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MEGAPIE IRRADIATION EXPERIENCE OF THE FIRST MEGAWATT LIQUID METAL SPALLATION TARGET

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and on behalf of the MEGAPIE Initiative

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- Design of the target system
- Integral test in MITS
- Integration in SINQ
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- Beam history
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- EMP performance
- Gas production
- Conclusions

Presentation on concept and design at HPPA4

Objectives

MEGAPIE is an experiment to be carried out in the SINQ target location at the Paul Scherrer Institute and aims at demonstrating the safe operation of a liquid metal spallation target at a beam power in the region of 1 MW. It will be equipped to provide the largest possible amount of scientific and technical information without jeopardizing its safe operation.

The minimum design service life will be 1 year (6000 mAh).

Target material will be the PbBi eutectic mixture.

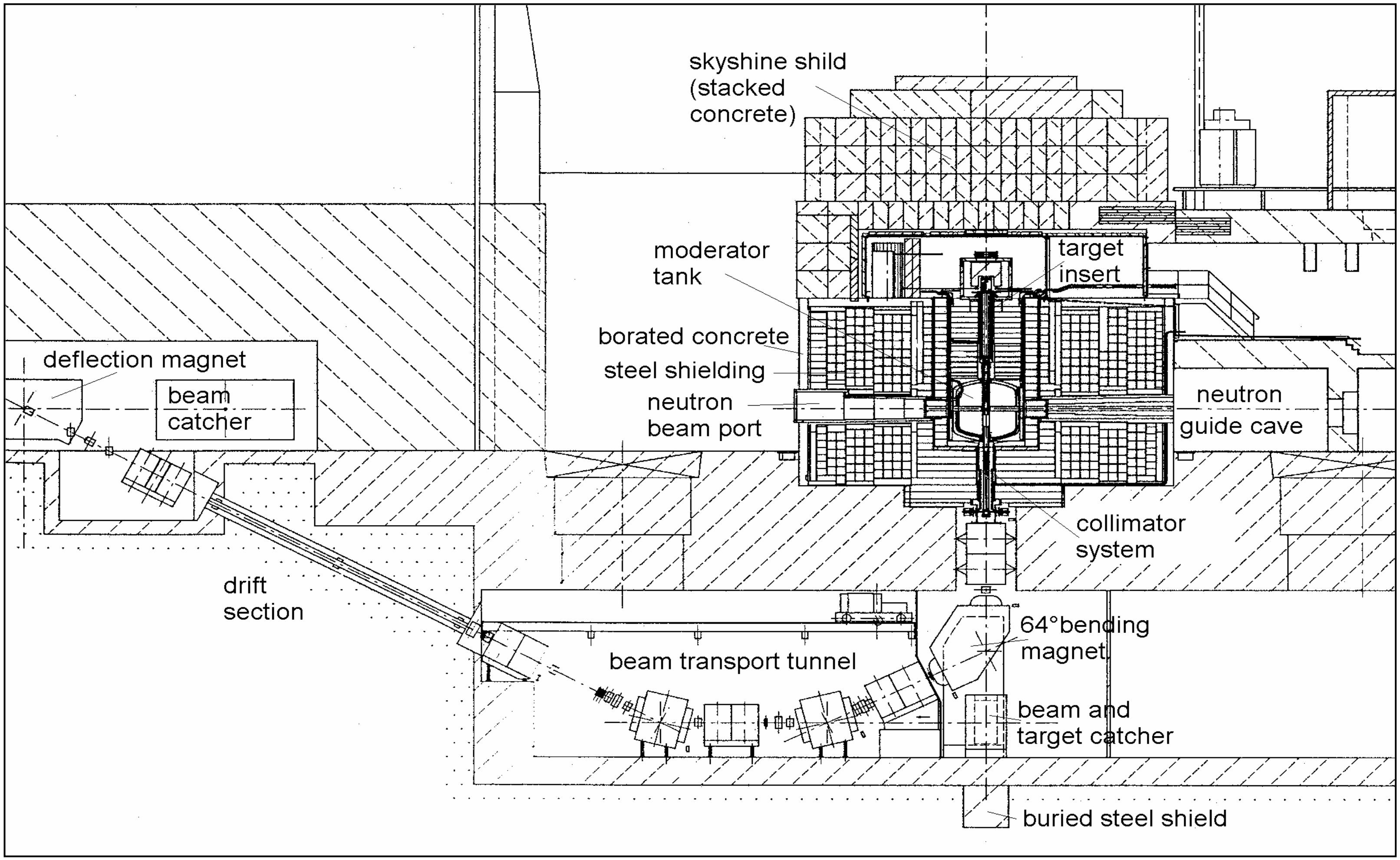
The design beam power is 1 MW at 600 MeV.

Existing facilities and equipment at PSI will be used to the largest possible extent.

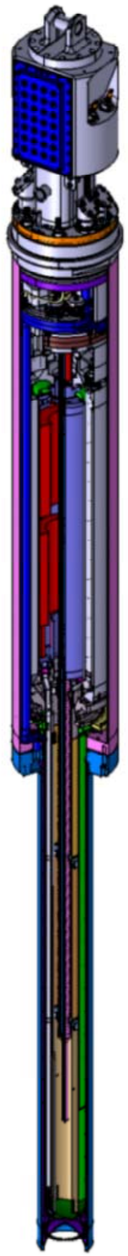
Cooling water loops of the target station will be left largely unchanged and will be ready for use with a solid target again within less than 1 month after termination of the MEGAPIE irradiation.

Contract of MEGAPIE Initiative, 2000

SINQ Spallation Neutron Source



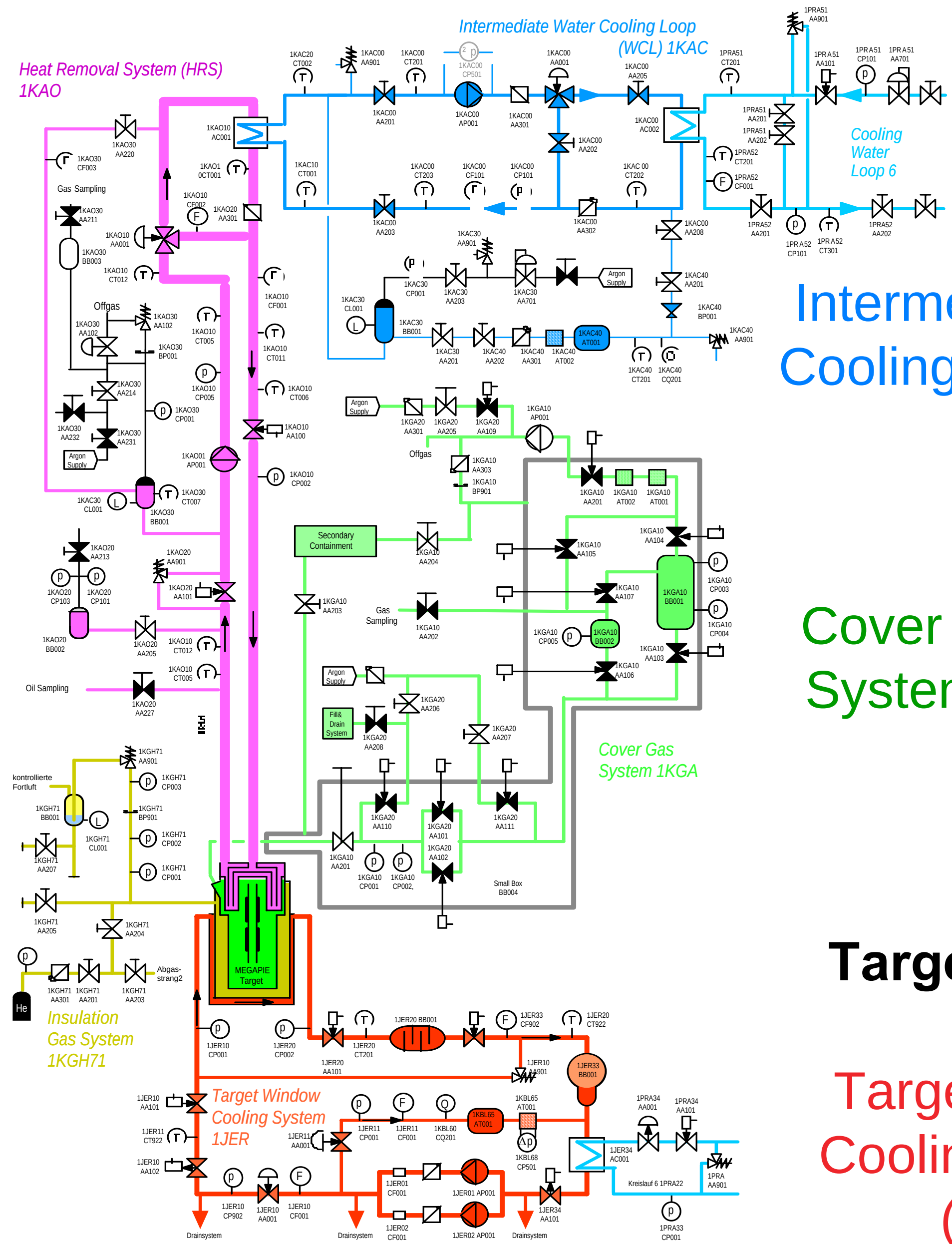
MEGAPIE Target



Design parameters

Beam energy:	575 MeV
Beam current:	1.74 mA
Design life:	1 year of operation (6000 mAh)
Target/coolant:	Lead-bismuth eutectic
LBE volume:	88 l
Wetted surface:	16 m^2
Deposited Heat:	650 kW
LBE T range:	230-380°C
Max. flow velocity:	~1.2 m/s
Beam window:	T91 steel
Window Temperature:	330-380°C
Radiation Damage:	20-25 dpa

MEGAPIE Target System in SINQ



Circulating Coopling Water Loop

Intermediate Water Cooling Loop (WCL)

