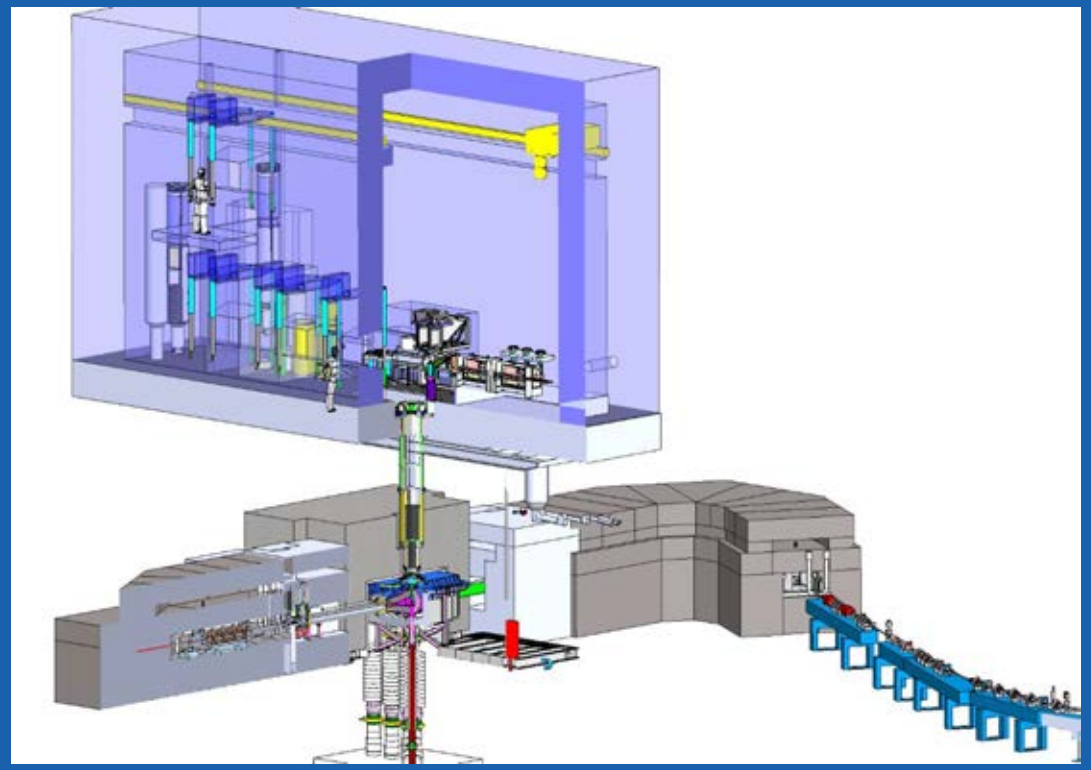

System engineering for SMART: Accelerator-based, high-volume production of medical isotopes

JOHANNES JOBST
SYSTEM ENGINEER AT DEMCON

Medical Radioisotopes

TECHNETCIUM-99M

- For diagnostic imaging with SPECT scans
- > 2/3 of nuclear imaging uses Tc-99m
- >35 million procedures yearly worldwide
- Half-life of 6 hrs

PARENT ISOTOPE: MOLYBDENUM

- Mo-99 $\xrightarrow{\beta^- \ \gamma}$ Tc-99m
- Half-life of 66 hrs

Made by DEMCON Nymus3D

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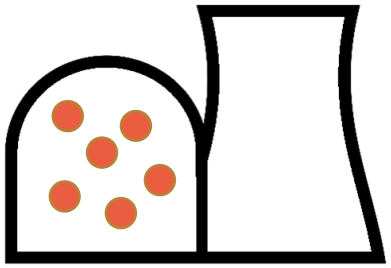
Production of medical isotope Tc-99m

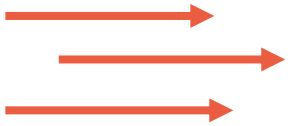
Current technology: using Nuclear reactors



neutrons

Uranium Target

SMART Project: using an electron accelerator (Lighthouse technology)



