Concepts for handling radioactive products from a liquid metal spallation target

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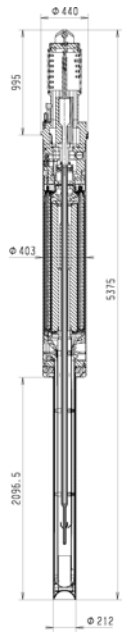
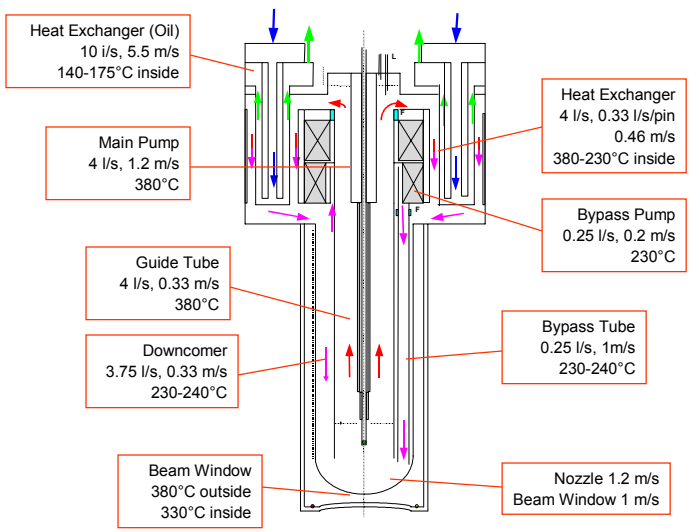
- Safety Concept
- Handling of LBE
- Handling of Volatiles
- Accident Scenarios
- Experience and Supporting Experiments

MEGAPIE Experiment

Beam energy:	**575 MeV**
Beam current:	**1.74 mA (design)**
Design life:	**1 year of operation (6000 mAh)**
Target material:	**Lead-bismuth eutectic (T_m=125°C)**
LBE volume:	**82 l**
Wetted surface:	**8 m²**
Deposited Heat:	**650 kW**
LBE T range:	**240-380°C**
Max. flow velocity:	**~1.2 m/s**
Beam window:	**T91 steel**
Window Temperature:	**330-380°C**
Radiation Damage:	**20-25 dpa**



Mass Transfer and Temperatures



Target Design

AD2000
European Specification for Pipe and Pressure Vessels

- **Static Loads (mechanical and thermal loads)**
  - **Admissible Operating Pressure at T_{op}** **p = K/1.5**
  - **Test Pressure at T_{op}** **p`= K/1.05**
  - **Admissible Operating Temperature** **→ 400°C**
  - **K = Mechanical Resistance** **→ 0.2% Yield Strength T91**
    1% Yield Strength 316L
- **Cyclic Loading for n > 1000** **→ n = 10000**
- **Creep Loading** **→ 6000 h**
- **Elastic Buckling**
- **Corrosion Allowance** **< 100 μm**

