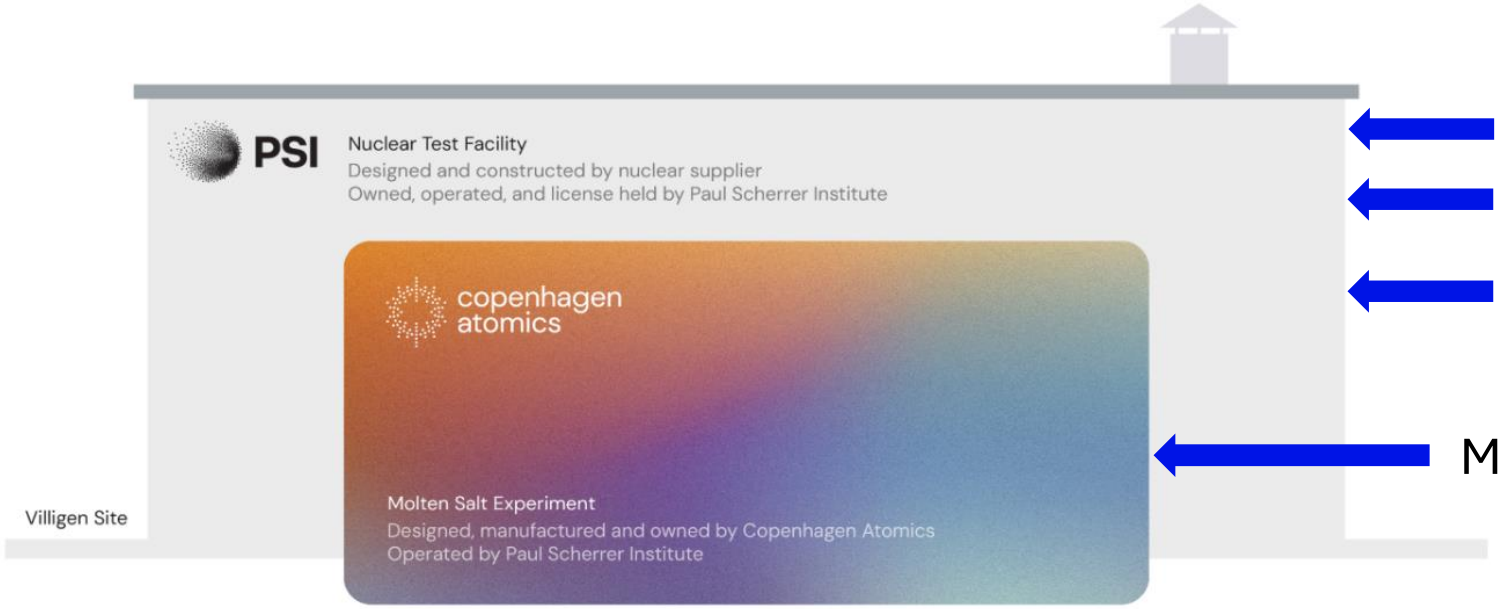
NT building including MSE



NT (building): Building permit → PSI

NT (building): Property → PSI

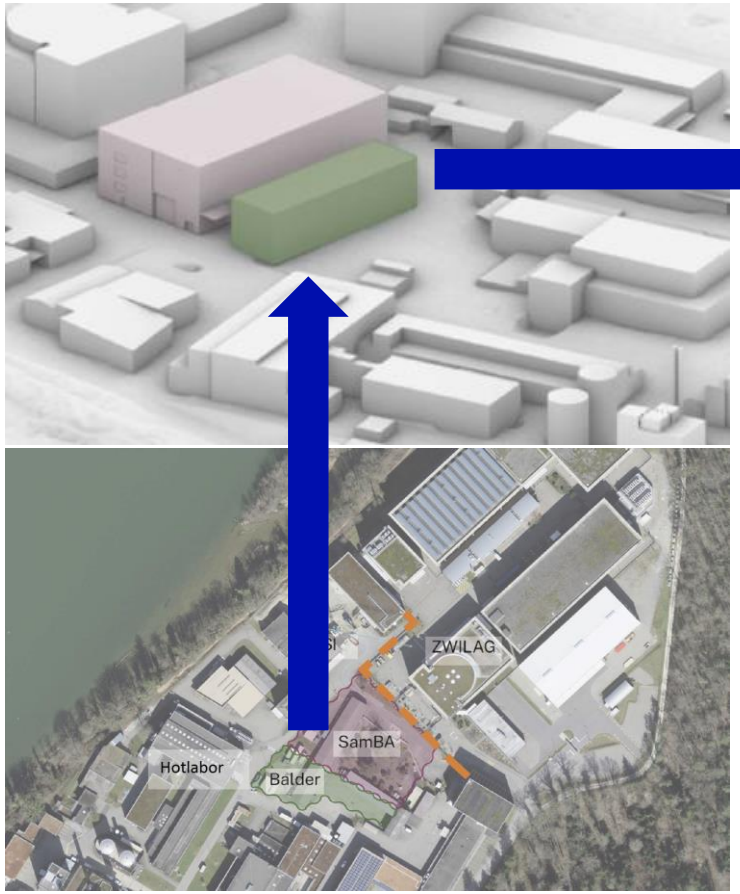
NT (nuclear power plant): Operating license → PSI