Heat Removal System (HRS) Diphyl THT

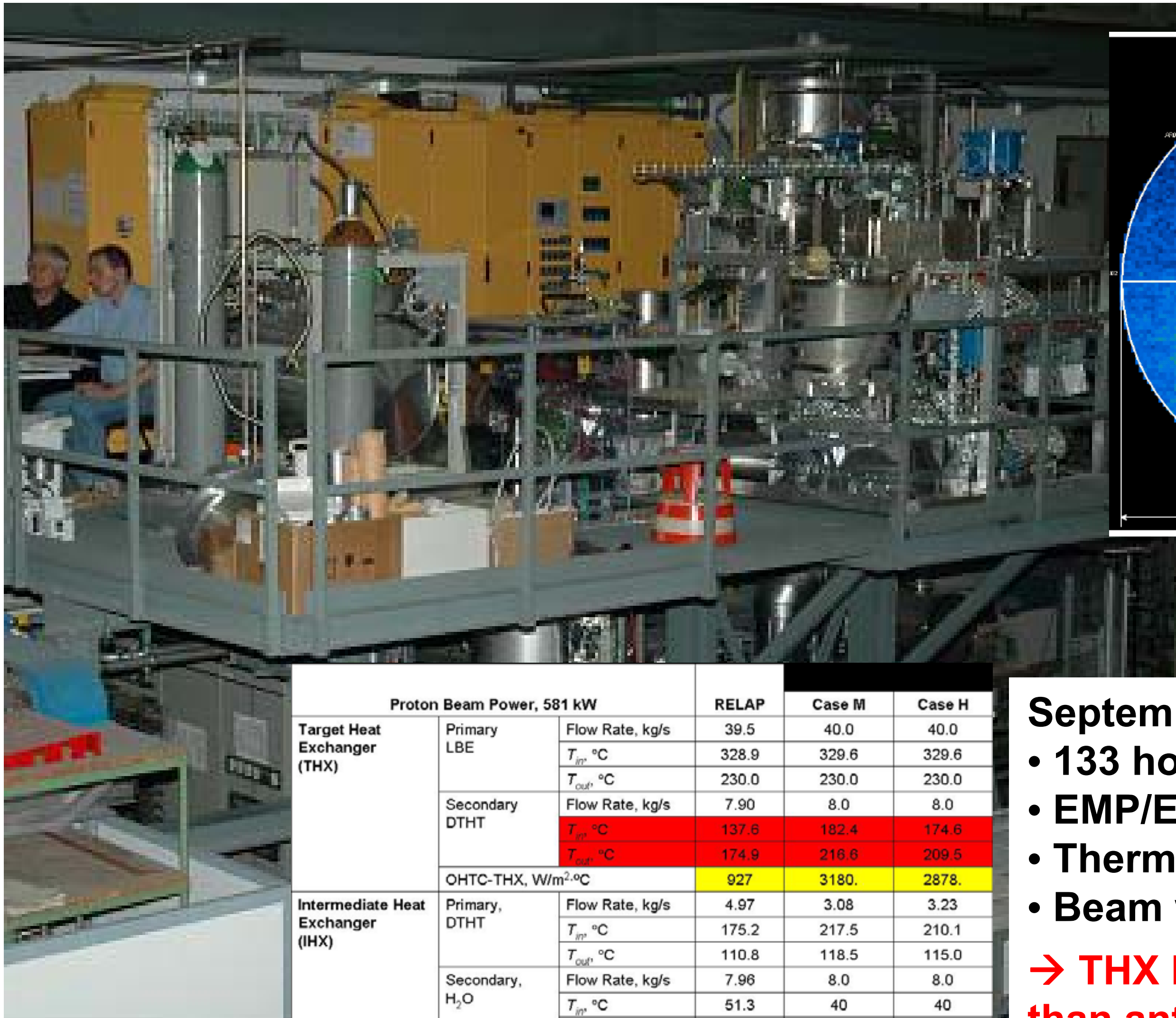
Cover Gas System Ar

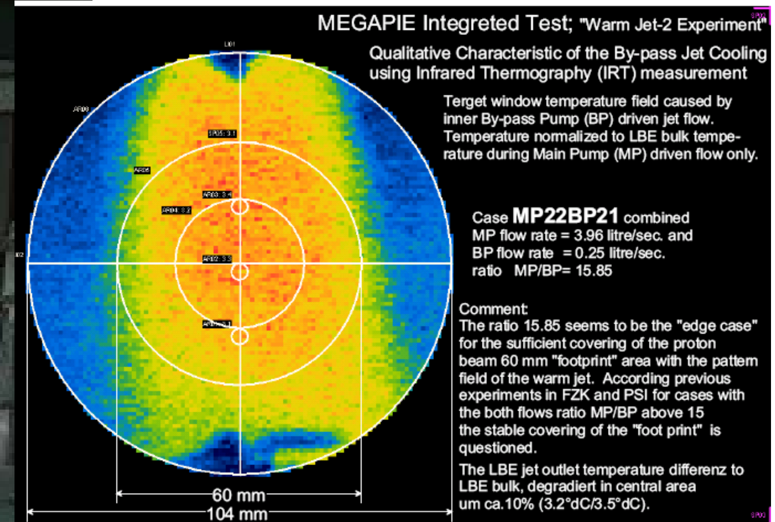
Isolation Gas System (IGS) He, Ar

Target

Target Window Cooling System (D2O)

MEGAPIE Integral Test





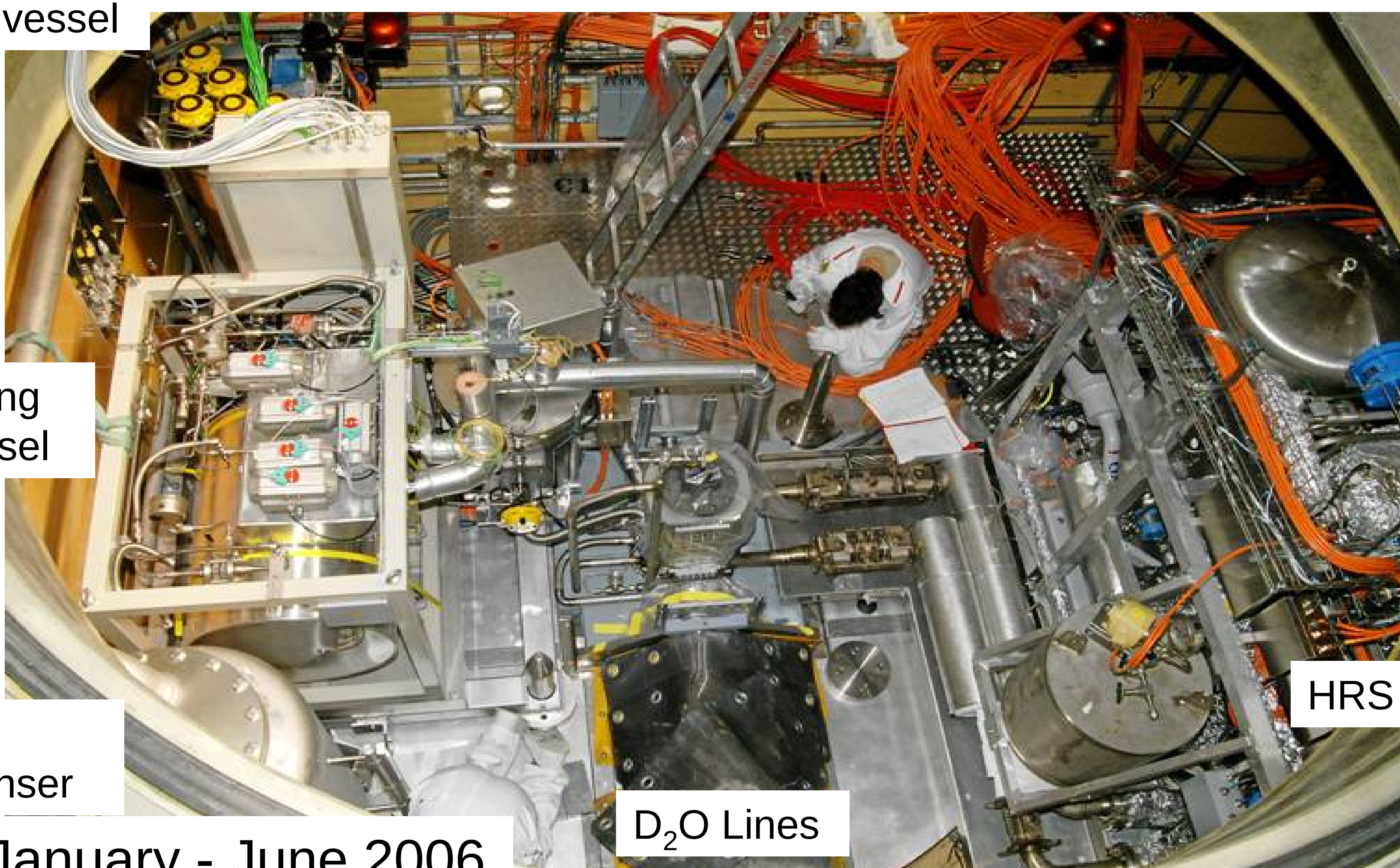
Proton Beam Power, 581 kW			RELAP	Case M	Case H
Target Heat Exchanger (THX)	Primary LBE	Flow Rate, kg/s	39.5	40.0	40.0
		T_{in}, °C	328.9	329.6	329.6
		T_{out}, °C	230.0	230.0	230.0
	Secondary DTHT	Flow Rate, kg/s	7.90	8.0	8.0
		T_{in}, °C	137.6	182.4	174.6
		T_{out}, °C	174.9	216.6	209.5
	OHTC-THX, W/m^2·°C		927	3180.	2878.
Intermediate Heat Exchanger (IHX)	Primary, DTHT	Flow Rate, kg/s	4.97	3.08	3.23
		T_{in}, °C	175.2	217.5	210.1
		T_{out}, °C	110.8	118.5	115.0
	Secondary, H_2O	Flow Rate, kg/s	7.96	8.0	8.0
		T_{in}, °C	51.3	40	40
		T_{out}, °C	69.5	57.8	57.8
	OHTC-IHX, W/m^2·°C		512	755.2	788.1

September – Dezember 2005

- **133 hours of operation with LBE**
- **EMP/EMF performance**
- **Thermal hydraulic test, 200 kW heater**
- **Beam window coolig tests**

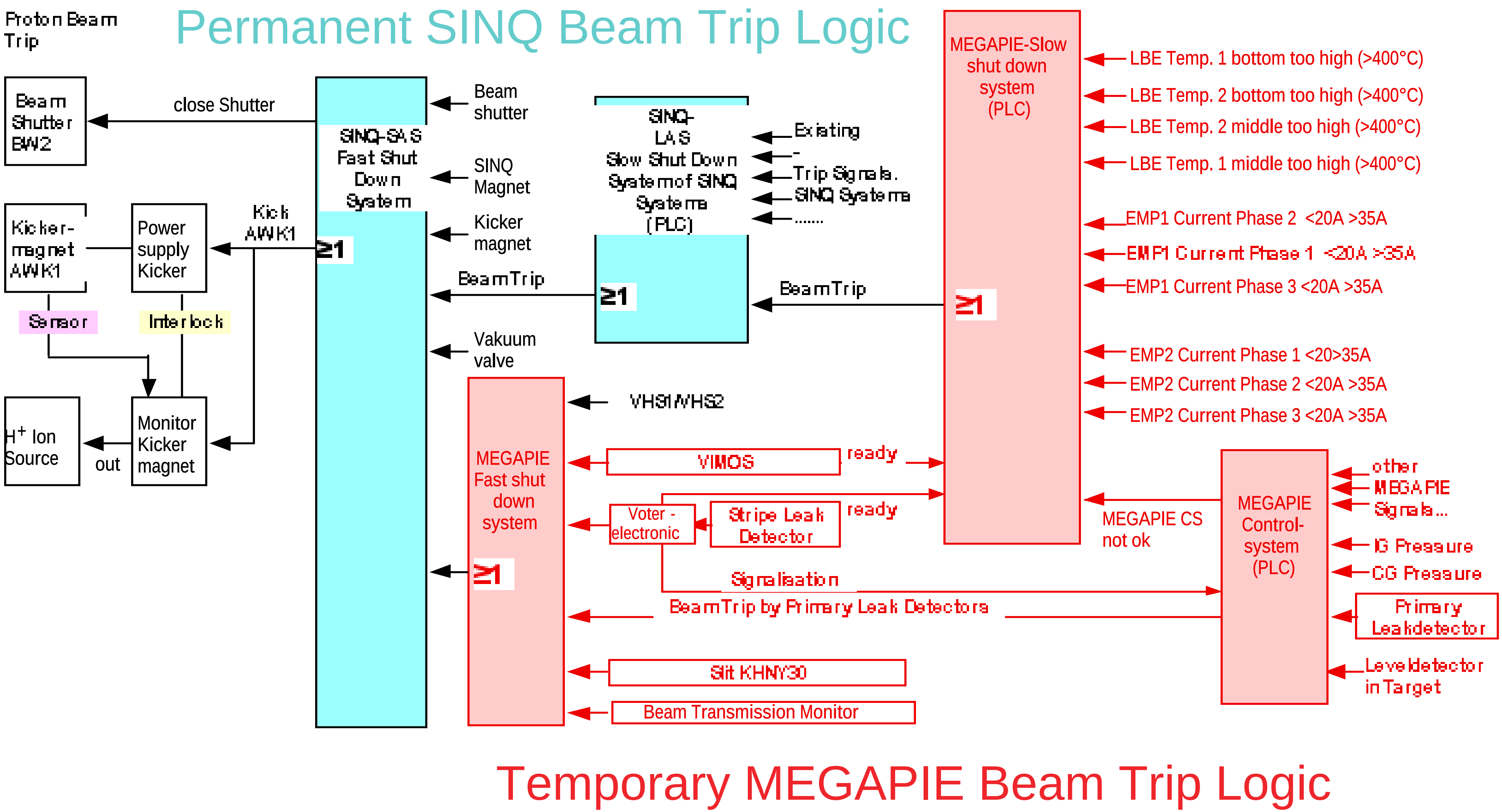
→ THX heat transfer (oil side) better than anticipated