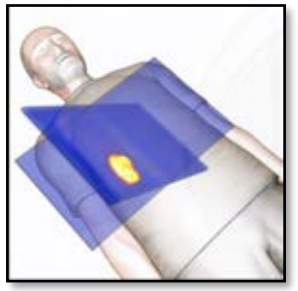
75 MeV electrons

Mo-100 Target

Mo-99

Tc-99m

SPECT imaging



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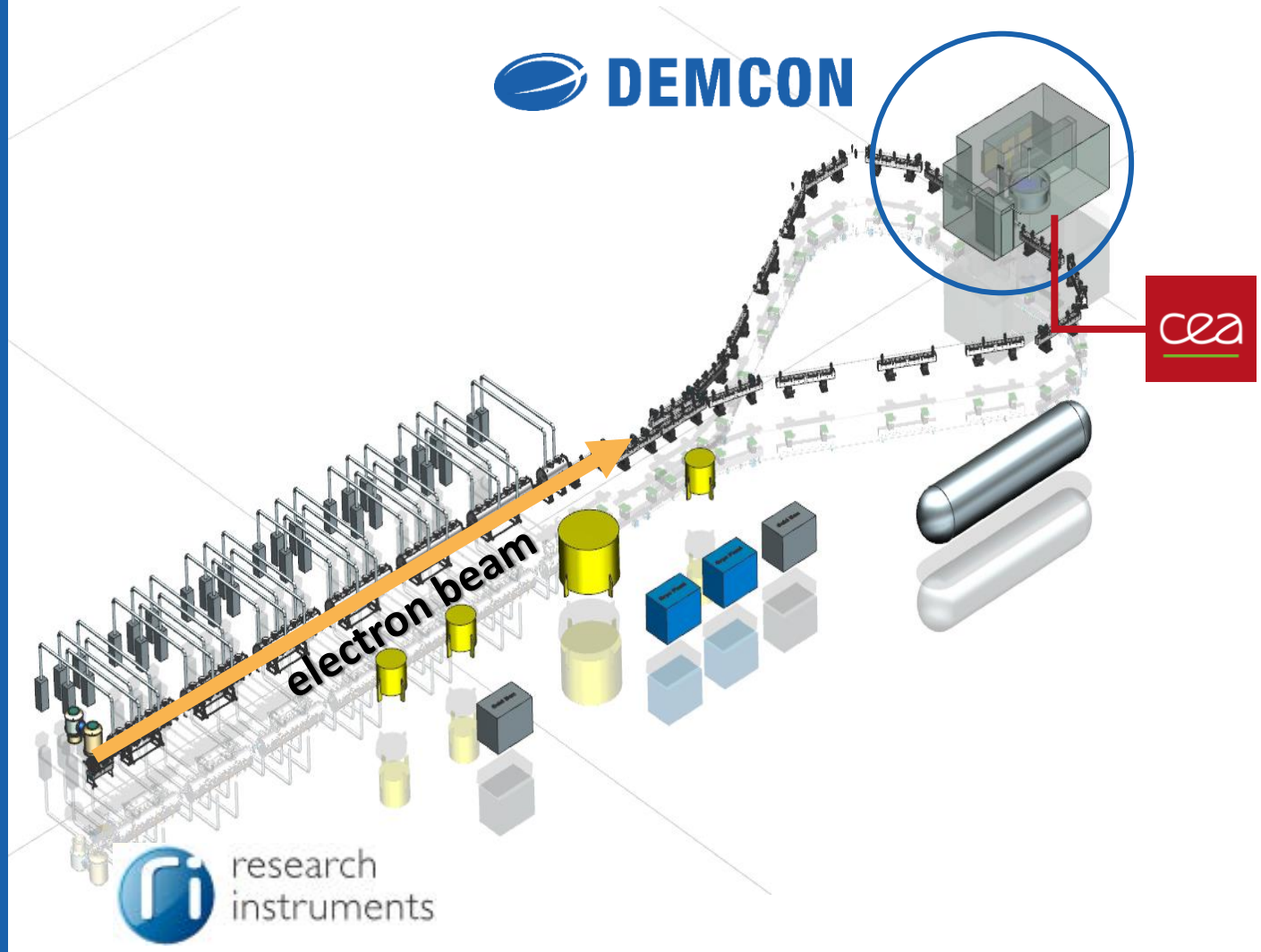
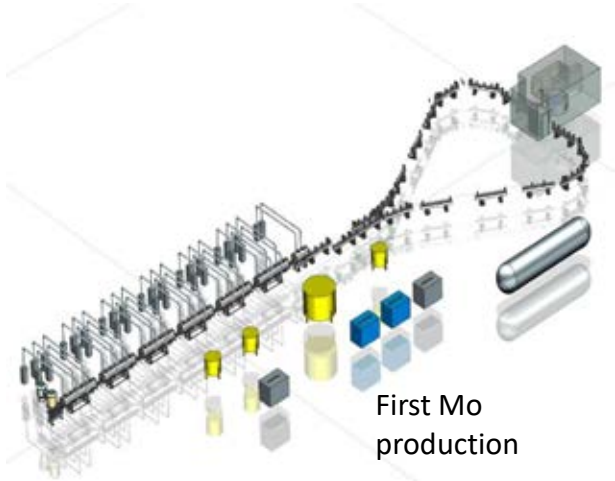
IRE | IRElit Radiopharma

SMART Factory

- Factory: size of soccer field
- Cryogenic accelerator cavities
- 3 MW electron beam
- Modular target with robotic handling
- Target cooling with liquid sodium
- Radioactivity and radiation



Project history & planning



Lighthouse project at ASML

National Icon

Start project at DEMCON

IRE: go/no-go decision

First Mo production

2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028

Demonstration of technical feasibility

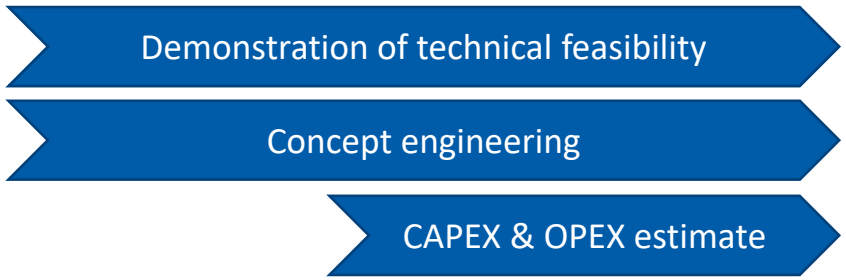
Remaining engineering and realization

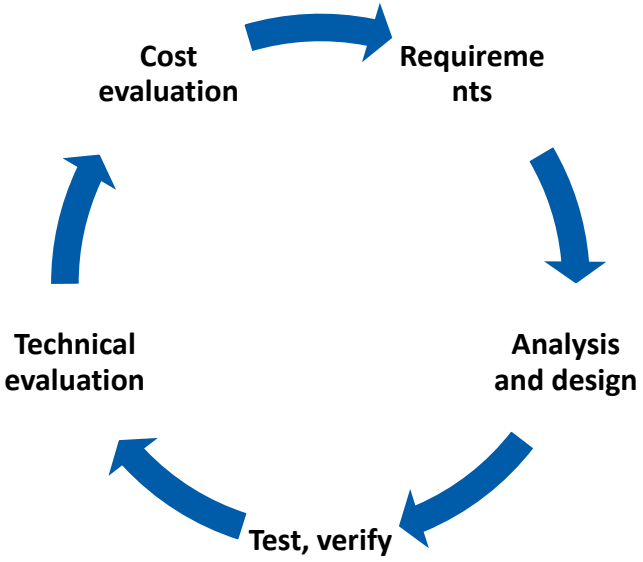
Concept engineering

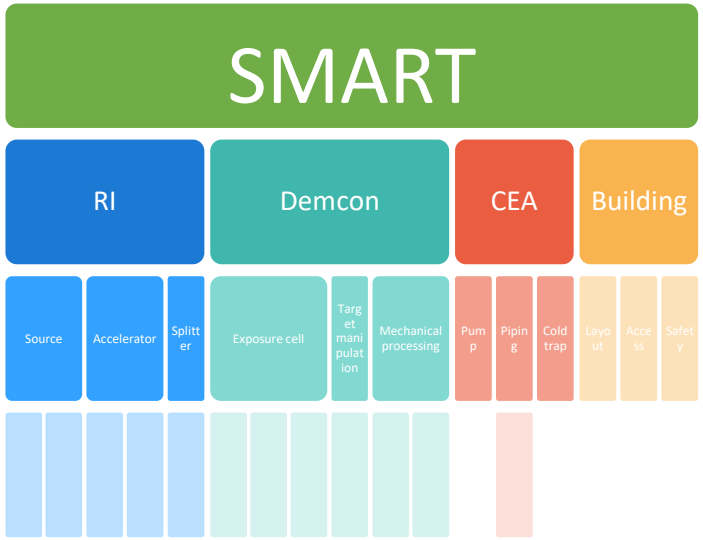
CAPEX & OPEX estimate

Included in SMART project of IRE

Concurrent engineering







- Goal: Speed up development to reach production milestone
- Risk: concepts worked out ‘too’ far and then discarded
- Regulatory requirements around radioactivity evolve with concepts
- Many requirements are discovered and changed during feasibility and design iteration