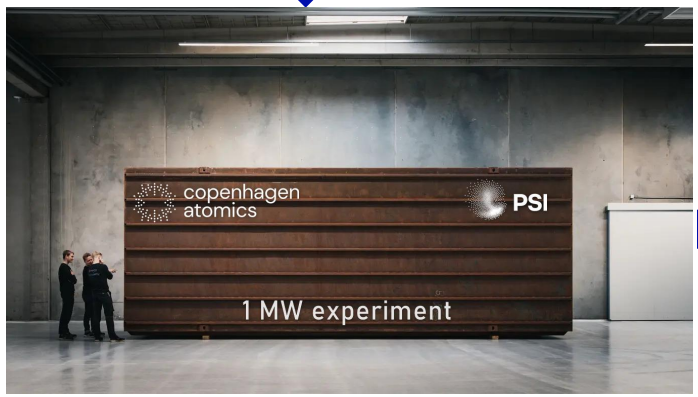
MSE: Property → CA

NT & MSE: Operation → PSI

Planned location of the “nuclear test facility”– near the hot laboratory

NT is classified as a core facility with “low hazard potential” (according to Art. 12 para. 3 KEG).
(>1 mSv/a follow-up dose for all events up to an occurrence probability of 10^{-6}/a)





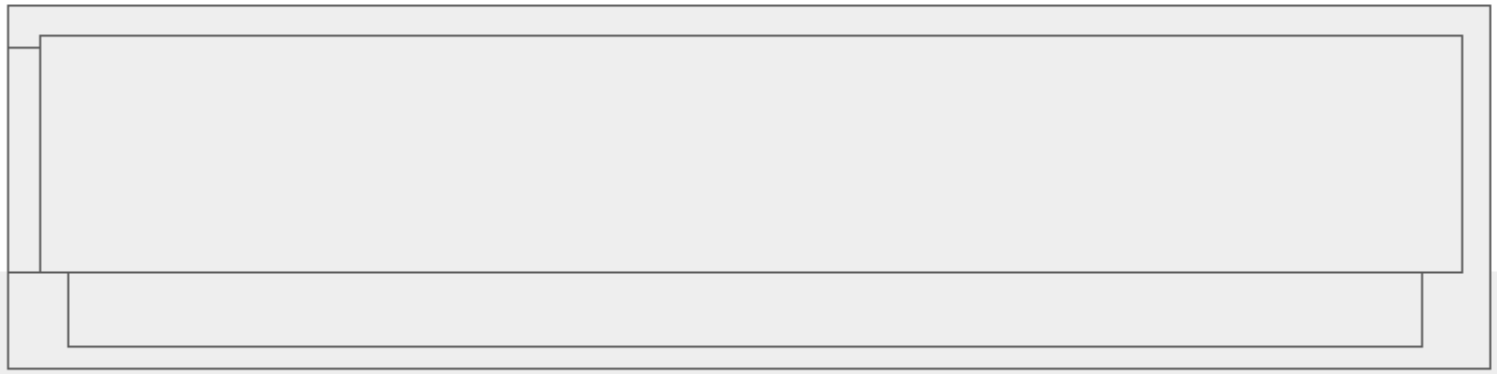
MS experiment with robust, inherently safe system behavior

Planned tests:

- **Inactivity tests**
  - **Cold tests (without fuel and moderator)**
  - **Hot tests (with fuel and moderator)**
- **Active tests**
  - **Criticality at zero power**
  - **Gradual increase in power up to 1MW**
- **Decomissioning the experiment**