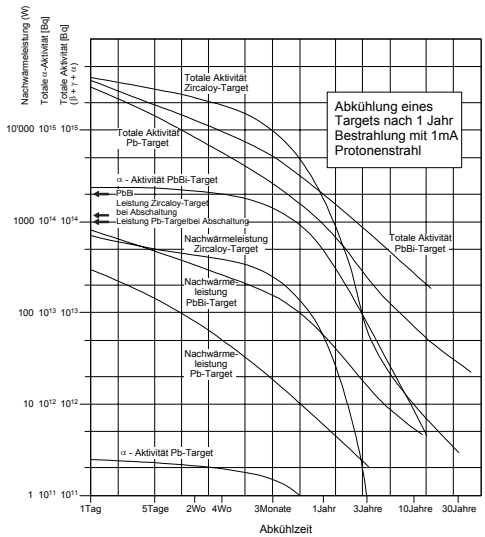
Spallation Products

Production (g) in a LBE target after 1 year and 6000 mAh

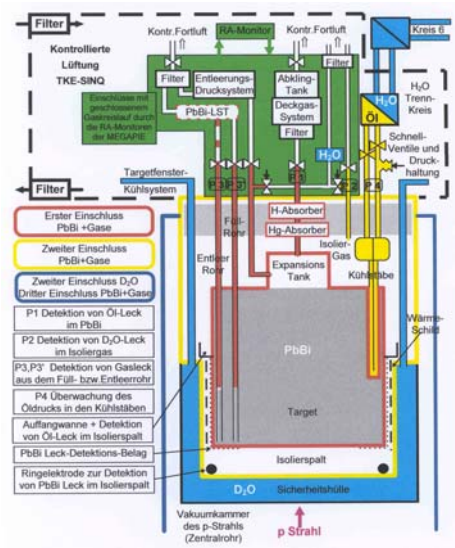
Po	1.17	Cs	0.027	H	0.548
Tl	4.59	J	0.048	He	0.479
Hg	11.78	Te	0.137	Ar	0.001
Au	2.53	Sn	0.274	Kr	0.205
Pt	3.50	Cd	0.274	Xe	0.137
Ir	1.03	Zn	0.055		
Os	3.08				

F. Atchison, SINQ/816/AFN-702

Decay Characteristics of a LM Target



MEGAPIE – Barrier Concept



Defense in depth:

3 barriers

Target Handling at EoI

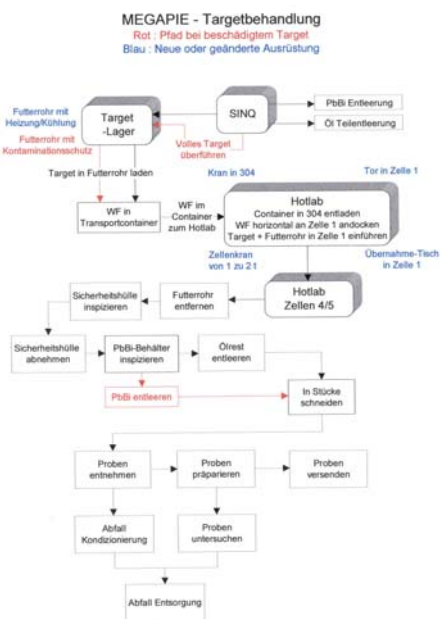
Option 1: Drain LBE

- Dispose LBE separately
- Empty target to Hotlab for sample extraction and disposal
- No solution in case of accident

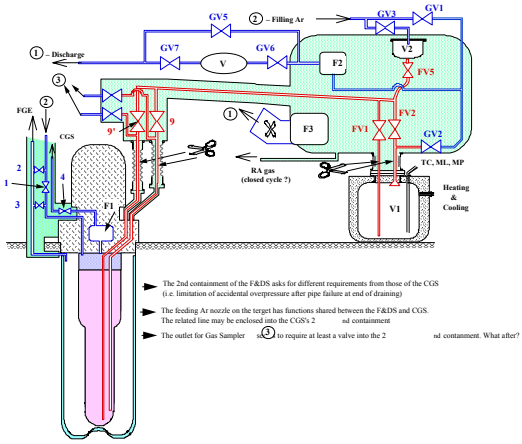
Option 2: Freeze LBE

- LBE volume expansion
- Separation of LBE from target needed for sample extraction
- Disposal of LBE and target together