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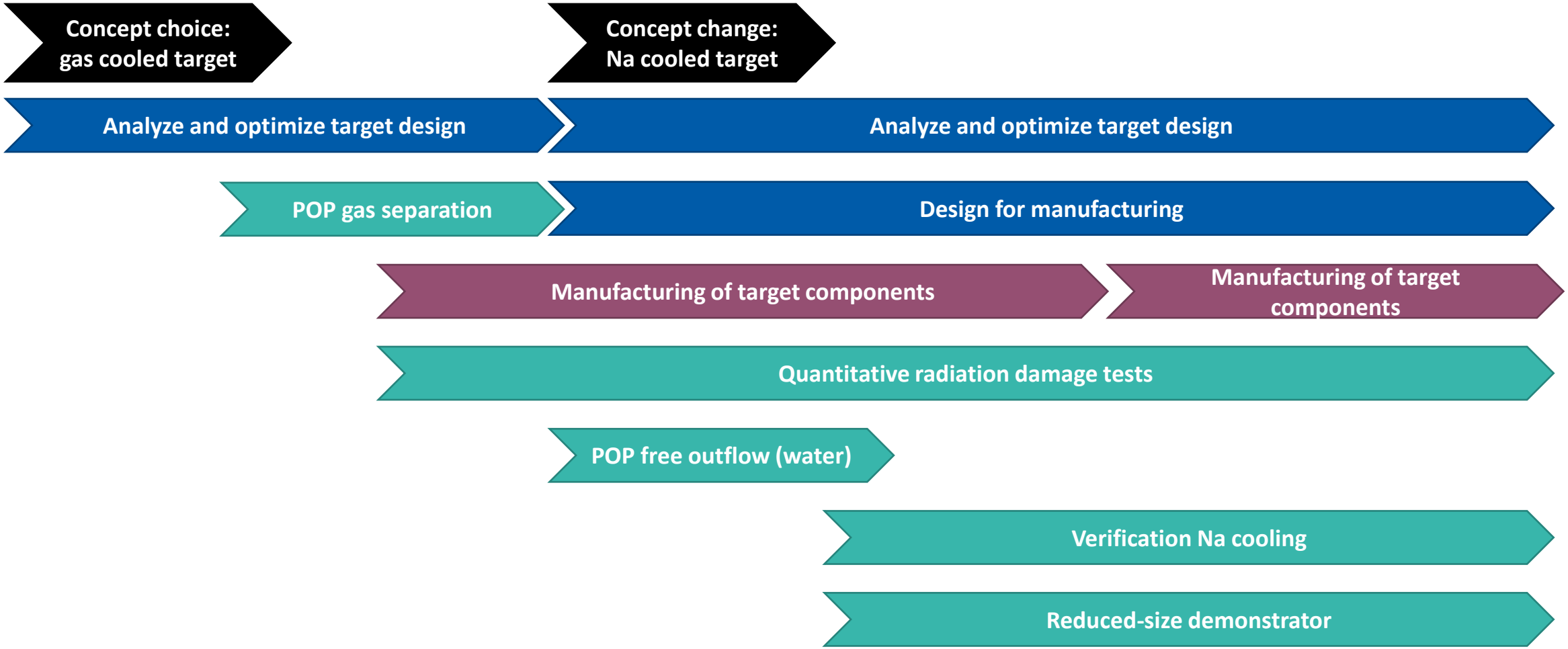
Concurrent engineering



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Concept verification

RADIATION DAMAGE

- Miniaturized version of SMART exposure unit
  - Size of target is 1:1000
  - Full power density and radiation damage

Goals

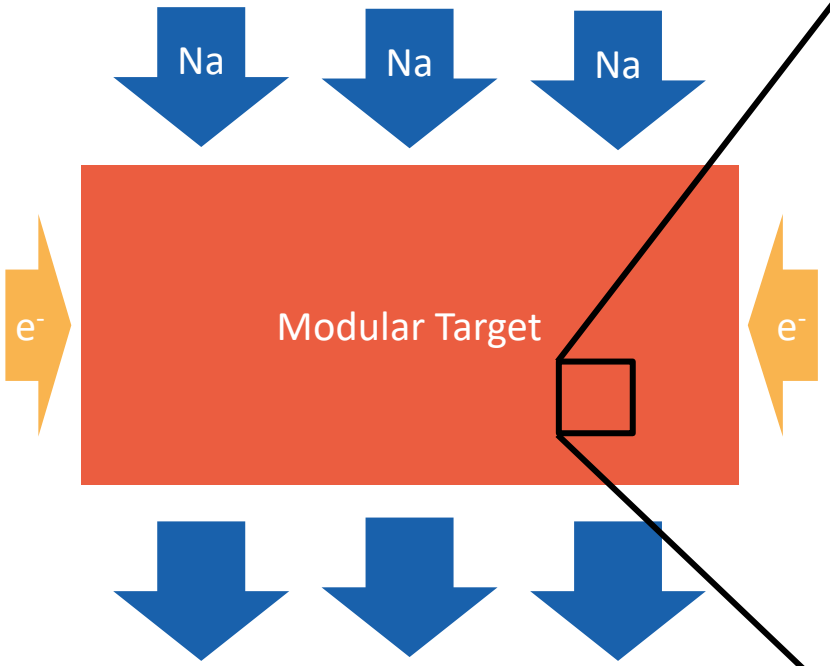
- Verify robustness of design against combined effect of radiation damage and liquid sodium
- Demonstrate feasibility of SMART concept