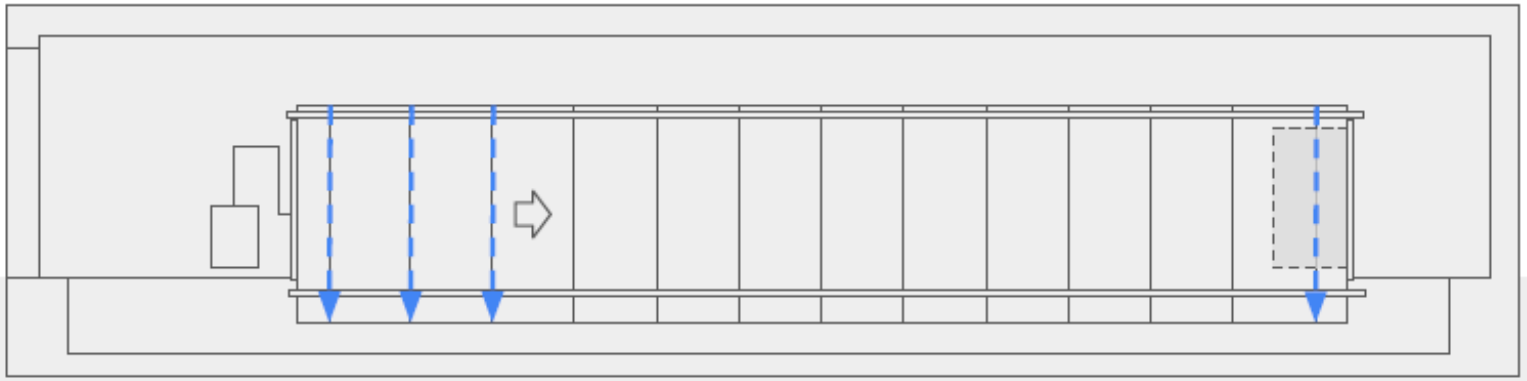
MS experiment leaves Switzerland

Construction of the NT

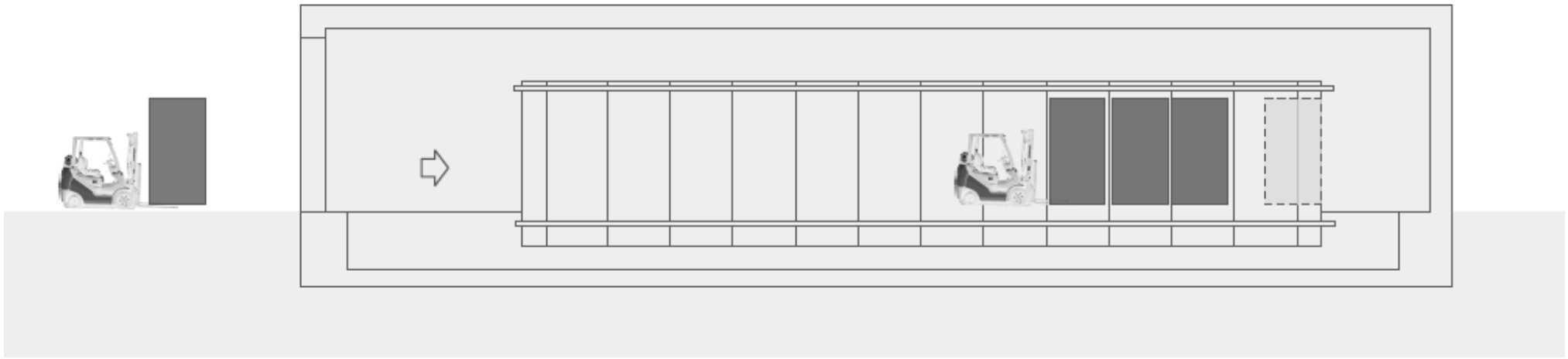


Structure of the cocoon

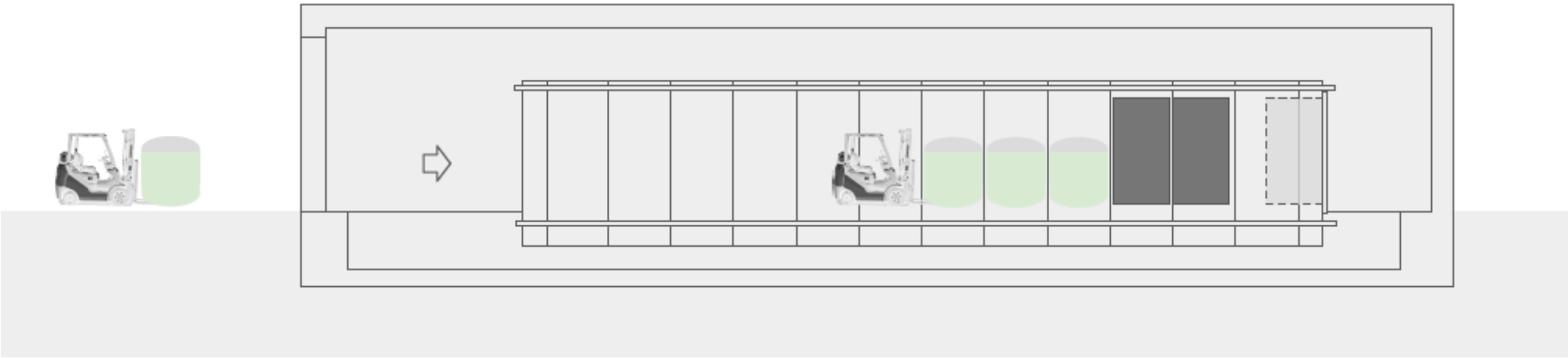
Cocoon welding and filter construction



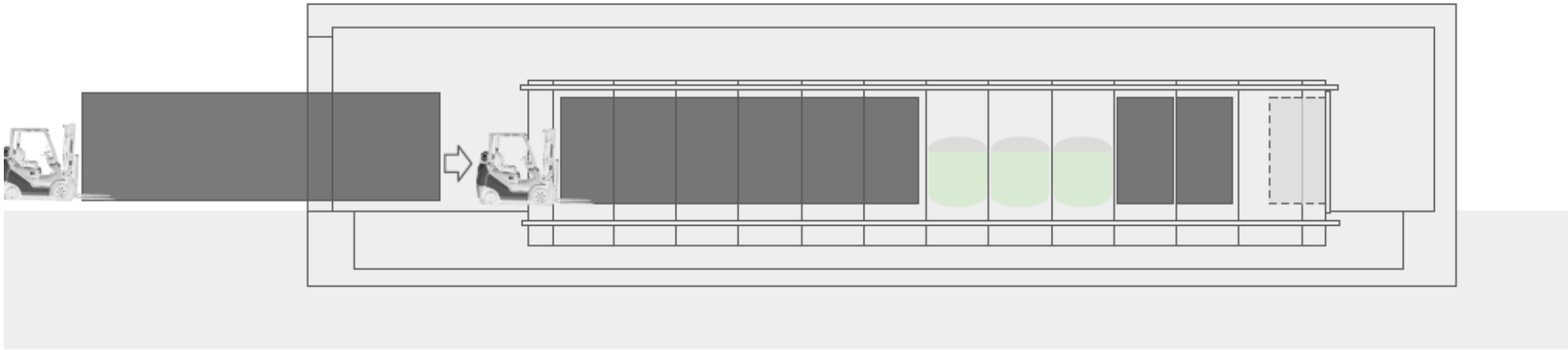
Exhaust air system installation



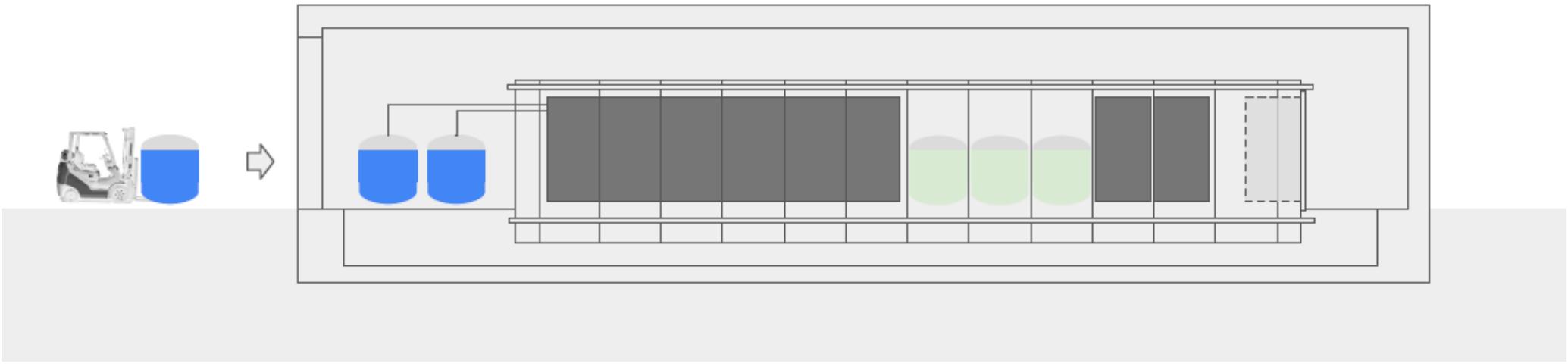
Salt transport tanks installation



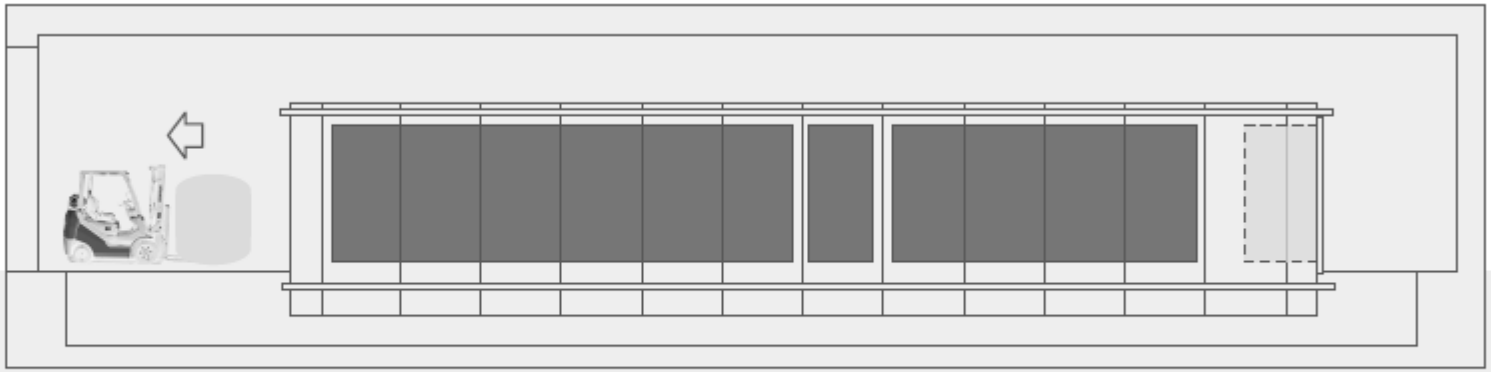
Container installation



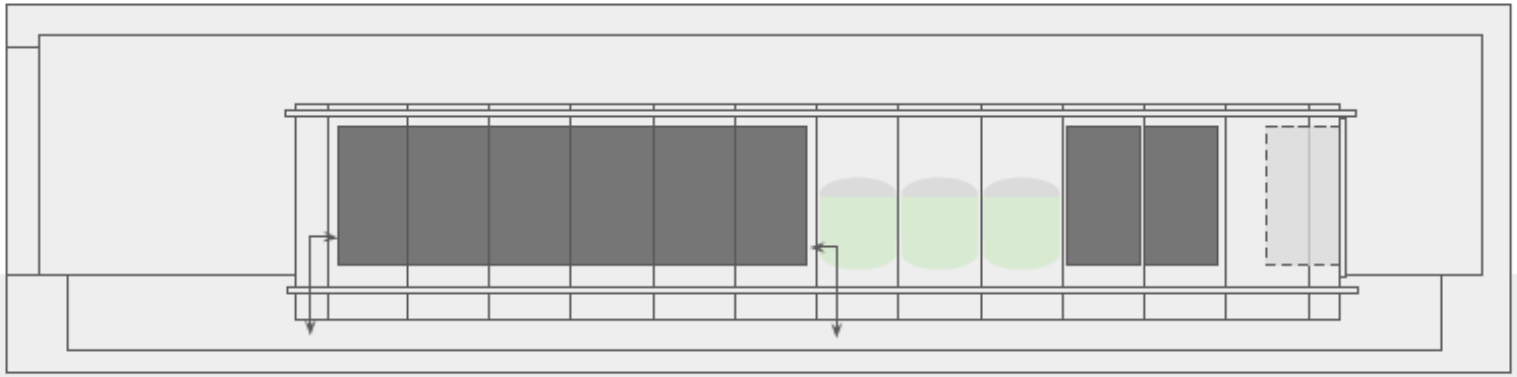