System Integration in SINQ



January - June 2006

SINQ Beam Trip Logic during MEGAPIE



Upgrade of ventilation system

Active carbon filters

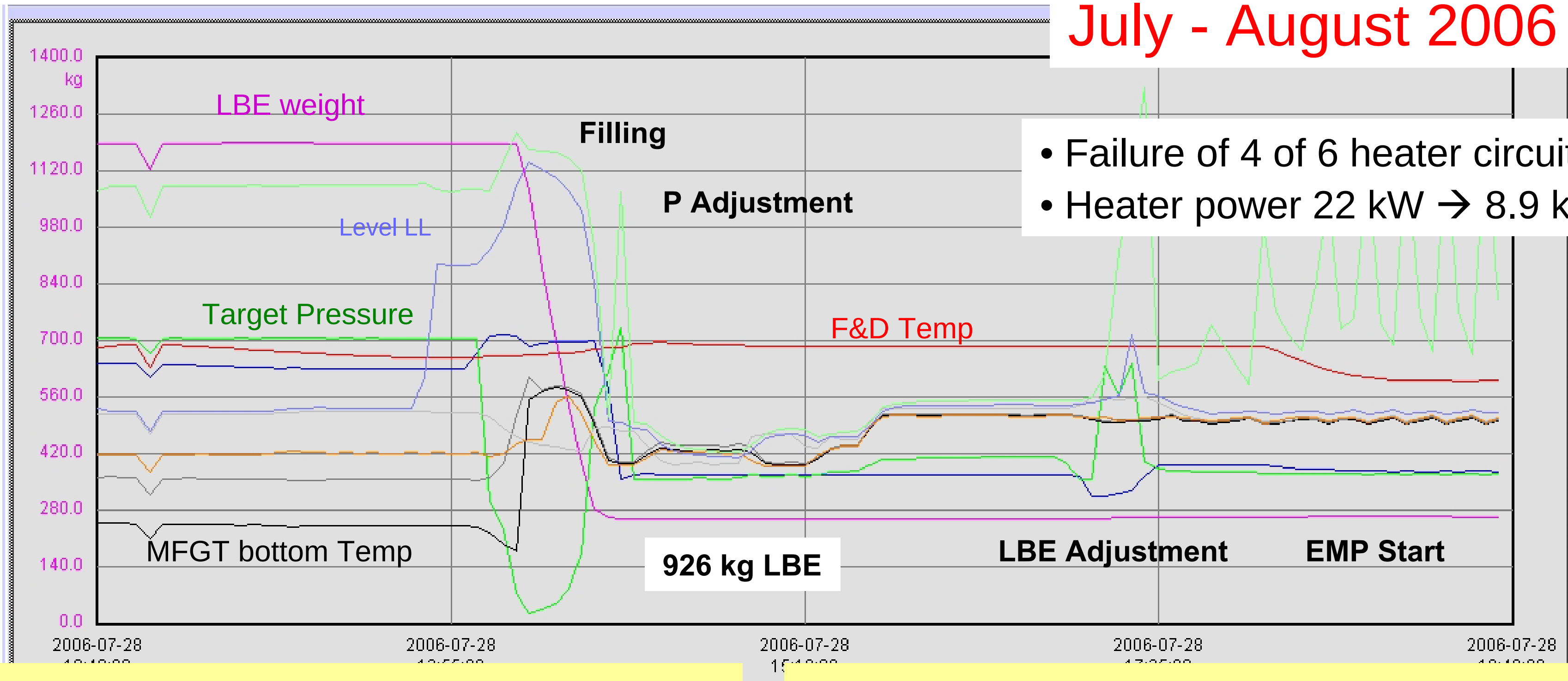
Earthquake strengthened shut-off dampers

Autonomous filter unit

LowOx-System (<13% oxygen) to mitigate fire hazard

Preheating, Filling and Off-beam Operation

July - August 2006



- Failure of 4 of 6 heater circuits
- Heater power 22 kW → 8.9 kW

Operation in Hot Standby over 17 days

- EMP performance assessment
- EMF/AFBM setup
- TH control adjustment
- Safety systems check

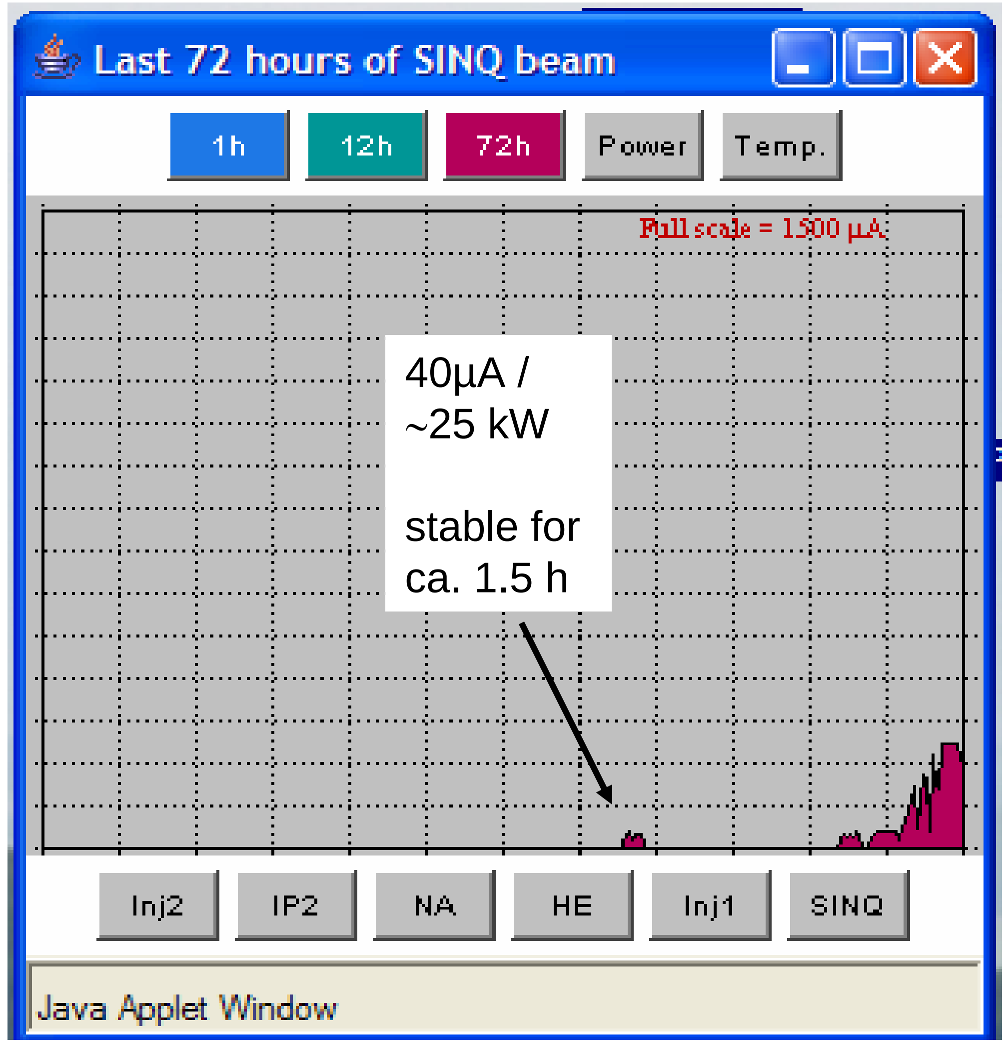
BAG permission for irradiation, August 11