SAAS
Systemanalyse & Automatisierungsservice GmbH

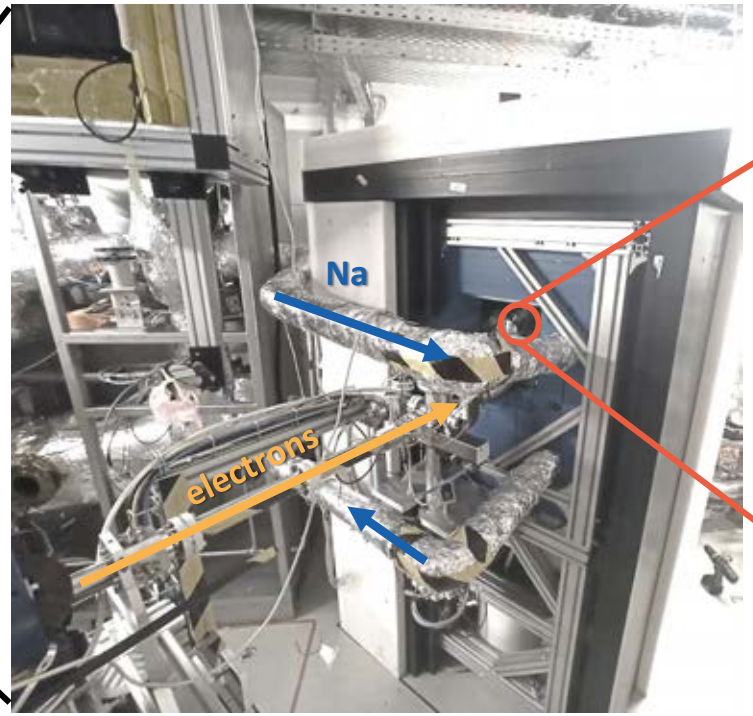
HZDR
HELMHOLTZ ZENTRUM
DRESDEN ROSSENDORF

Successful demonstration of the concept

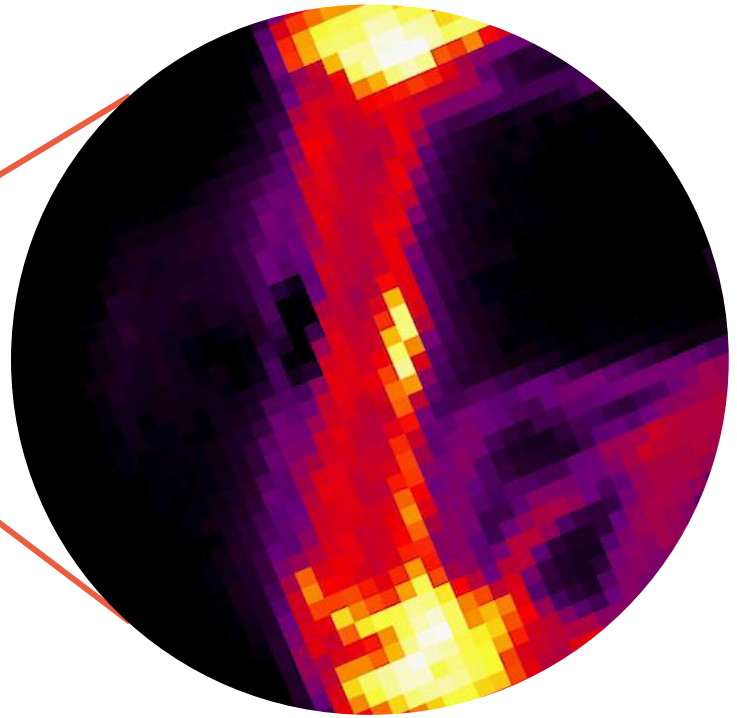
SMART exposure unit



Demonstrator



Beam on target



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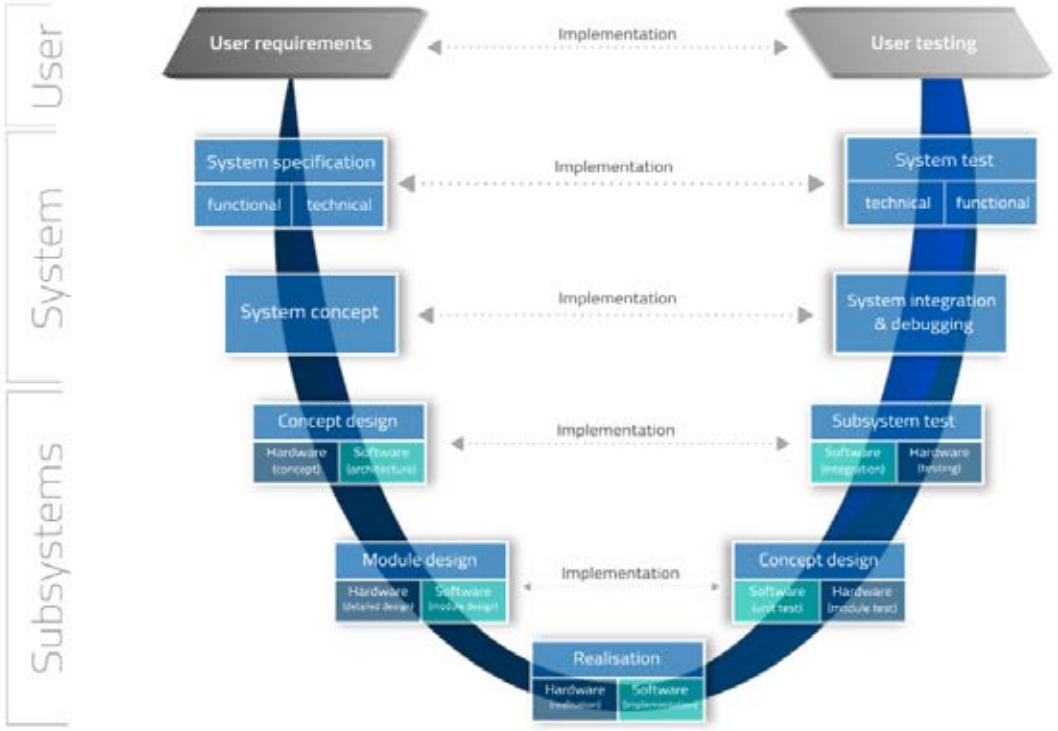
Requirements



Two customer requirements (non-negotiable for business case) largely drive system complexity

1. Mo99 yield (Ci/harvest)
   - 75 MeV, 40 mA → 3 MW electron beam
   - Mo target needs ~1 week of electron exposure to reach required activity
2. Mo99 yield density (Ci/g)
   - Compact Mo target size → extreme heat load & radiation damage

- Together → reduce decay losses
  - 23/7 in operation
  - <1 h per day for Mo harvest/replenish
  - Few maintenance days per year