Transfer of water and heavy water



Removing empty water tanks

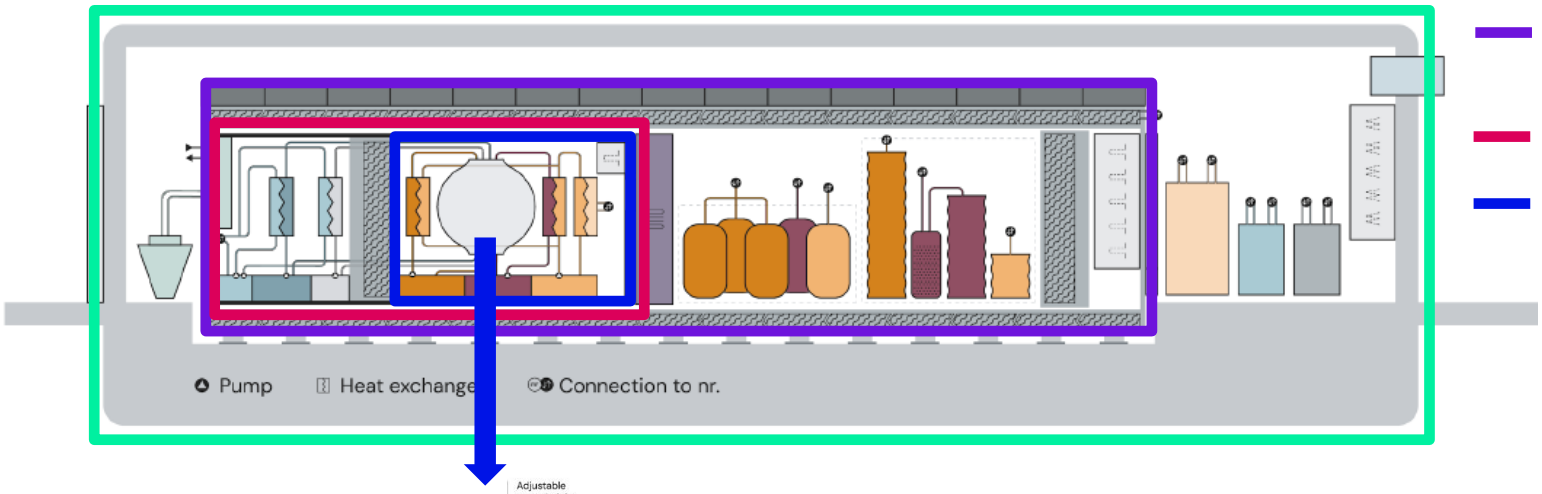


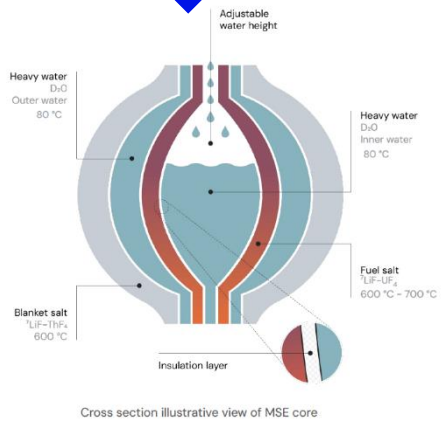
Connecting, sealing and inerting



Barrier concept of NT building and MSE

NT is designed so that the other barriers can be dispensed with.
(Assumption: all barriers and safety functions of the MSE fail)
-> NT as a barrier against the worst-case scenario!





Cross section illustrative view of MSE core

Barrier functions:

- NT (building)

MSE consisting of:

- COCOON
  (equivalent to NPP-Containment including. shielding)
- CONTAINER (sealed)
- CORE (separated within the container)

Key data MSE from CA

- Onion seed: Innovation from CA
- Fuel salt: F-Li-LEU (4.95 % enriched), ~ 500 l
- Shielding salt: F-Li-Th, ~ 3000 l
- Moderator: D_2O, ~ 3000 l
- Walls: SS-316, Zircaloy
- Power: Max 1 MW/30d (cf. commercial target CA: 100MW/1800d)

During the experiments, NT will be sealed off, i.e., no persons will be allowed in the building.

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Postulated Worst-Case Accident scenario

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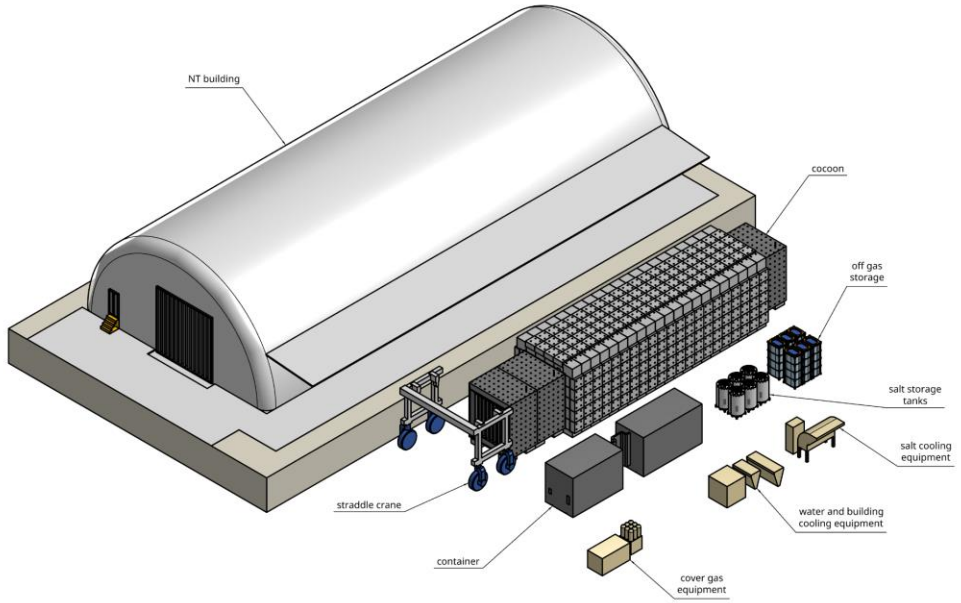
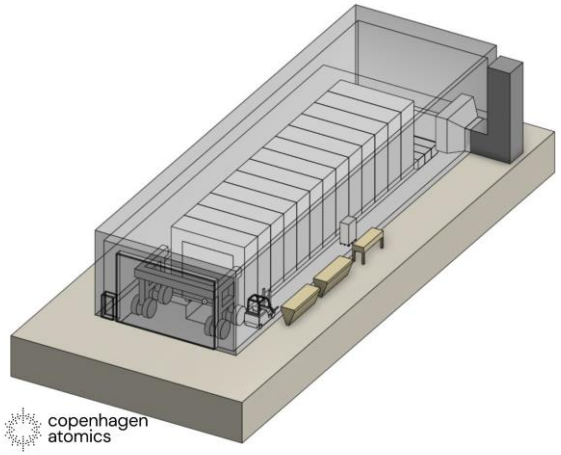
Worst-case accident scenario

Postulate: Simultaneous release of radioactive substances from the entire stockpiles of fuel salt, cover salt, exhaust gases, and irradiated heavy water, leading to a leak and mixing of radioactive materials inside the MSE container on the last day of full-load operation (maximum activity).