- 4 milestones
- 52 additional requirements fulfilled

First beam on Target on 14 Aug. 2006

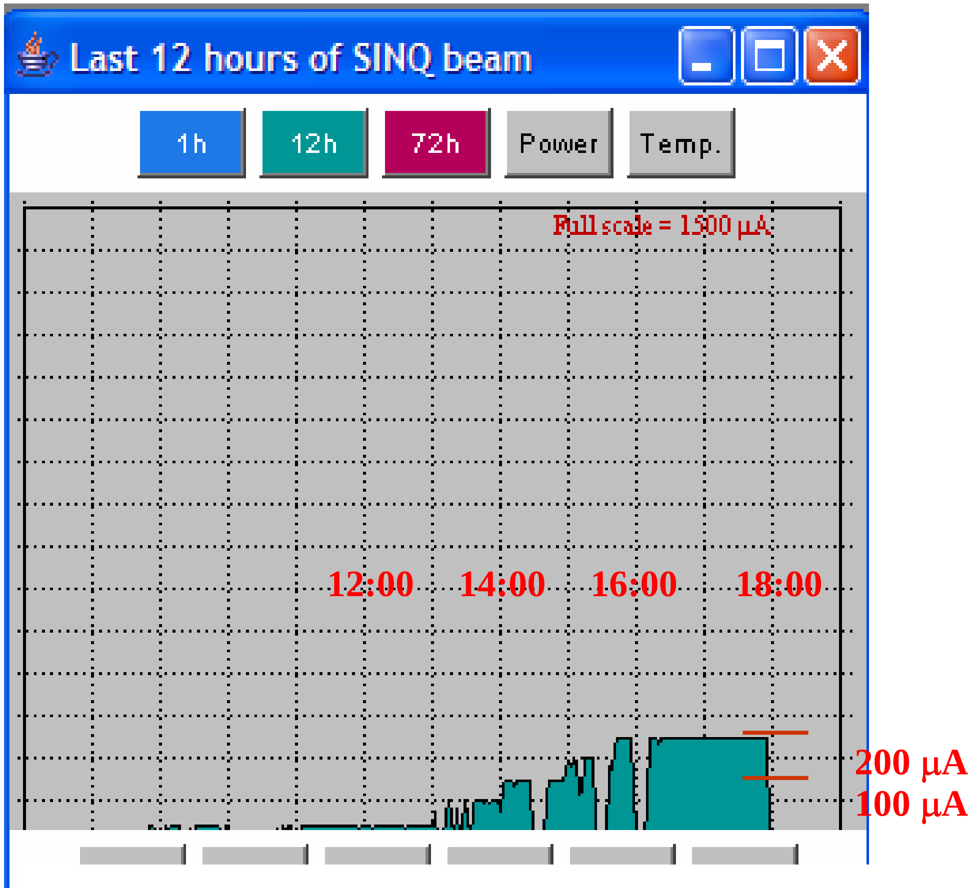
Accelerator Control Room

SINQ Control Room

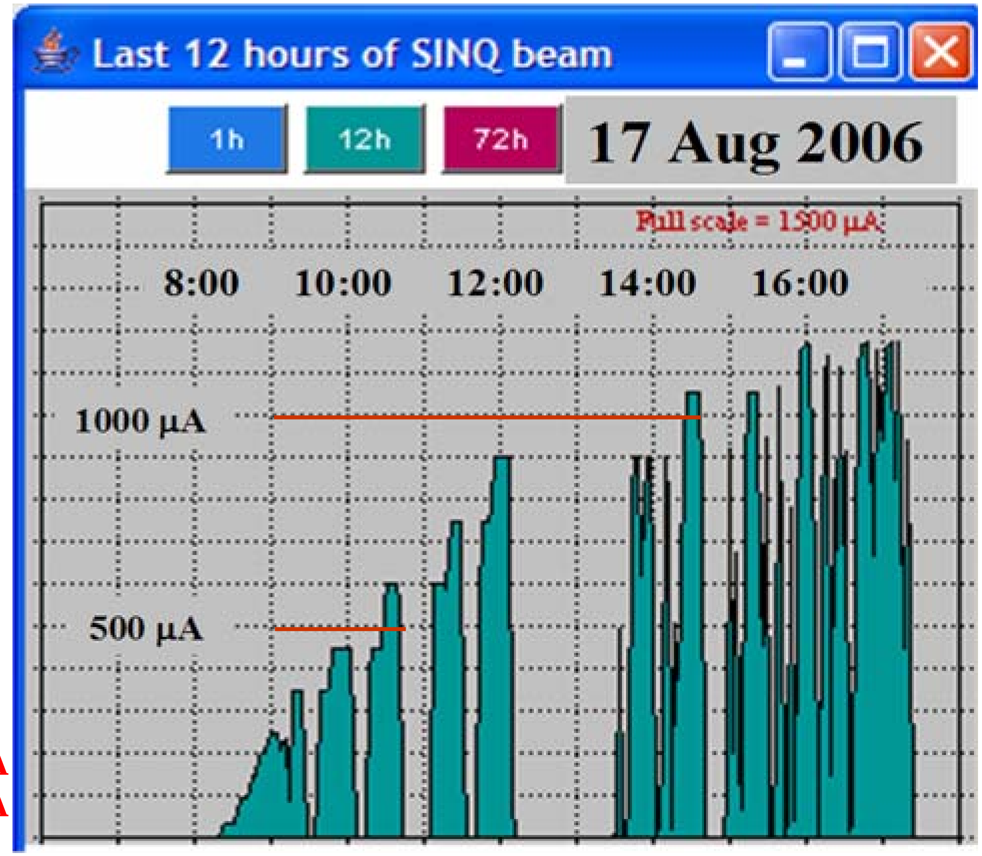


MEGAPIE Operation Start-Up

Phase 2: Tue., Aug 15, 2006

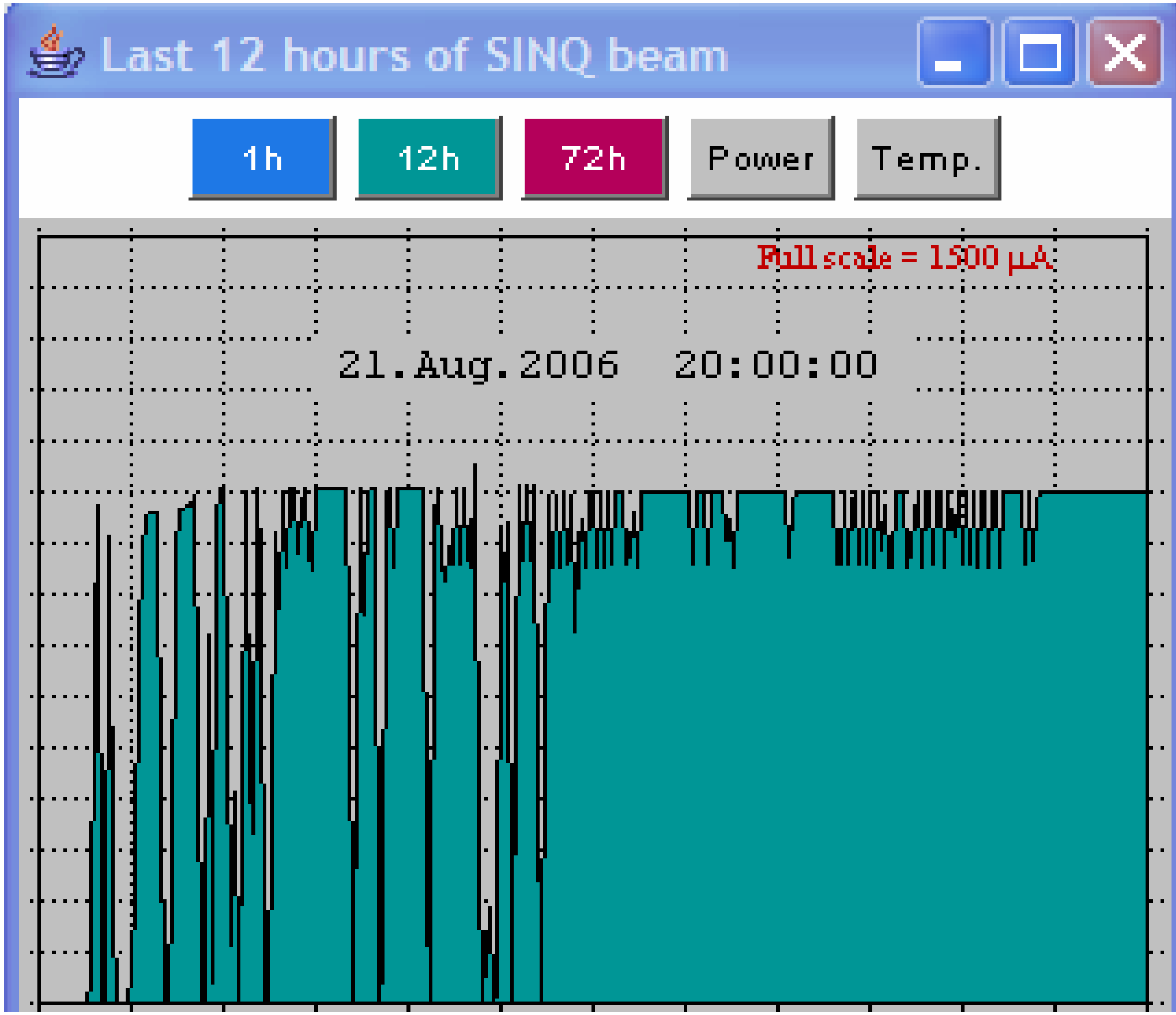


Phase 3: Thu., Aug 17, 2006



Check of proper functioning, safety systems and gas sampling

Regular operation August 21



1000 µA

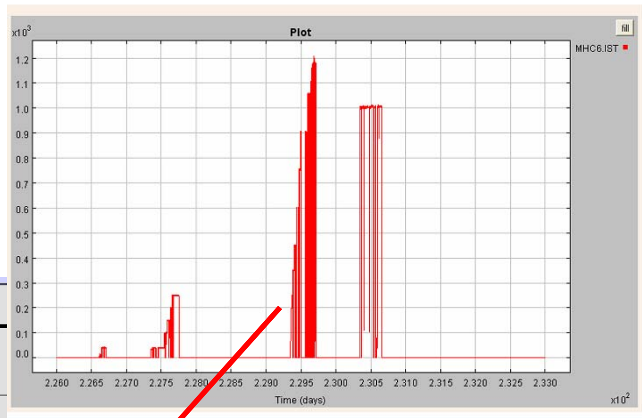
Manned operation

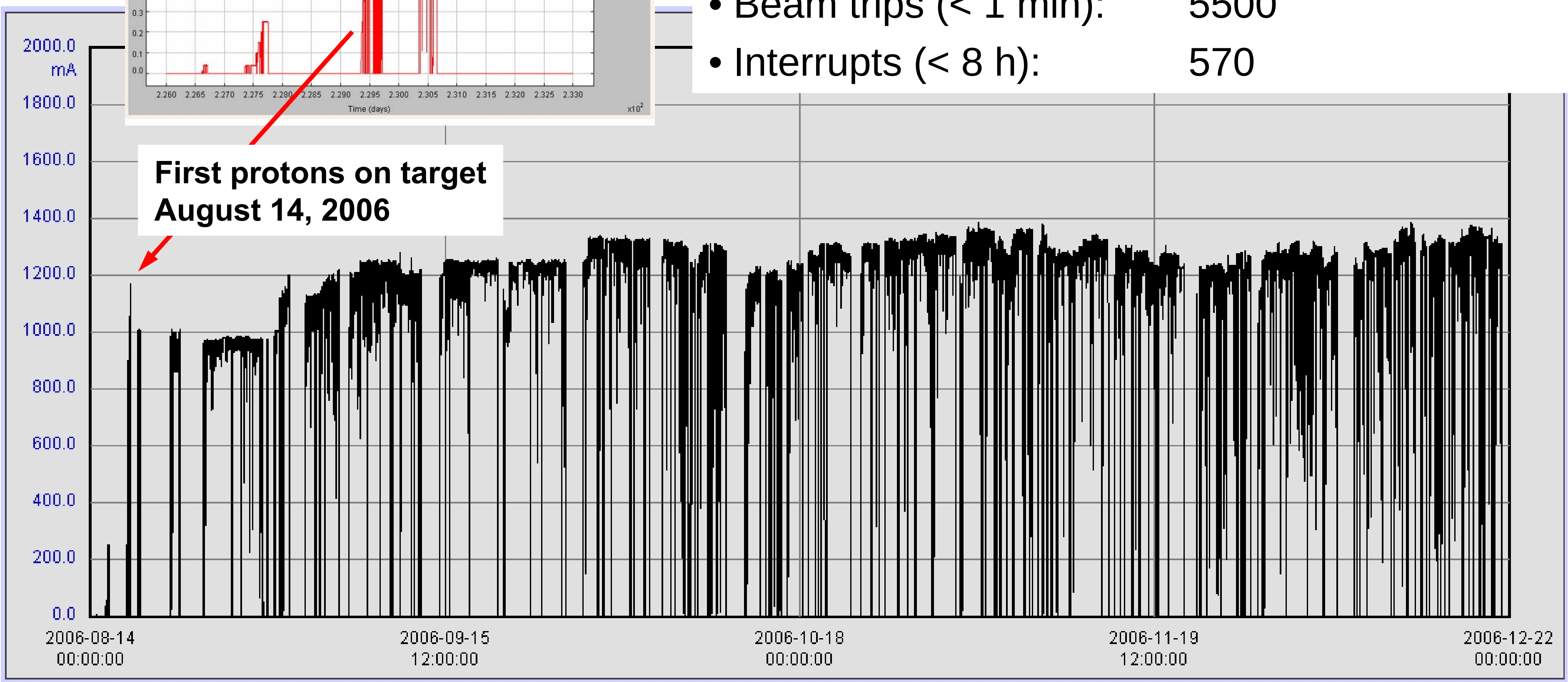
Unmanned operation from August 24 onwards

MEGAPIE Target Operation

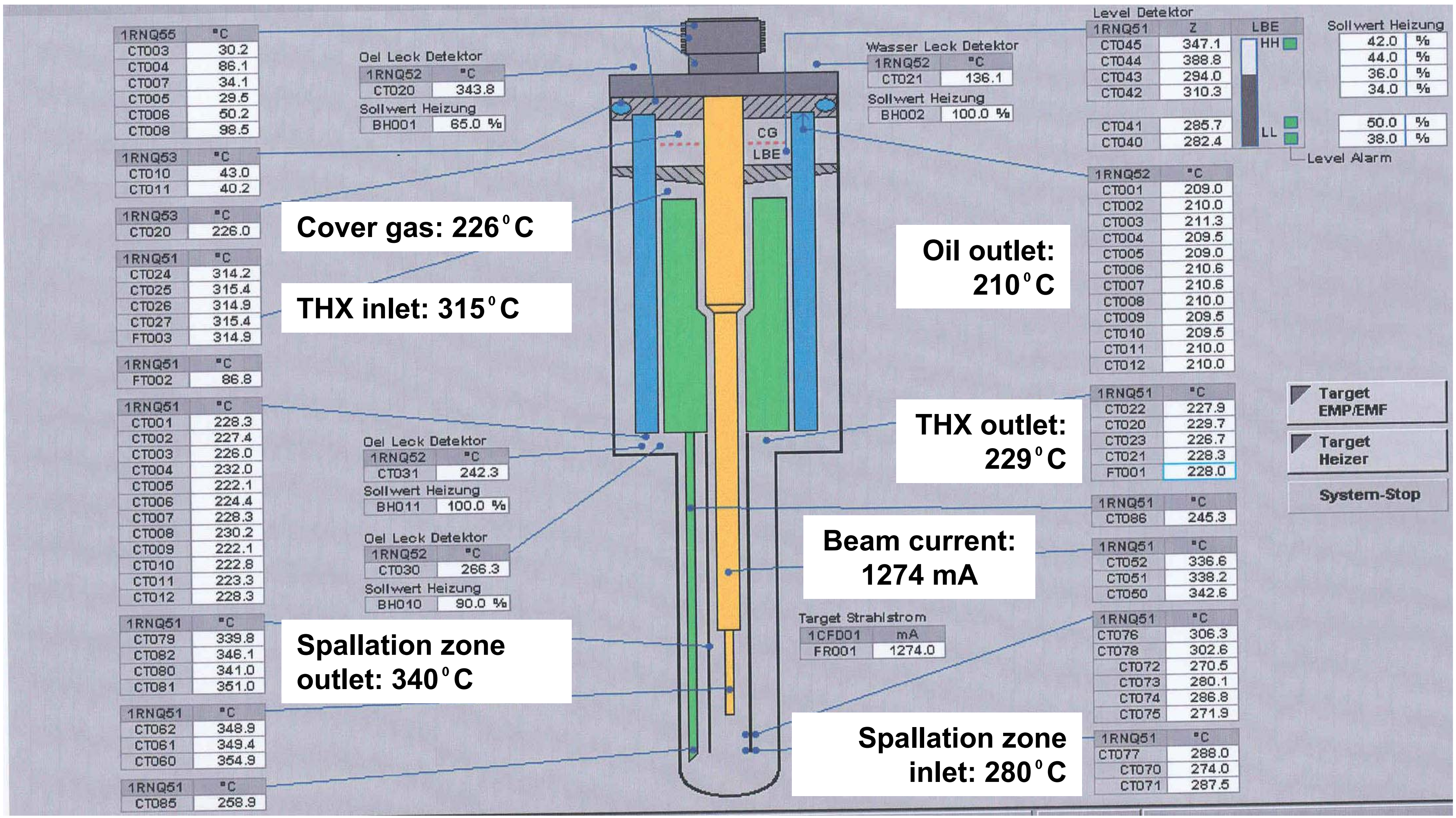
On beam: August 14 – December 21, 2006

- Accumulated charge: 2.8 Ah
- Peak Current: 1400 μA
- Beam trips (< 1 min): 5500
- Interrupts (< 8 h): 570