PSI Hotlab: β,γ cells ZWILAG hotcell: α cell

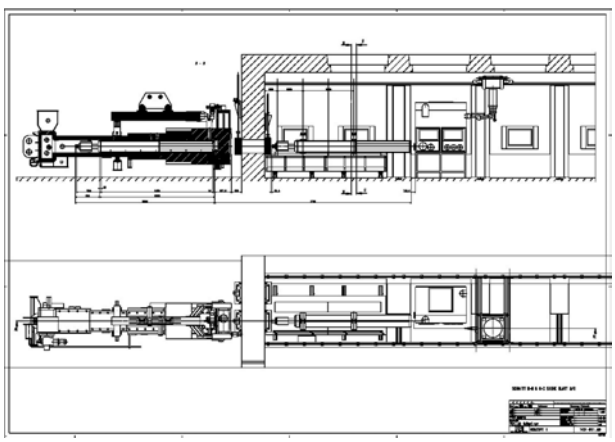


Fill & Drain System



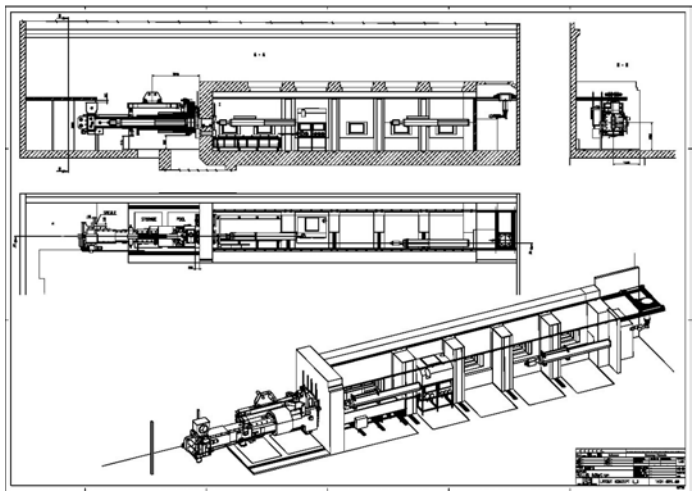
- LBE expansion during freezing
- Empty target during standby and repairs
- Reduce activity during transport
- No draining as an option and after target damage
- Double containment
- Cut & Squeeze System to separate installation from target

Target Disposal Hotlab Option



- Draining of LBE in TKE
- Transfer of Target to Storage with Exchange Flask
- Loading into „Futterrohr“
- Cool down in storage (6 months)
- Transfer of Target in Futterohr & Exchange Flask to PSI Hotlab (Transport Container)
- Transfer into Hotcell (β, γ)
- Cutting into segments
- Extraction of samples
- Conditioning for Disposal