NT Building Design Parameters





- External dimensions of the building: **18 x 45 x 9 [m]**
- External events in accordance with Swiss regulations
- Internal events WCA :
  - Max. temperature: **200 °C for 0,5 h**
  - Relative humidity **≥90 %**
  - Maximum public dose: **1 mSv** (10^{-6})
  - Leak-proof building
- Option 1: *No ventilation and overpressure*:
  - Cocoon NOT classified for safety purposes → **γ-shielding**
  - Max. relative overpressure: **2 bar**
- Option 2: *Passive filters only:*
  - Cocoon classified for safety
  - Max. relative overpressure: 50 mbar
- Option 3: *With venting of the containment vessel and filters*:
  - Cocoon NOT classified for safety purposes → **γ-shielding**
  - Max. relative overpressure: **50 mbar**

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Plan

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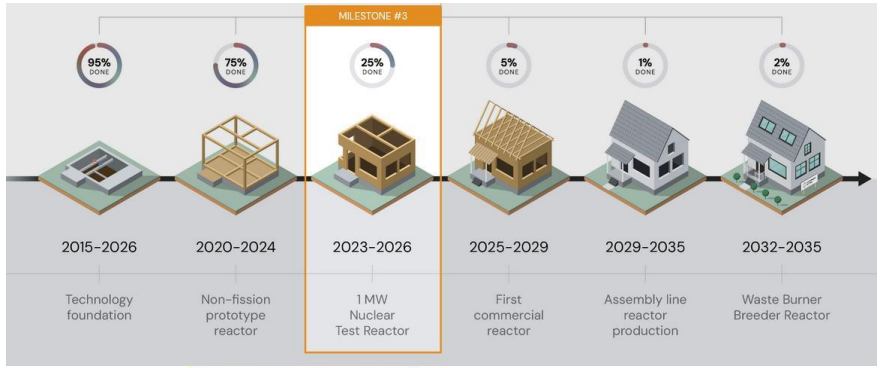
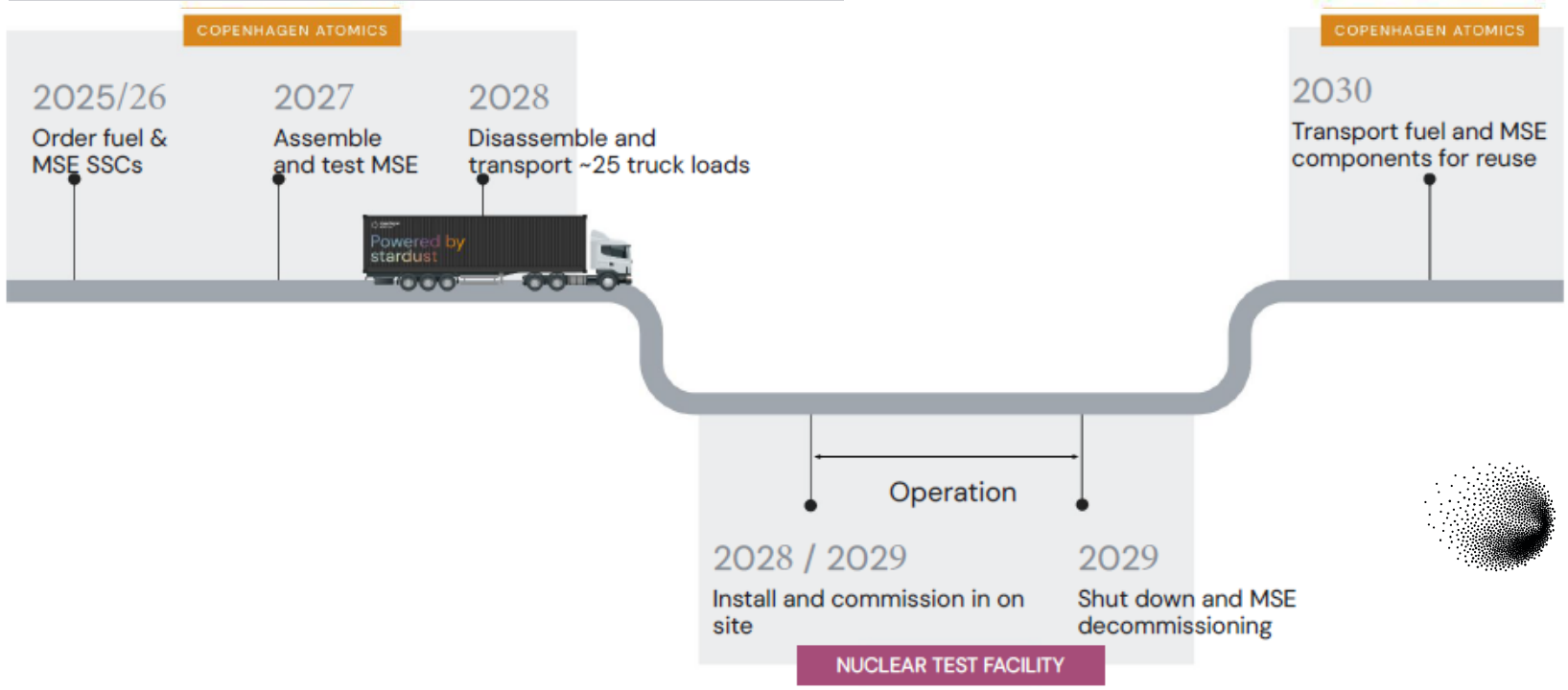
Ambitious schedule for the rest of the project