Target temperatures at full beam

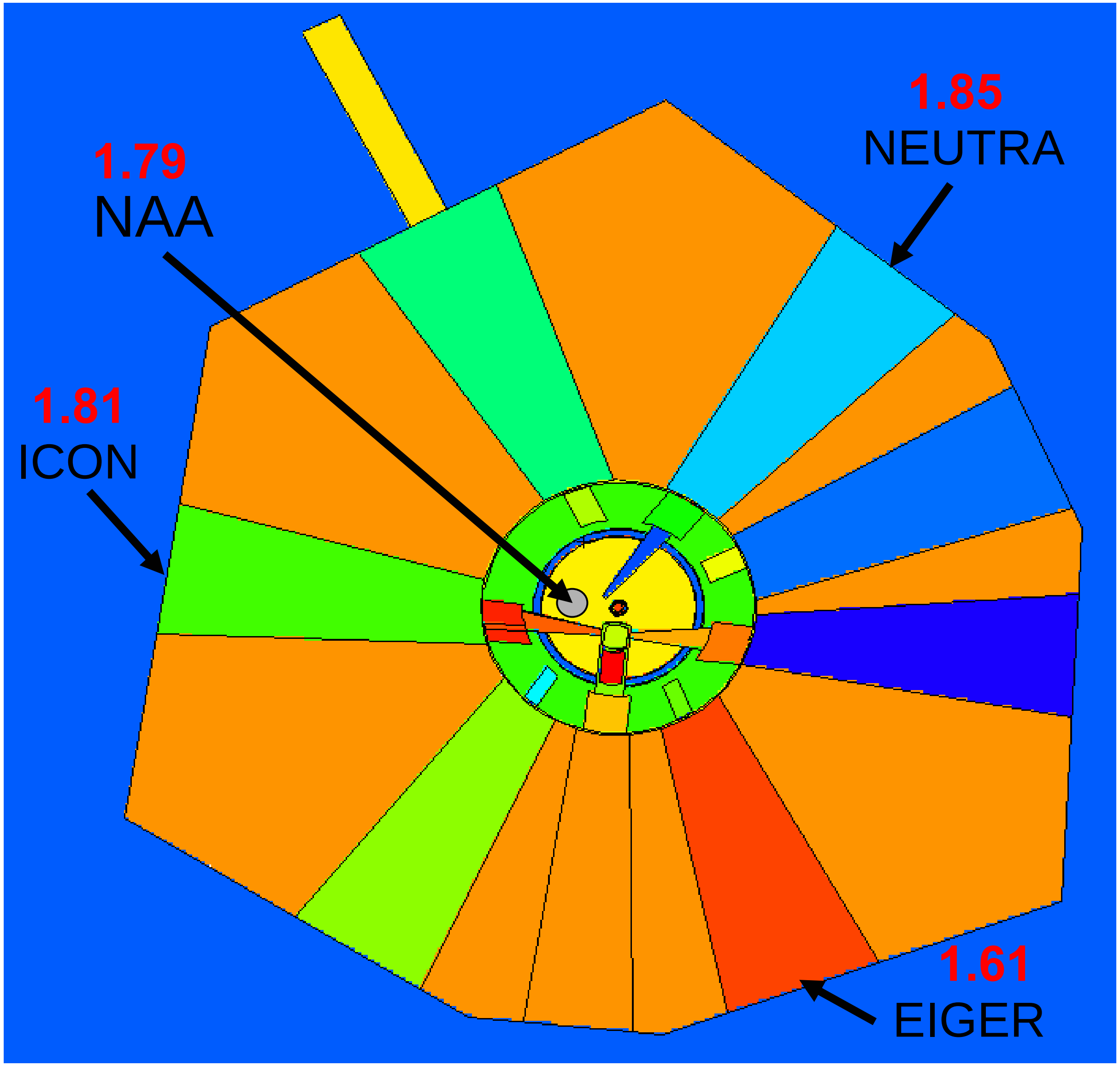


Neutronic Measurements

- Task 1: delayed neutron measurements
- Task 2: micro fission chambers
- Task 3: bonner spheres flux measurement

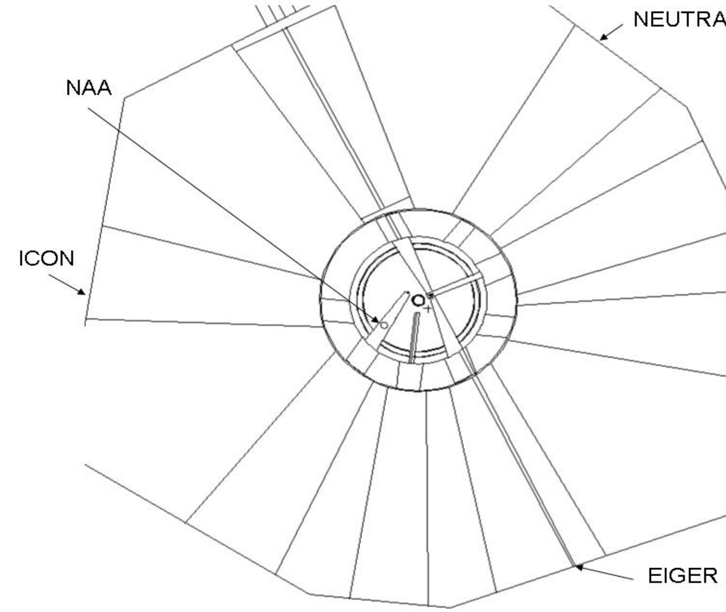
  (+ monitoring with fission chamber)
- Task 4: gas production
- Task 5: gold foil activation
- Task 6: activation foils at PNA/NAA
- Task 7: flux at ICON

Gold Foil Measurements at ICON, NEUTRA and EIGER beam lines and NAA station



Ratio of MEGAPIE/SINQ thermal flux.

Comparison of flux measurements and calculation
(fluxes in n/cm²/s/mA)

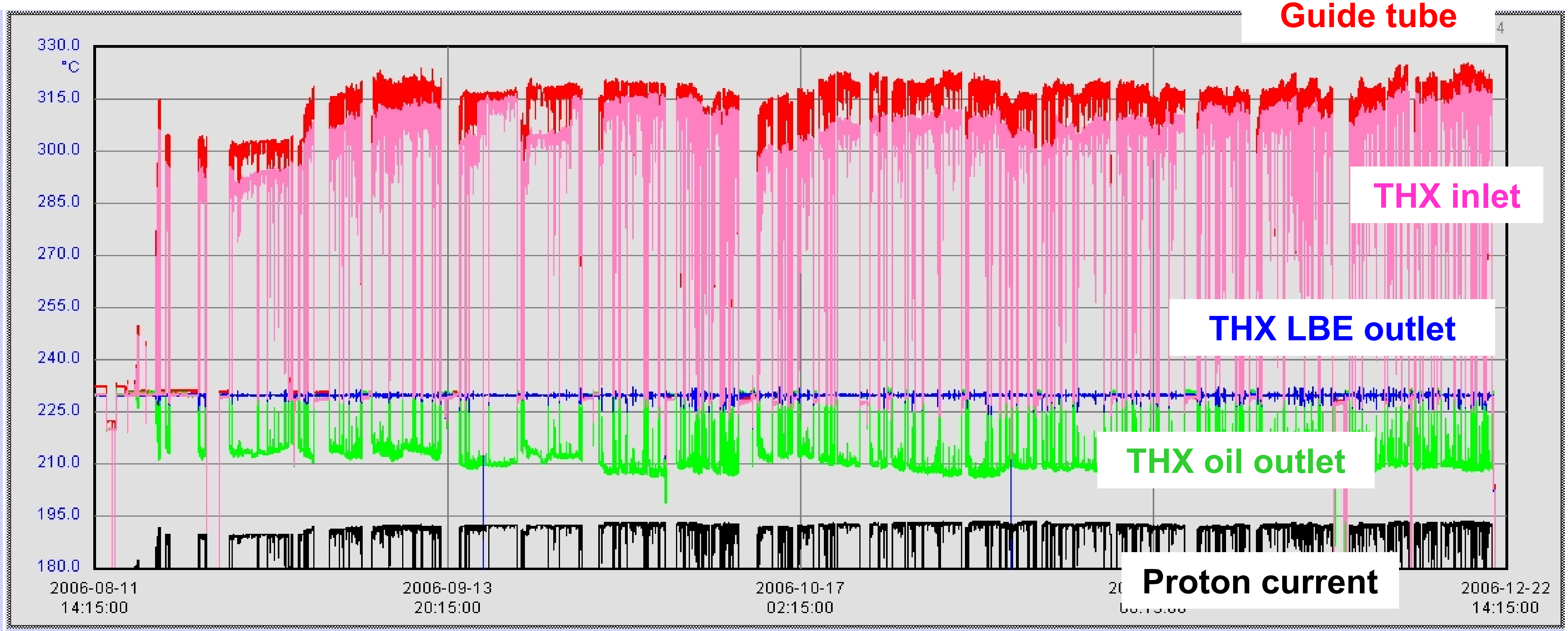


MCNPX 2.5.0
F5 tallies
MEGAPIE nps=1000000
SINQ nps = 300000

	SINQ target 6 (2005)		MEGAPIE (2006)		RATIO	
	EXP	CALC (E<1eV)	EXP	CALC (E<1eV)	EXP	CALC (E<1eV)
NEUTRA (30)	2.59 10^7 (5%)	2.42 10^7 (1%)	4.80 10^7 (5%)	3.85 10^7 (.5%)	1.85	1.59
ICON (50)	3.80 10^8 (5%)	4.57 10^8 (1%)	6.89 10^8 (7%)	7.70 10^8 (.5%)	1.81	1.68
EIGER (82)	6.46 10^8 (5%)	7.49 10^8 (1%)	1.04 10^9 (5%)	1.51 10^9 (.5%)	1.60	2.02
NAA	5.82 10^{12} (5%)	6.31 10^{12} (1%)	1.05 10^{12} (9%)	1.12 10^{13} (.1%)	1.80	1.77