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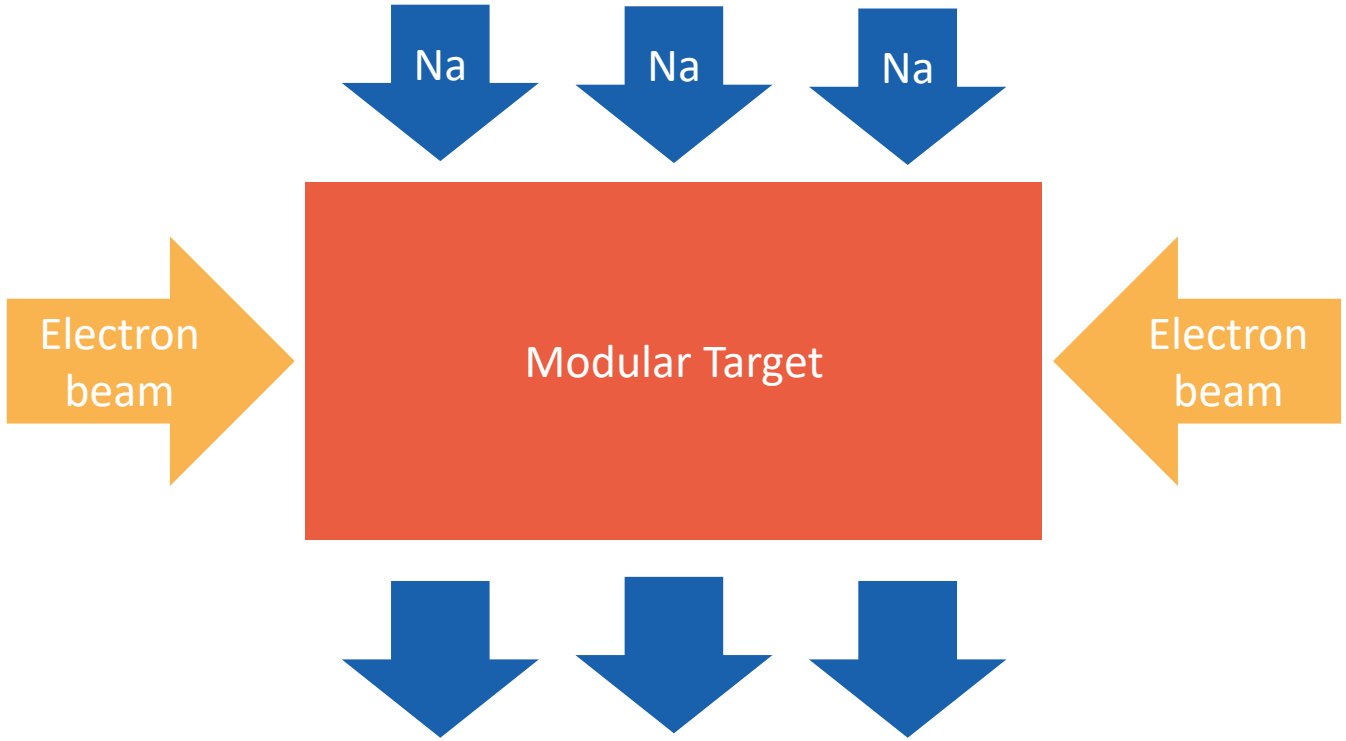
Verification of Na cooling

Challenges

- 2 MW in a matchbox-sized target
- Power density
  → light saber from Starwars



Solution

- Cooling with liquid sodium
  - Good cooling, melting point <100°C
  - Flammable and chemical aggressive

L. Willcocks, *Calculating The Power Output of Qui-Gon Jin's Lightsaber.* Journal of Interdisciplinary Science Topics **6** (2017).

Concept verification

LIQUID SODIUM COOLING

- Sodium cooling test circuit
- Designed and built-up at DEMCON site in Best for this project

Verification goals

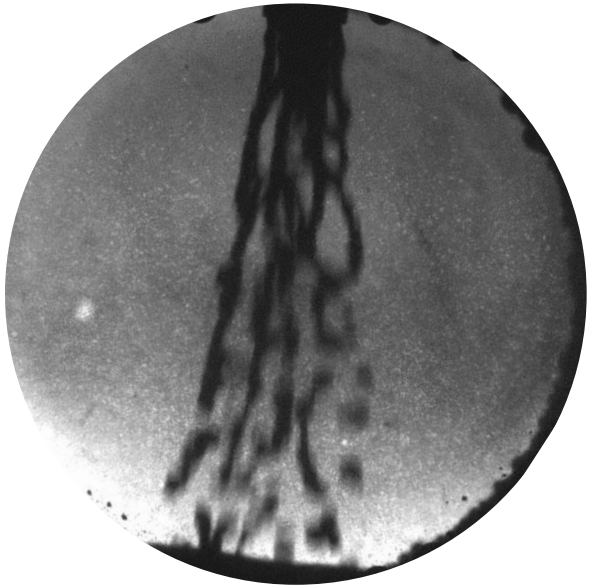
- Cooling concept
- Sodium corrosion
- Fluid dynamics of liquid Na

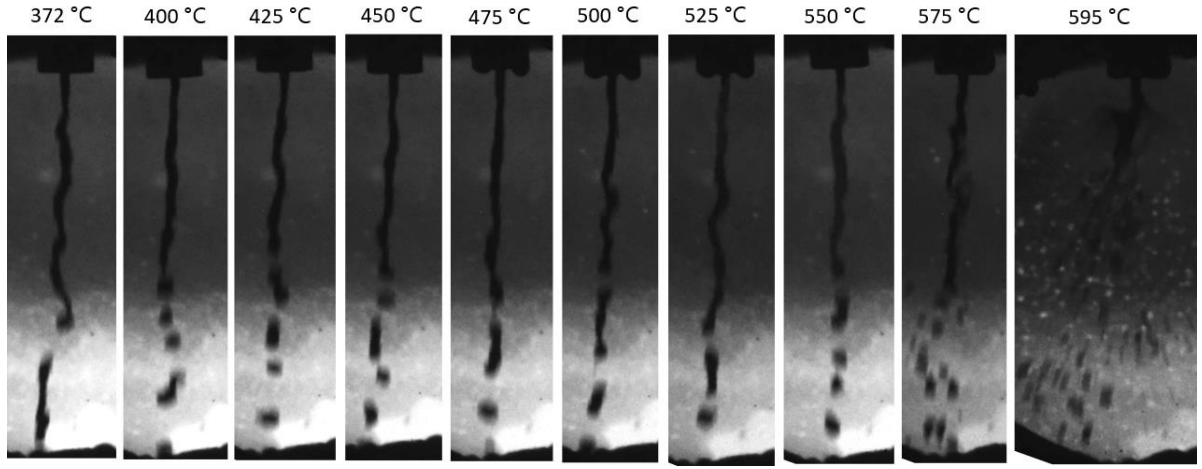
SAAS Systemanalyse & Automatisierungsservice GmbH

TÜV SÜD ISO 9001

KIT Karlsruher Institut für Technologie

Liquid Na: fluid dynamics and free-outflow





CFD and verification

- Targets have complex shape and cooling is critical
- CFD of liquid Na (<10% error)
- Verified by experiment

Free-outflow

- Na ejects into vacuum chamber
  → difficult to model with CFD
- Analytical predictions verified by experiment