Target Disposal – Hotlab Option



Gas Production and Handling

Production (Liter NTP) in a LBE target after 1 year and 6000 mAh

H	6.0
He	0.24 .. 2.6
Ar	0.0026
Kr	0.06
Xe	0.024
Total	6.3 ... 8.7

Enderle: Neutronic Benchmark

Absorption of volatile products

Pd + Hg → PdHg < 150 °C

$CuO + H_2 \rightarrow Cu + H_2O$

$CaO + H_2O \rightarrow Ca(OH)_2$

140 - 200°C

Gas Handling

Option 1: Continuously vent

- Not applicable due to emission limits

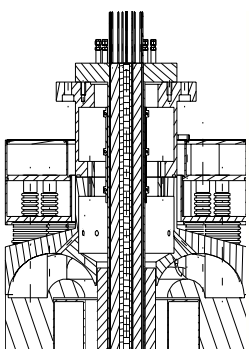
Option 2: Collect and vent after decay

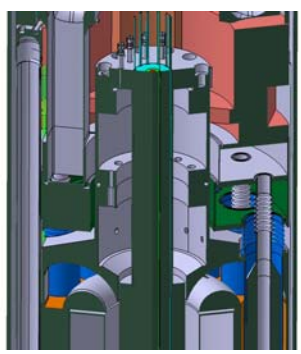
- Only solution at high gas production

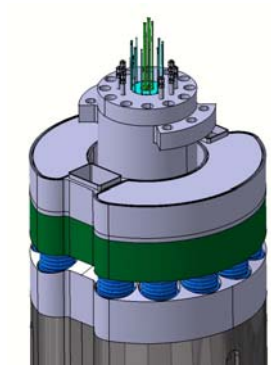
Option 3: Enclose and vent in hotcell

- Only for small gas production

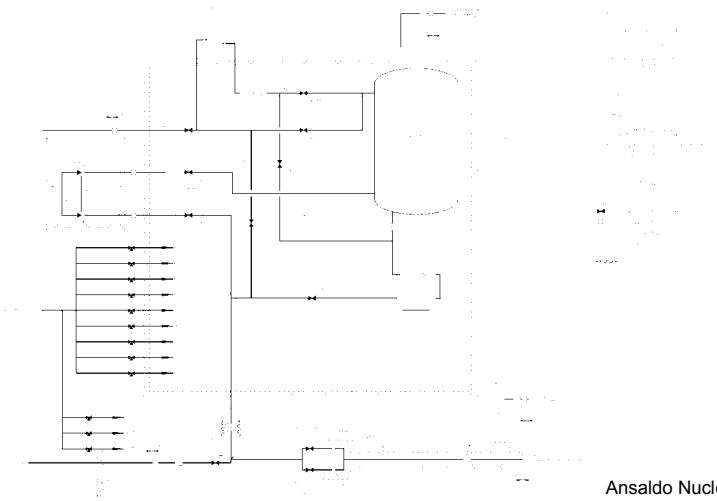
Target Cover Gas Enclosure





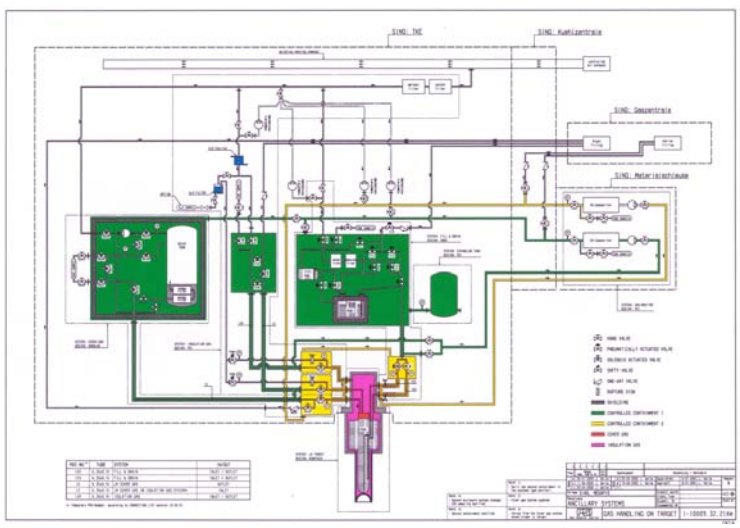


Cover Gas System

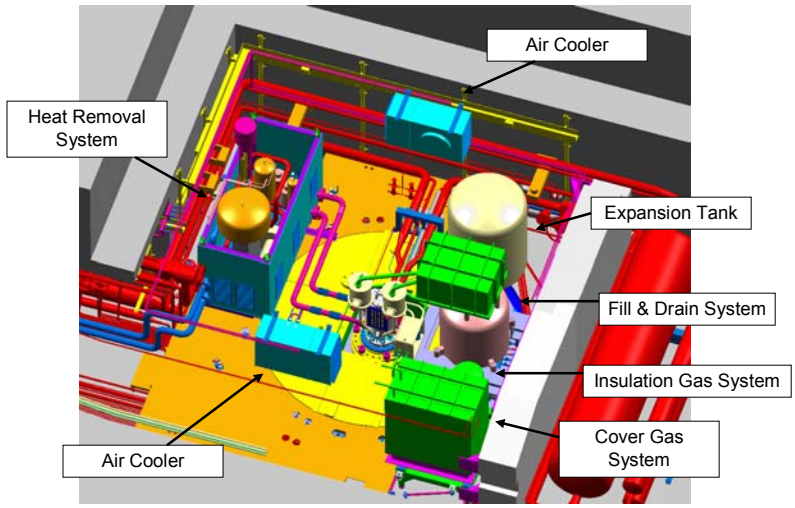


Ansaldo Nucleare

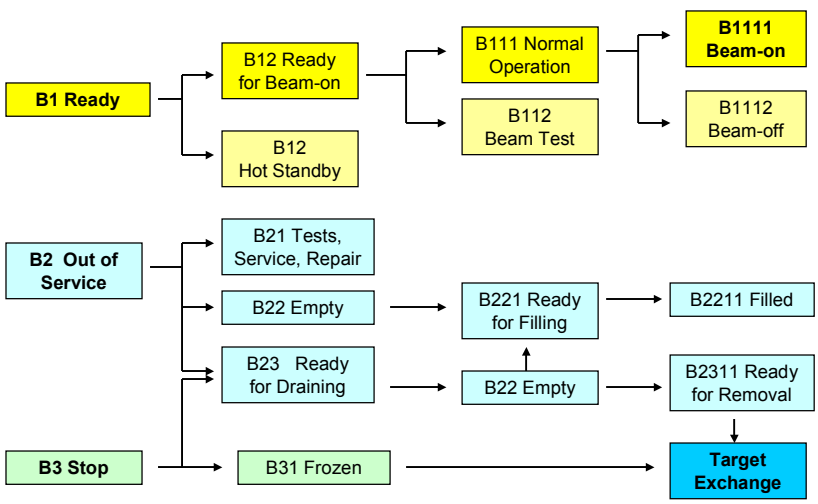
Gas Handling



Ancillary Systems in TKE



Target Operating Conditions



Safety Analysis

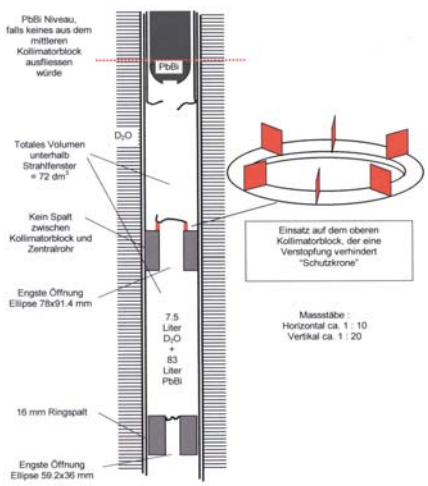
Design Base Accidents

- Break of Liquid Metal Container