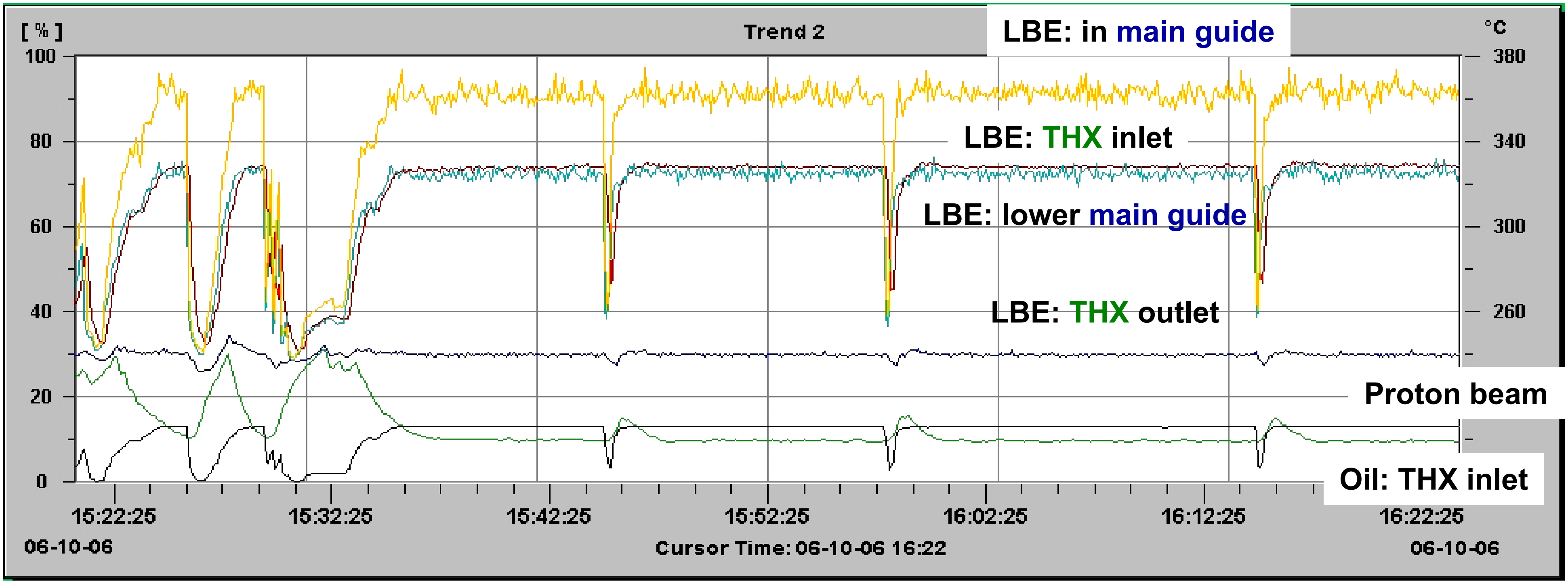
Factor 1.77 increase vs. SINQ target 6
good agreement between measurements and calculations

LBE and Oil Temperatures



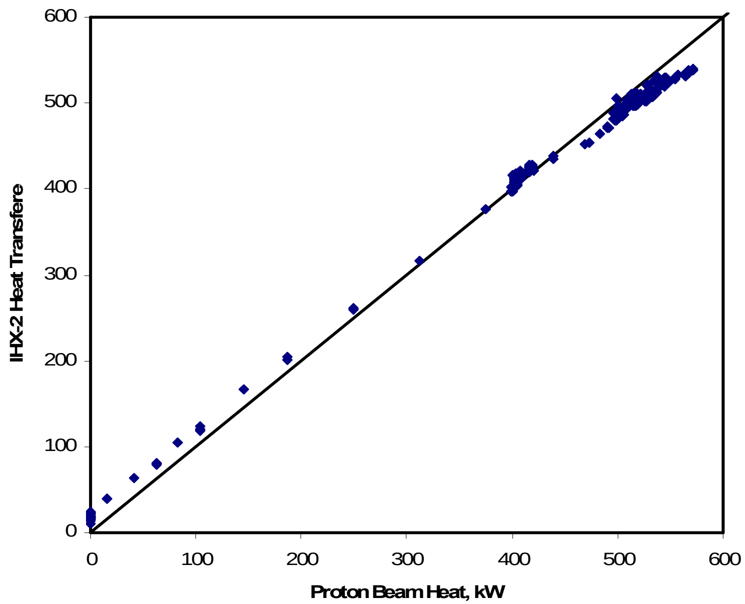
Target temperatures as predicted

Temperature Transients with Beam Drops



The Proton Beam Heating

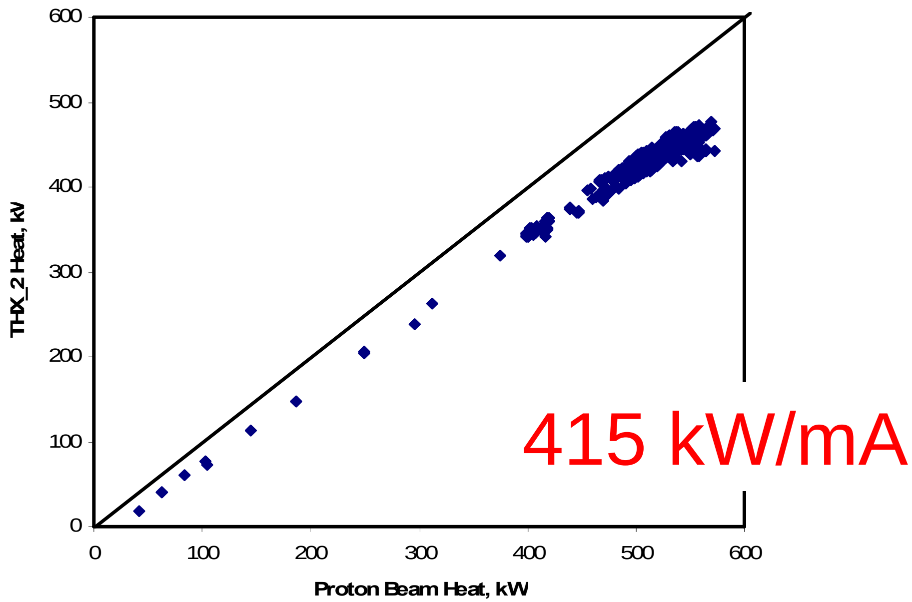
Secondary side of the IHX



The average errors are:

+1.9%, -2.% and max: 5.71%

Secondary side of the THX



The average errors are

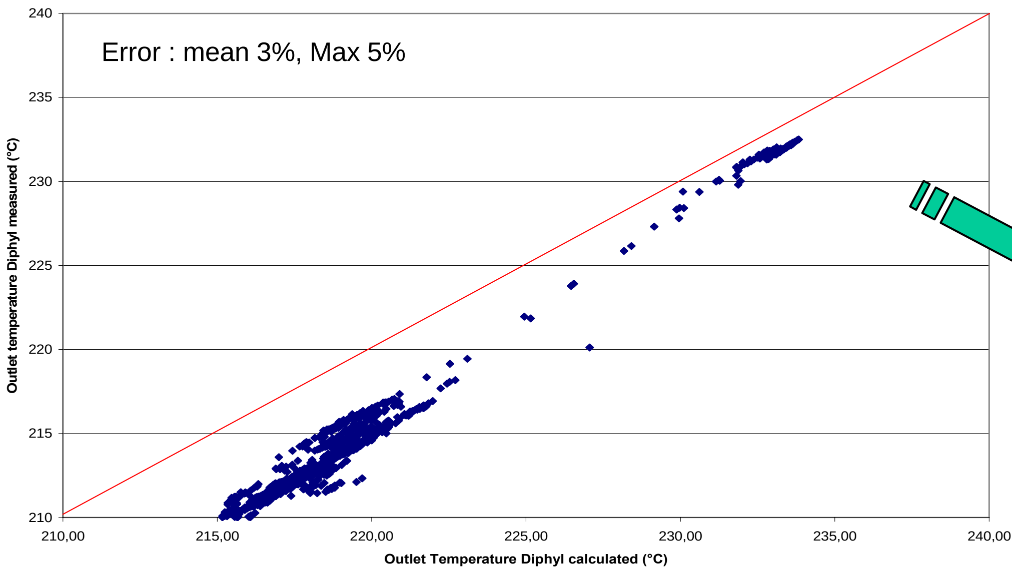
-13.6 % and max: -22.4 %

~6 kW of EMPs and 18 kW ICL Pump so as the heat losses were not included in evaluating the reference power.

The Monte Carle codes predicted the heat deposition quite well in this range, but it seemed that the error would be larger at high current.

MEGAPIE - THX behaviour

Outlet Diphyl temperature

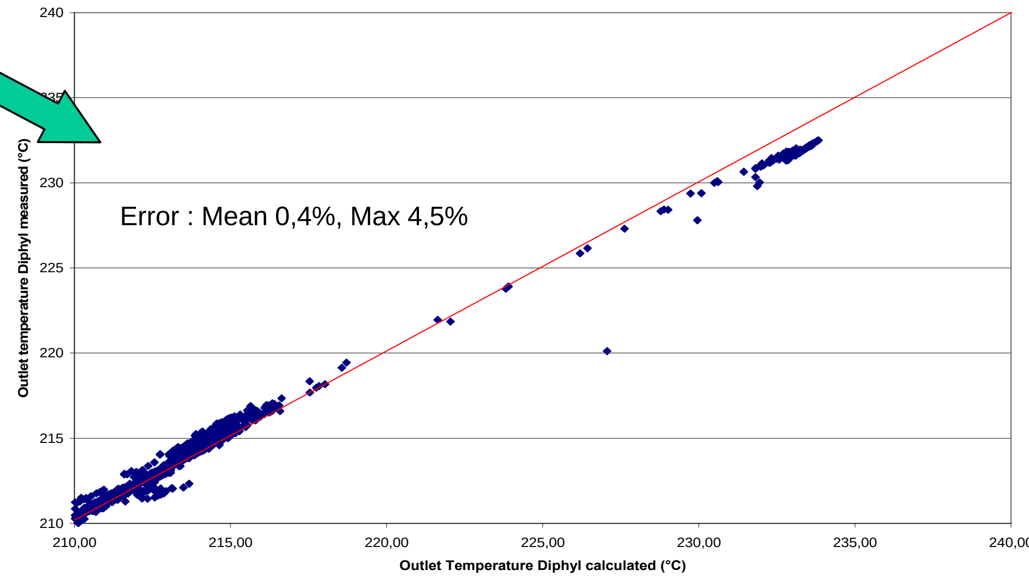


Flow rate Correction of the two fluids:

Diphyl : +25%

LBE: 26 – 41,5 kg/s

$$\dot{m} = Q \Big/ C_p \cdot \Delta T$$



Comparison of ε-NUT model with experimental data

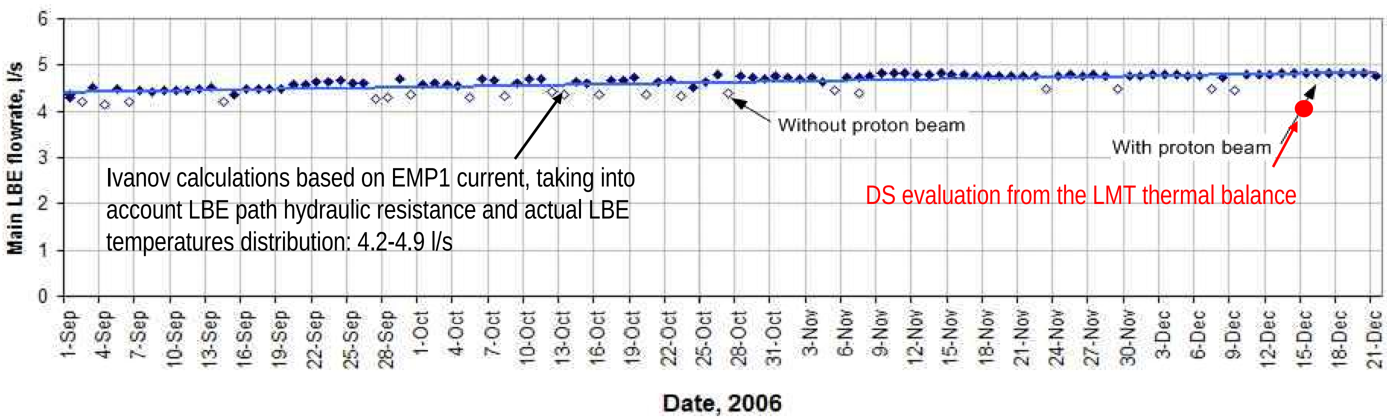
Good agreement if flow rates are adjusted