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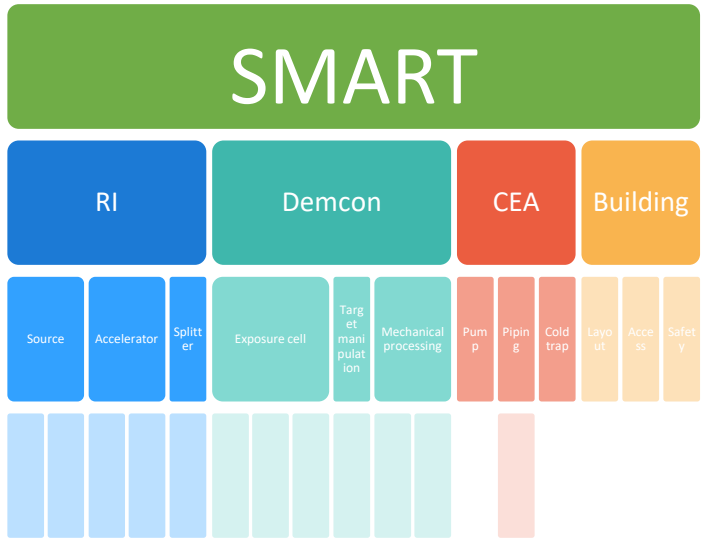
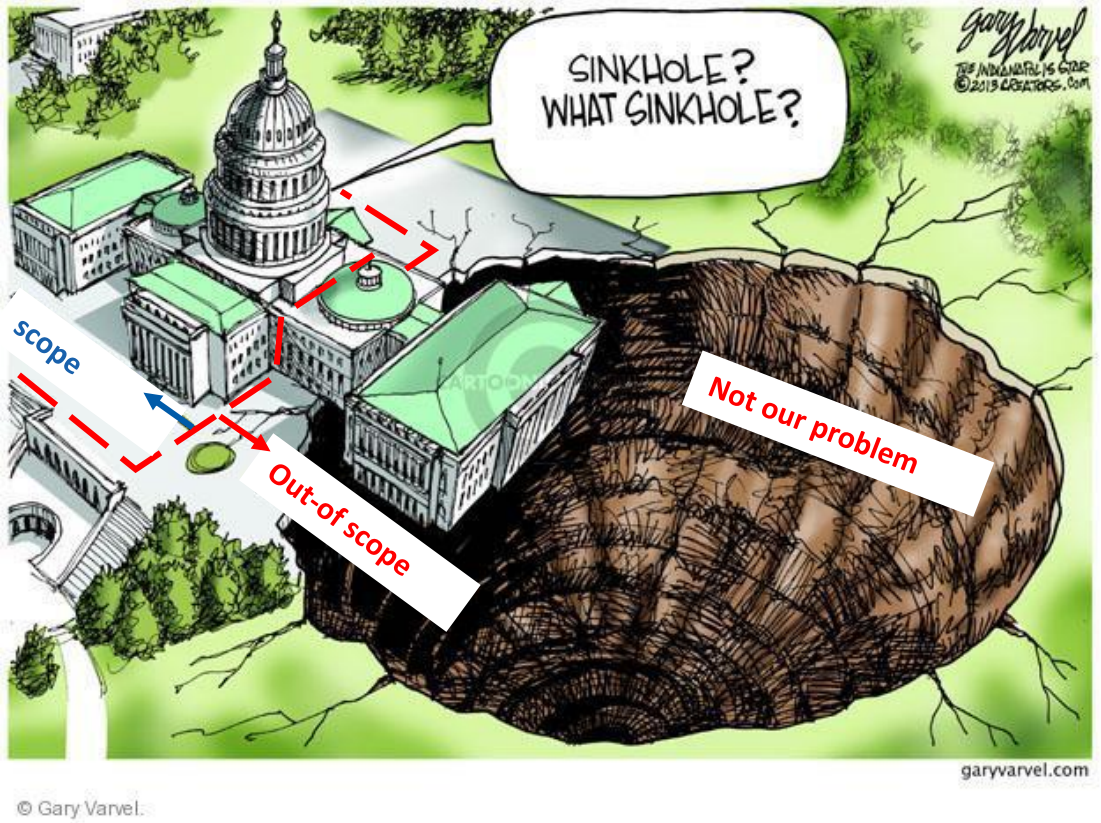
Teams and cooperation

- Project wide
  - 5 main partners (IRE, ASML, Demcon, RI, CEA)
  - In 4 different countries
  - Many industrial and academic partners world-wide

→ define clear scope
→ look beyond own scope to optimize system





© Gary Varvel.