https://www.psi.ch/de/ahl/project-balder

› PSI Center for Nuclear Engineering and Sciences › Hot Laboratory

Project: BALDER

The "BALDER" project is a collaboration project between PSI and Copenhagen Atomics (CA) with the aim of carrying out a critical experiment by CA in a nuclear test facility with low hazard potential on the PSI site.

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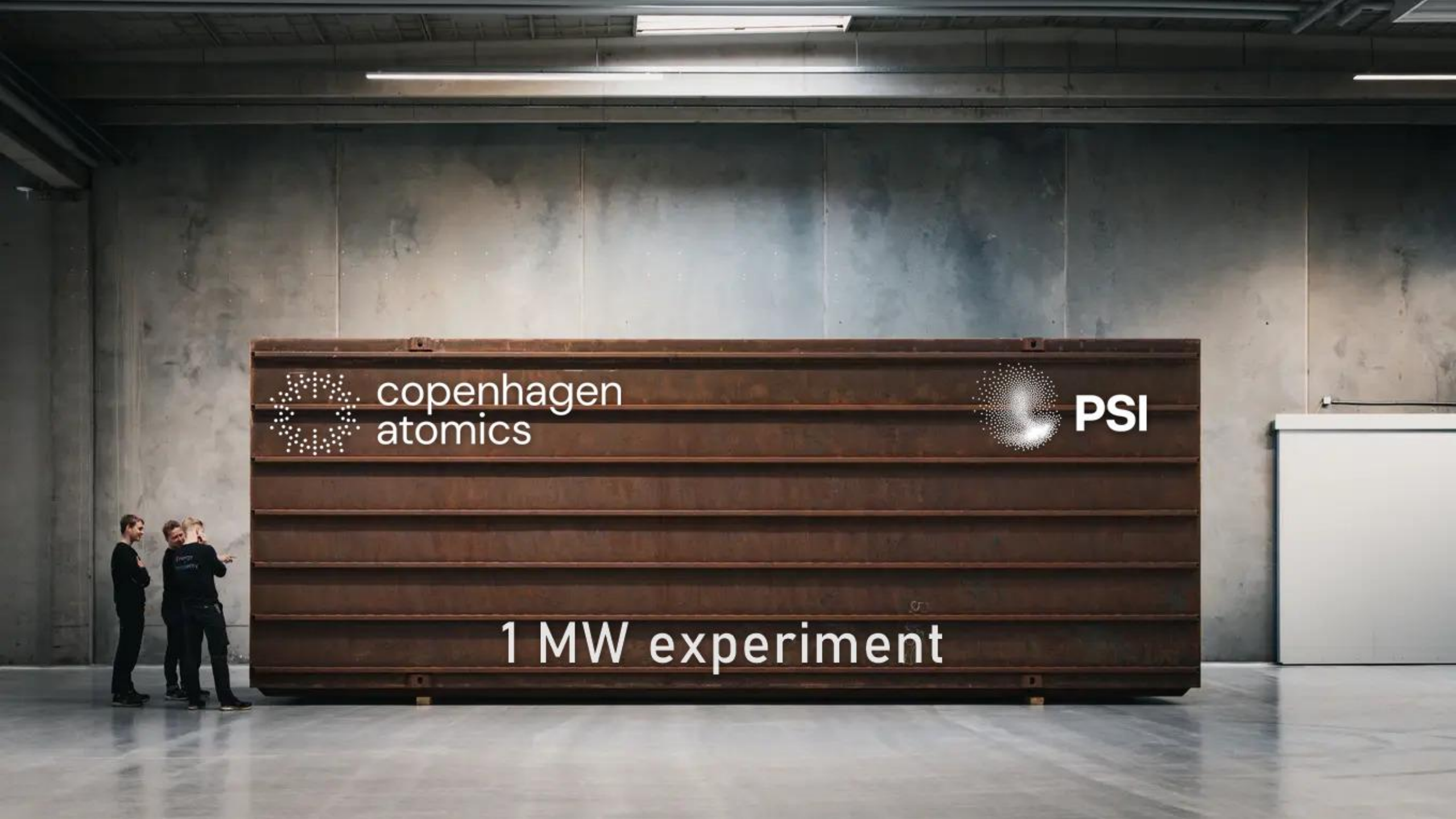
«The future depends on what we do today.»

Mahatma Gandhi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1 MW experiment