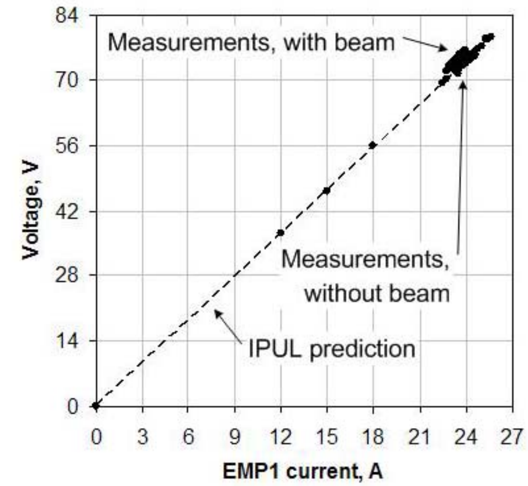
Known uncertainty in flow rates in LBE and Oil loop

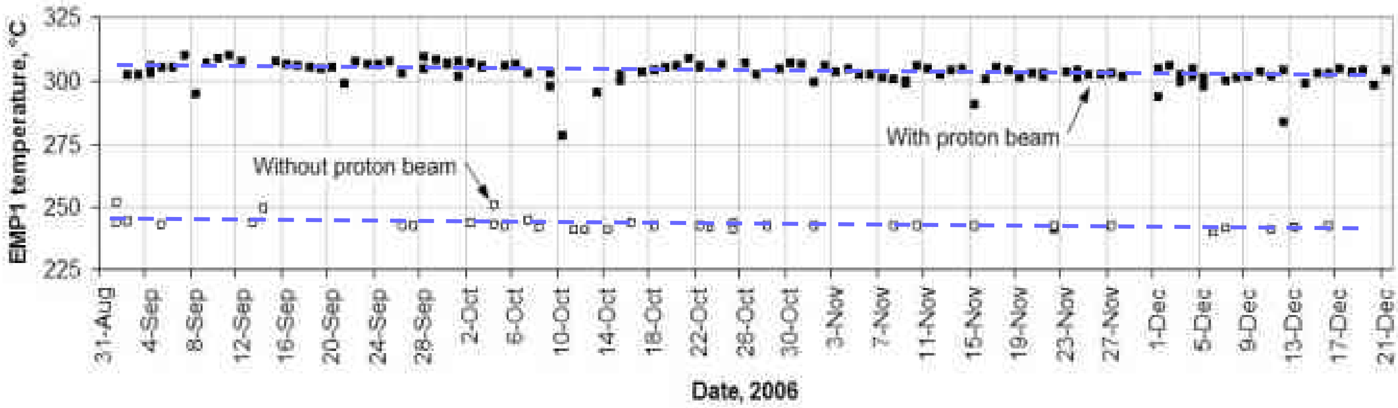
Main flow EMP

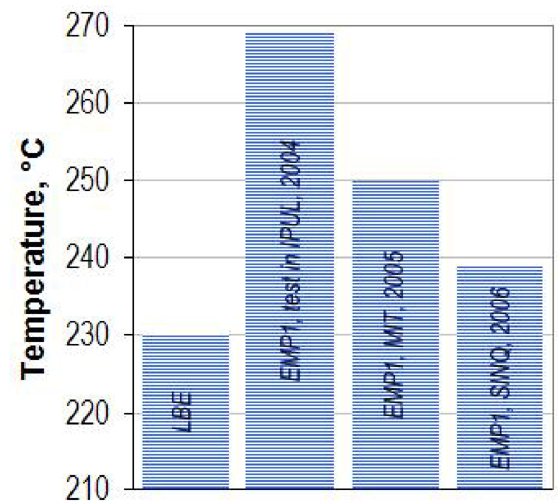
☺Resistance of electrical insulation is >1MΩ

☺No change in the coils el resistances



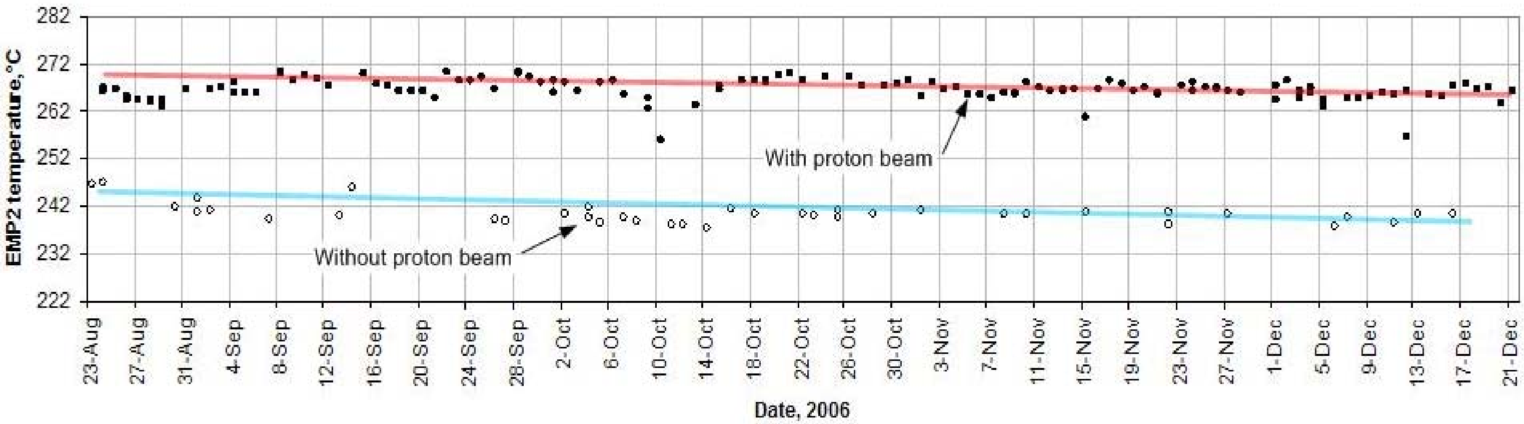


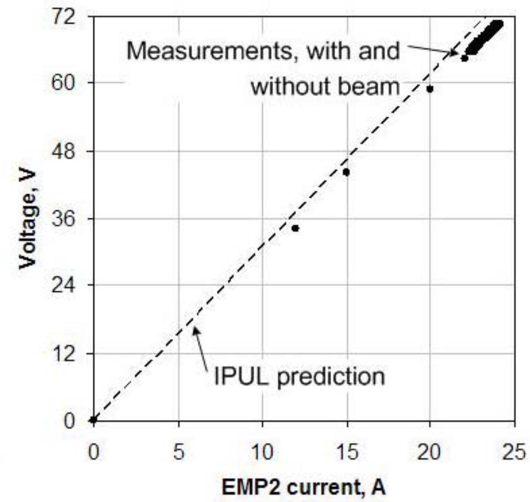




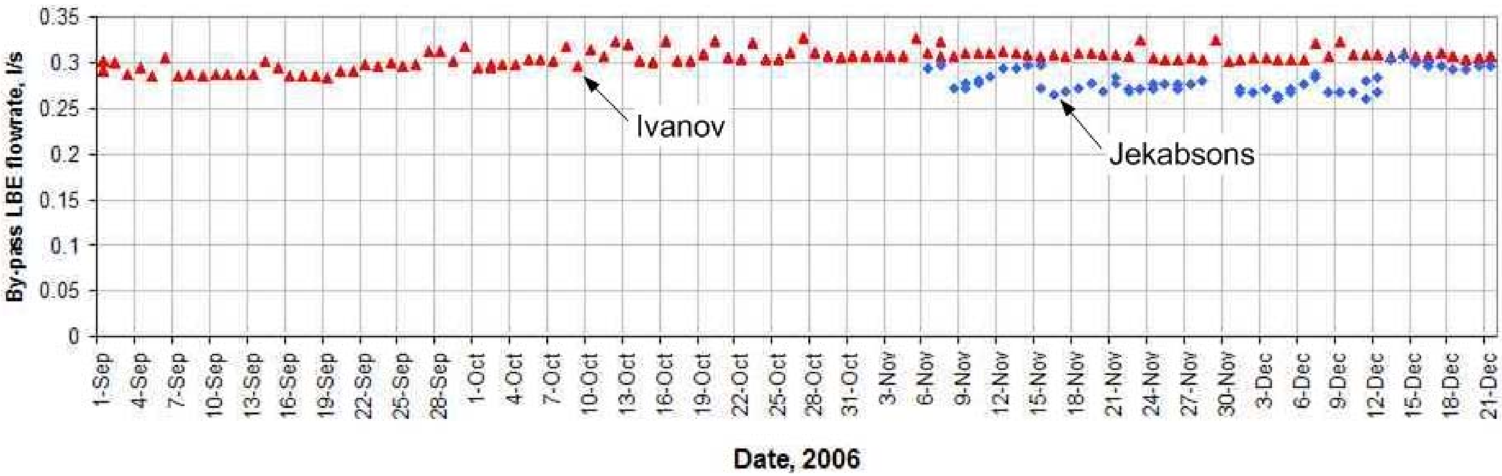
By-pass flow EMP

▼ The pump temperature very slowly goes down (approx. 0.5K/month) evidently because of decomposition of green stuff. There are correlations between IG pressure and EMP2 temperature as well





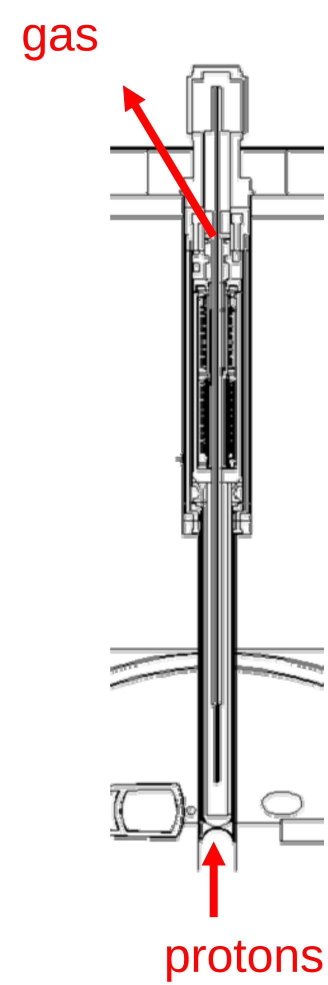
▲ The pump U-I characteristic corresponds to prediction. Resistance of electrical insulation is >1MΩ



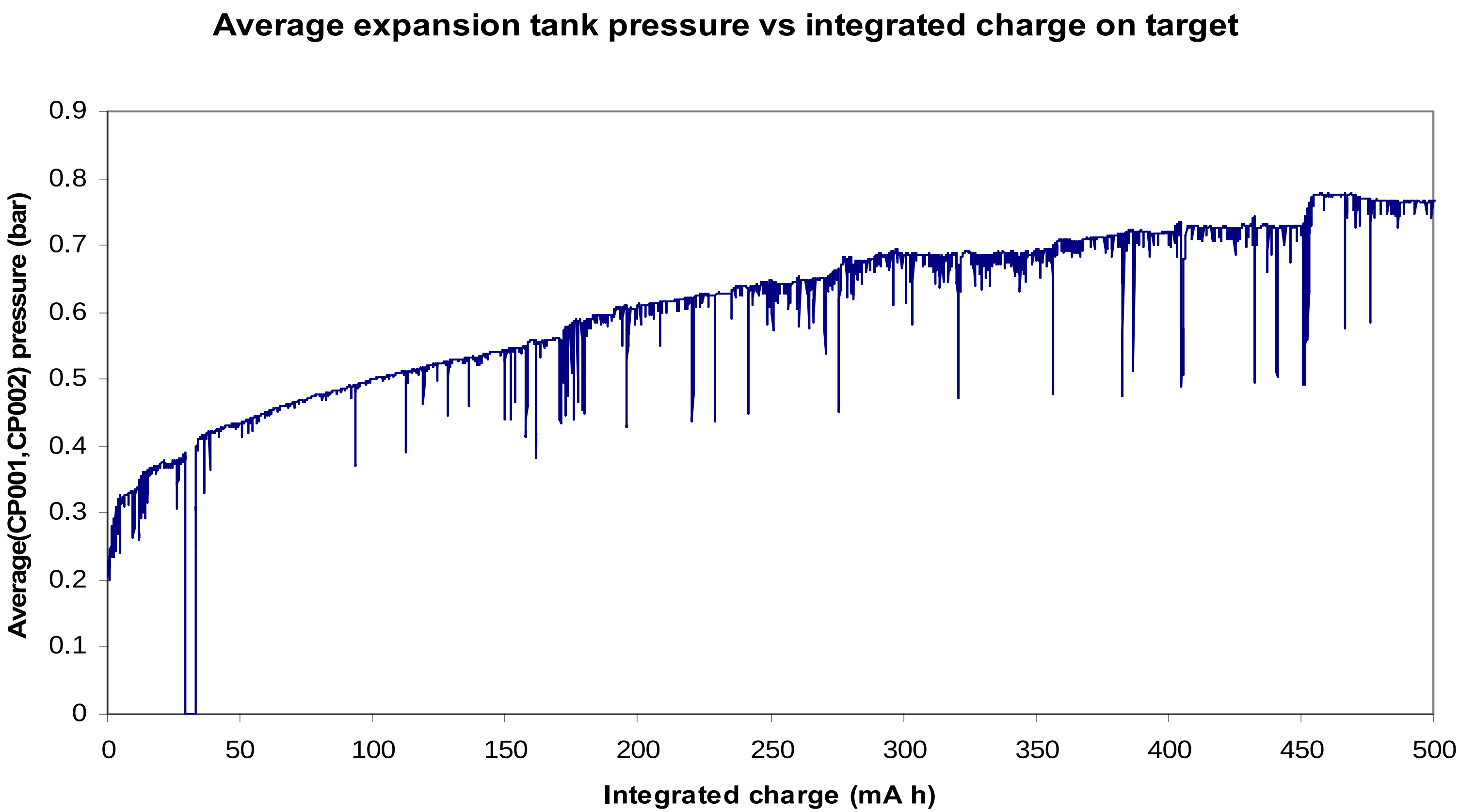
◄ LBE flowrate through by-pass nozzle calculated from EMP2 current, taking into account LBE path hydraulic resistance and LBE temperature distribution: 0.26…0.34 l/s