- Focused Proton Beam

Beyond Design Accidents

- Simultaneous Perforation of all 3 Beam Windows of the Target
- Perforation and Blockage of the Collimator by Frozen LBE
- Simultaneous Leakage of LBE and D_2O into Insulating Gap
- Heavy Earthquake

Accident Scenario



Safety Analysis

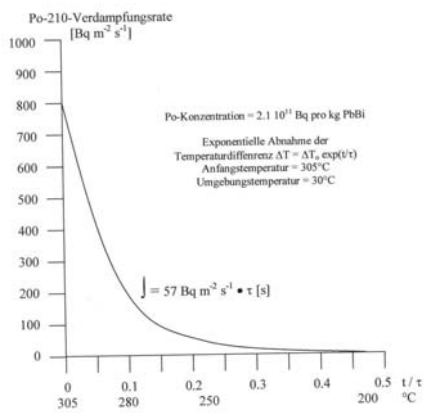
Operating Incidents → Stop

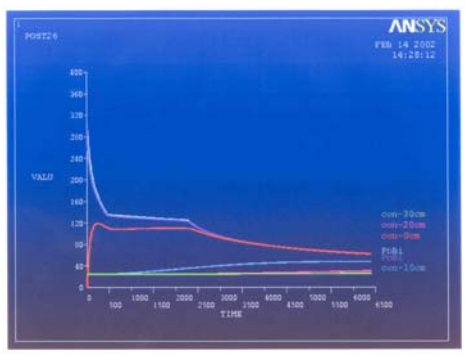
- **Leakage of LBE from LMC (upper and lower)**
- **Leakage of D_2O (insulating gap, beamline)**
- **Leakage of Oil (insulating gap, LBE)**
- **Leakage of Gas (insulating gap, 2nd containment)**
- **Failure of EMP System (main or bypass pump)**
- **Failure of Internal Heater**
- **Break of Guide or Bypass Tube**

Incidents at Ancillary Systems → Repair?

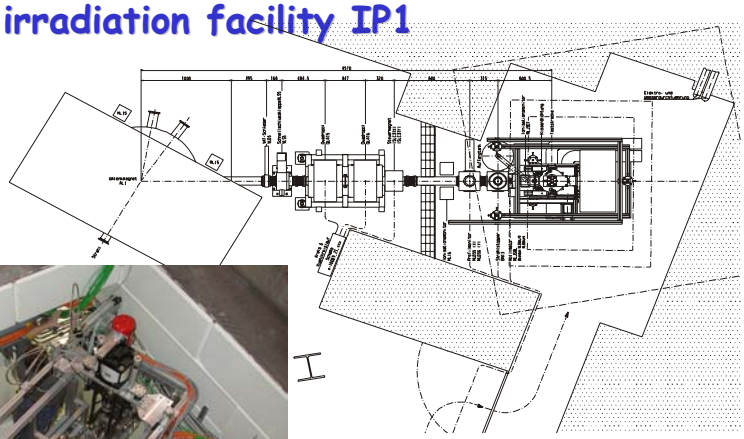
- **Heat Removal System**
- **Cover gas System**
- **Fill and Drain System**
- **Second Containment**

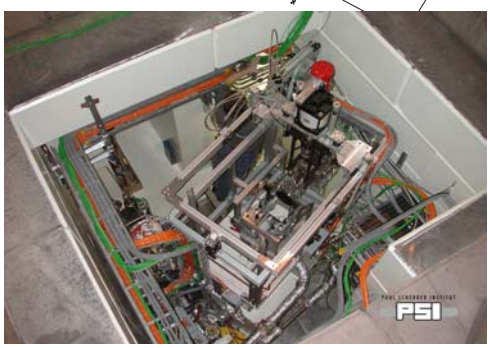
Po evaporation rate





LiSoR in irradiation facility IP1





Beam energy-72MeV
Max current-50 μA
Max proton flux- 3.1×10^{14} p/cm^2/s
Beam time per test-10, 20, 40 days
Radiation damage- ~ 0.5, ~1, ~2 dpa