DEMCON

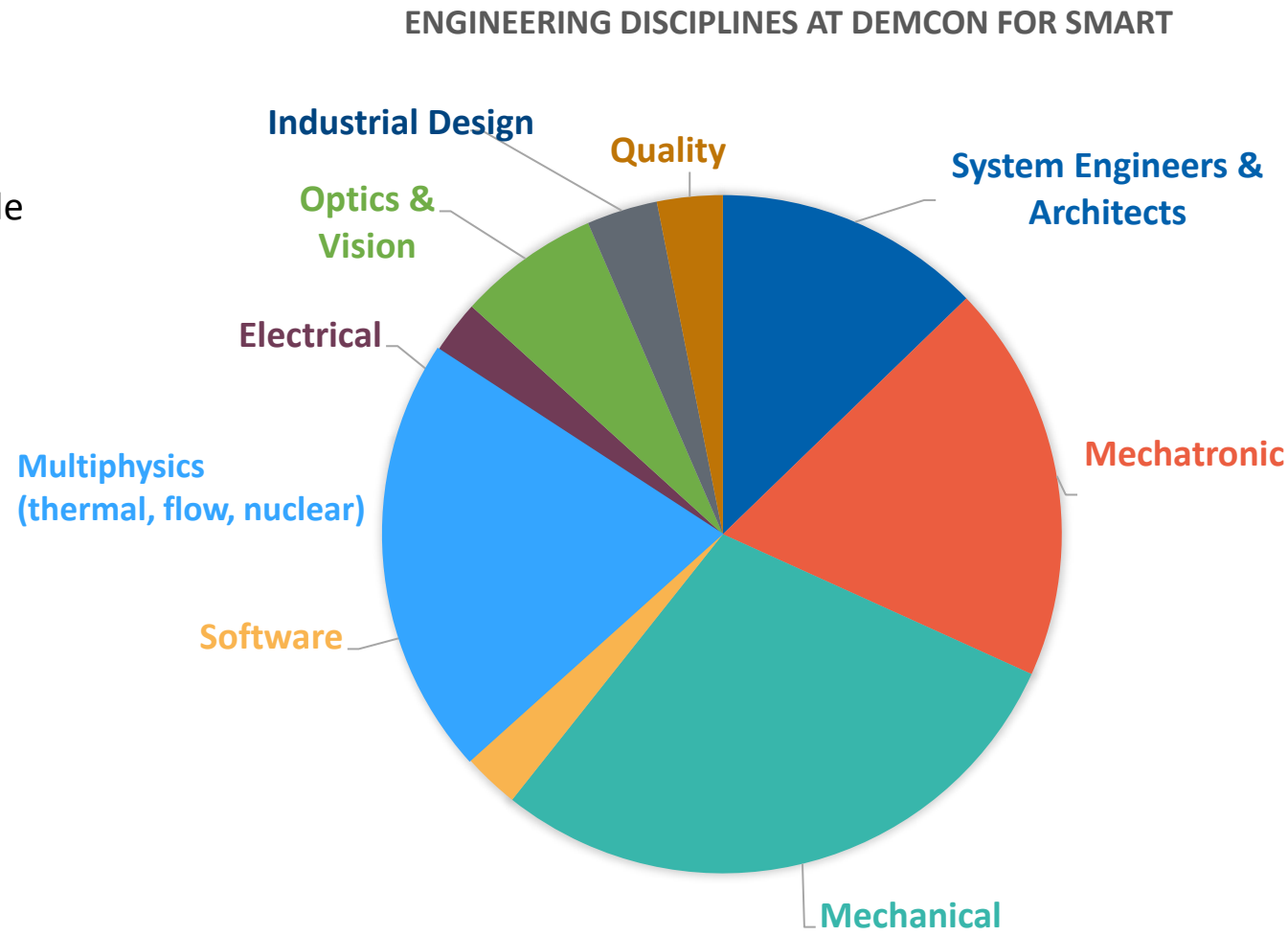
Teams and cooperation

- Project wide
  - 5 main partners (IRE, ASML, Demcon, RI, CEA)
  - In 4 different countries
  - Many industrial and academic partners world-wide

  → define clear scope
  → look beyond own scope to optimize system

- At Demcon
  - Large team (~80 people)
  - Multiple locations
  - Multi-disciplinary
  - Specialized know-how

→ communication is key!



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Managing complex interfaces

Goal

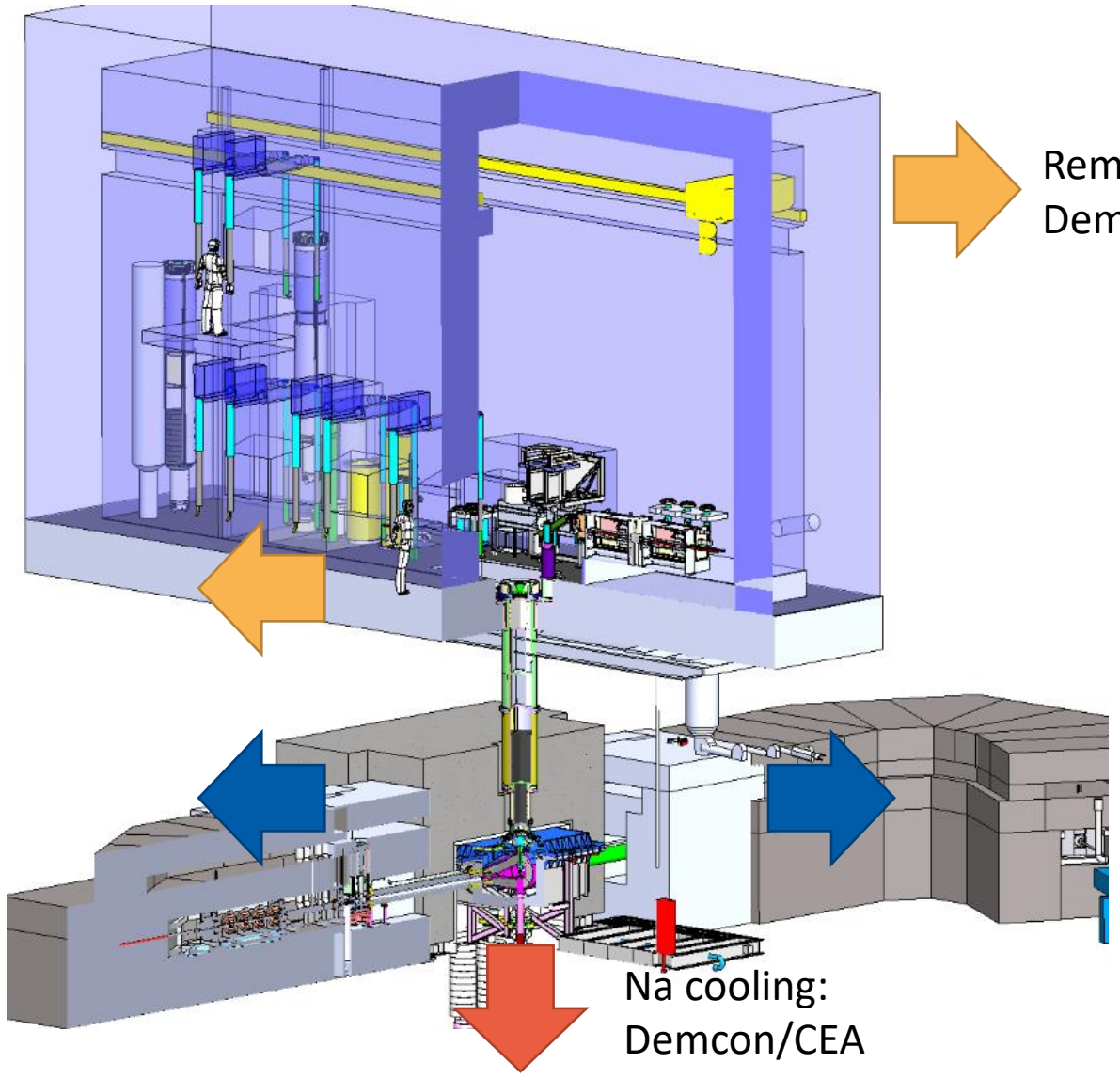
- Concrete agreements
- Accommodate uncertainty of concurrent engineering

Approach

- Weekly bilateral meetings
- Living interface documents

Example

- Beam properties defined early
- Baseline for achievable tolerances later
- Exact position of interface moved late
- Location of pumps moved across interface
  → change of scope



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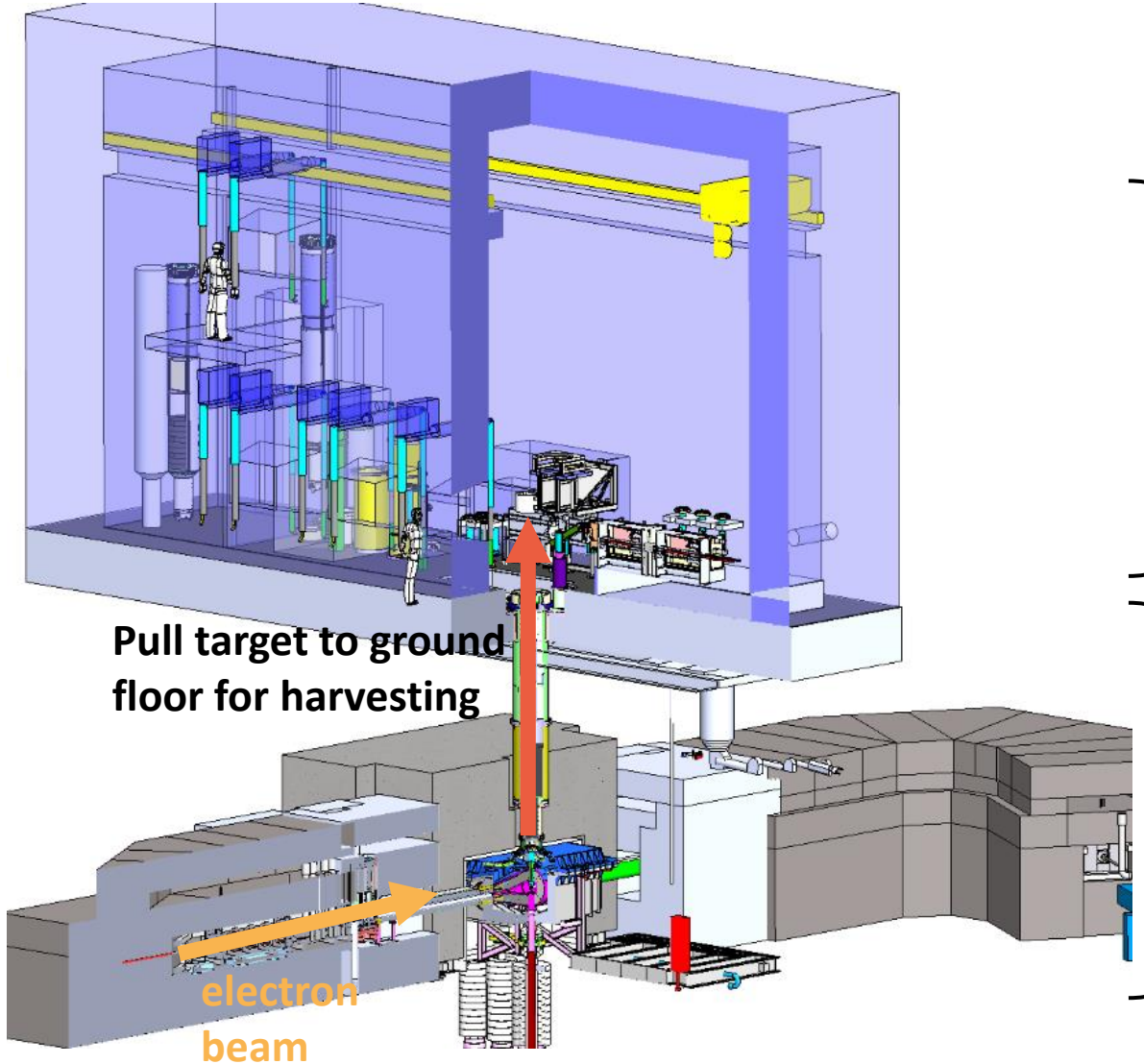
Factory design with required reliability

Challenges

- 24/7, year-round
- In complex environment
- Hot, activated target

Solution

- Modular design
- Servicing during operation
- Automated harvesting



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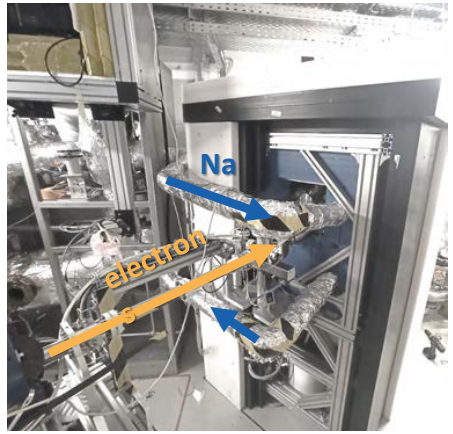

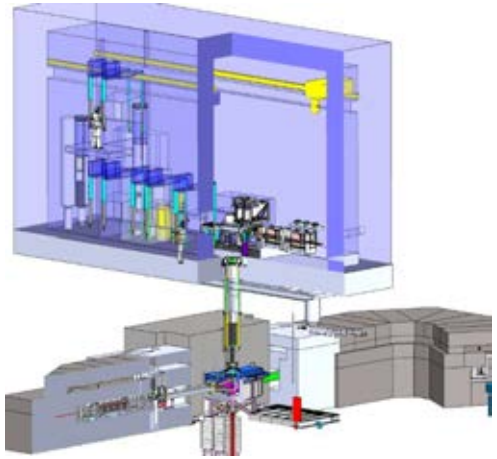

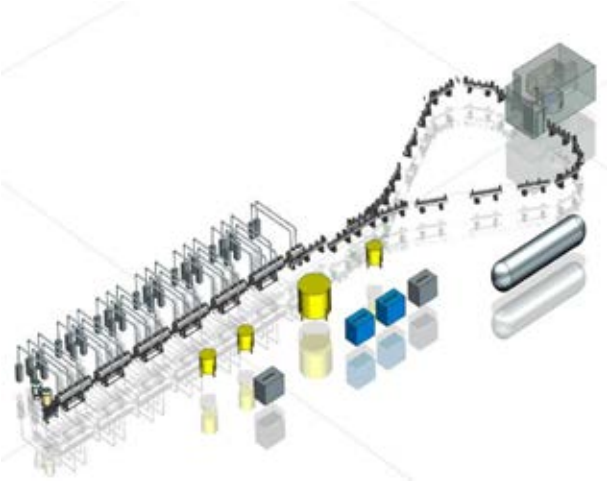

ASML

LightHouse Isotopes

Lighthouse project at ASML

National Icon

Start project at DEMCON

Start test setup development

Successful demonstrators

IRE: no-go decision

First Mo production

2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 20??

Demonstration of technical feasibility

Remaining engineering and realization

Included in SMART project of IRE

Concept engineering

CAPEX & OPEX estimate

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DEMCON

johannes.jobst@demcon.com


imagine
tomorrow.
challenge
today.
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