Gas production measurements

- Measurement of the radionuclide inventory: samples taken at the start up (few mA h on target)
- Measurement of stable light nuclei (mainly ^{4}He): samples taken later.
- Important for safety reasons
- Information on the release process of gases in a real molten metal target.
- Benchmark of Monte Carlo models

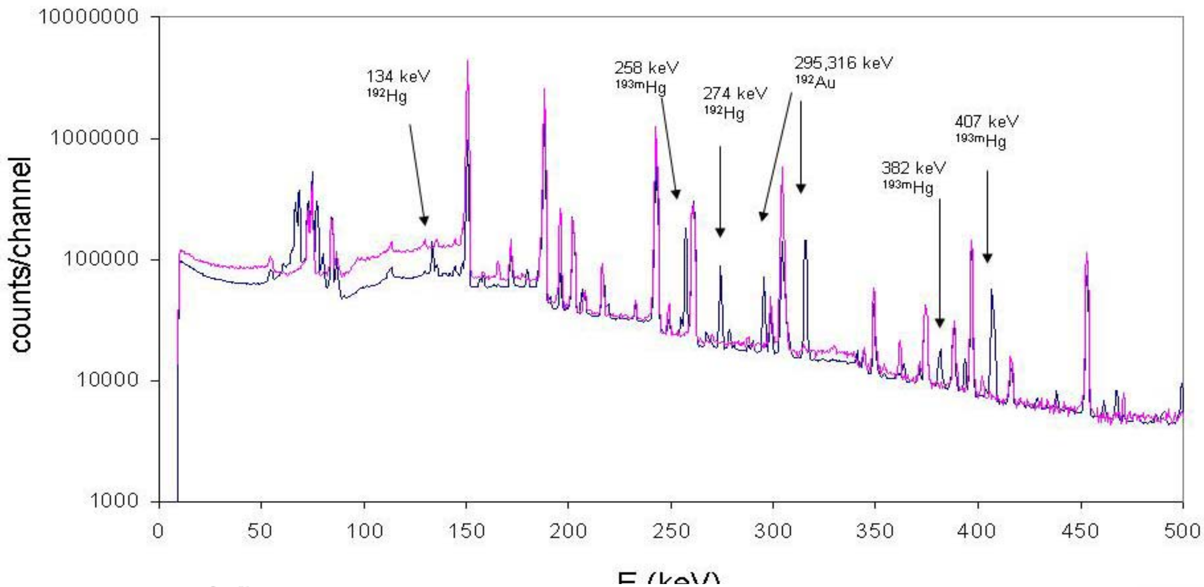


Pressure increase in expansion volume



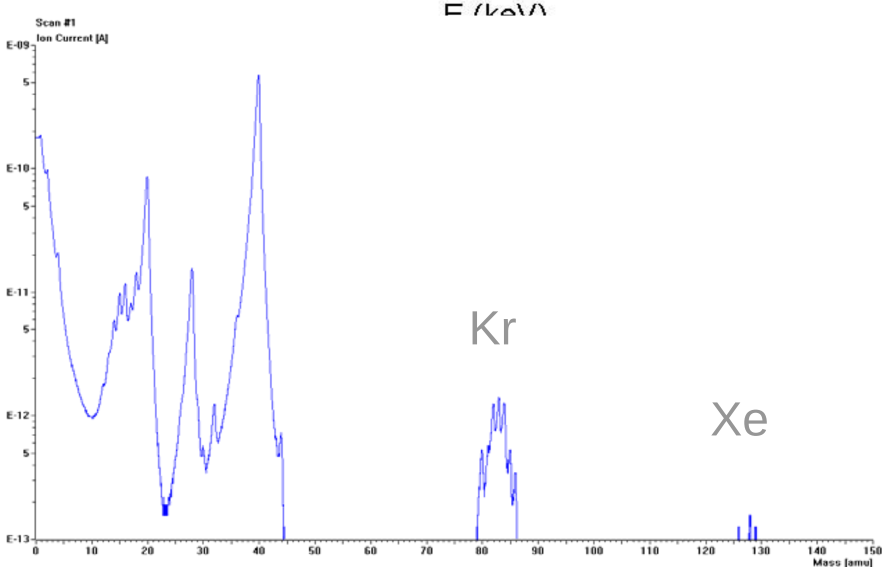
X9 estimates: 1 l NTP after 1 month at 1.74 mA (=1253 mA·h) , that is about 0.4 l after 500 mA h.

Gamma and mass spectroscopy



Gas samples taken after phase 2 of start-up

Second sample with Ar flushing did not show Hg and Au isotopes



Komponente	Zusammensetzung in Vol-% Mittelwert	± 1 s
Krypton	0.250	0.001
Argon	82.4	0.4
Xenon	0.015	0.002
Helium	14.0	.0.4
Stickstoff	2.9841	0.0006
Sauerstoff	0.38	0.02
Kohlendioxid	0.0365	0.0001

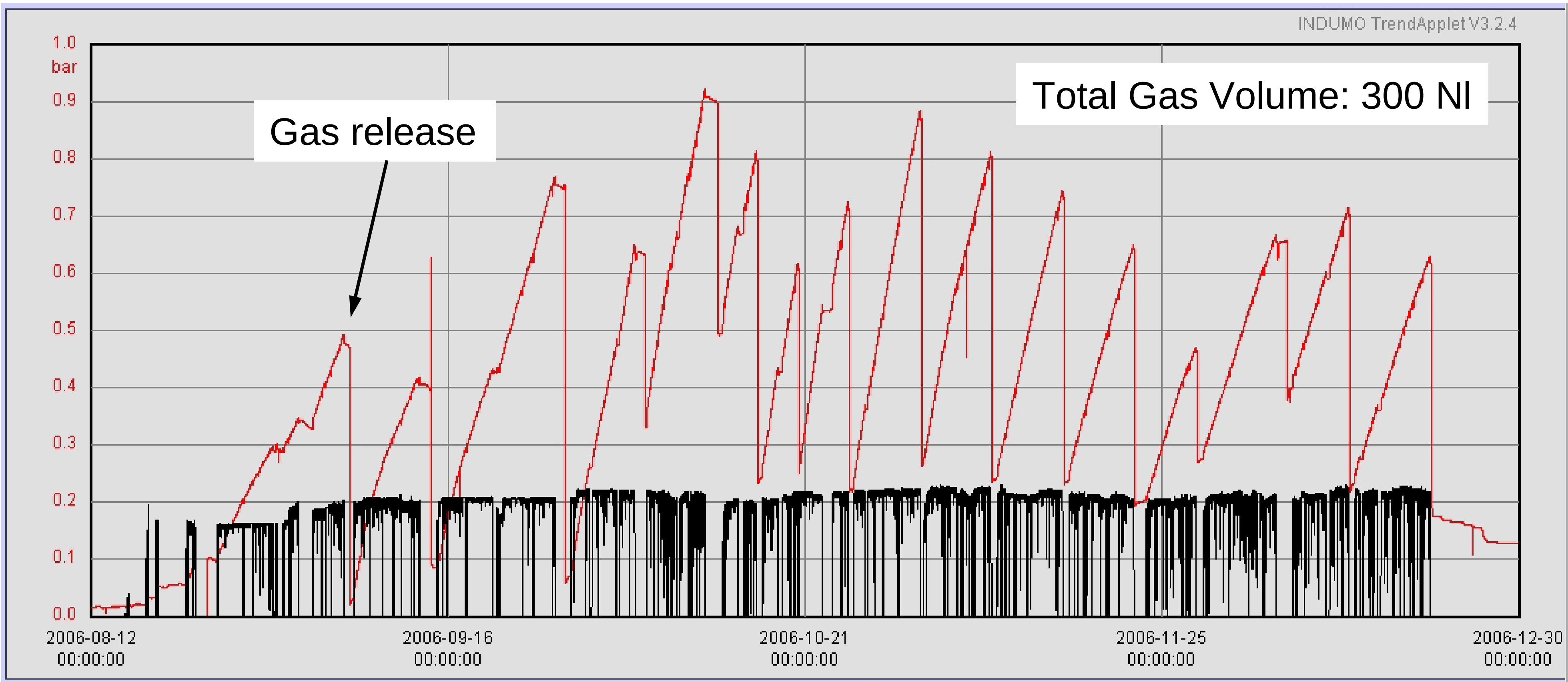
Release Measurements of Cover Gas

Release from decay tank on 6.12.06

Isotop	Activity calculated [Bq]	Activity measured [Bq]	UDAK [Sv/Bq]	Dose to public [Sv]
H-3	1.34E+11	1.33E+11	5.83E-18	7.75E-07
Kr-79	1.77E+12	7.76E-03	7.06E-19	5.48E-21
Kr-85	1.93E+08	1.91E+08	6.11E-21	1.17E-12
Xe-122	2.27E+10	3.59E-15	3.29E-19	1.18E-33
Xe-125	8.54E+11	2.72E-18	6.70E-19	1.82E-36
Xe-127	5.20E+11	1.40E+11	7.85E-19	1.10E-07
Xe-129m	8.26E+10	3.80E+08	2.03E-19	7.72E-11
Xe-131m	1.09E+07	1.97E+05	9.80E-21	1.93E-15
Xe-133	2.45E+10	2.71E+06	9.80E-20	2.66E-13
Xe-133m	5.70E+07	1.82E-02	2.05E-19	3.74E-21

Excellent agreement between measurements and calculation

Isolation Gas Pressure during Irradiation



Temporary installation of isolation gas decay tanks in the SINQ cooling plant room

Conclusions

- The MEGAPIE target operation was successful
- The neutronic performance yielded the expected flux increase
- The thermalhydraulic behaviour was stable and beam trips could be well controlled
- The release of radioactive noble gases in liquid targets is much more important than in solid targets. Careful design of the handling system is needed. We experienced some unexpected leaks and could manage them successfully
- The large amount of data collected and experience gained needs further evaluation and documentation
- The experience gained is extremely important for future LM target design and operation

Acknowledgement

PAUL SCHERRER INSTITUT

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Technik und Umwelt

MEGAPIE-TEST

This presentation was prepared on behalf of the MEGAPIE team

H. Heyck, S. Dementjev, L. Zanini, K. Berg, W. Leung, L. Cachon and G. Hauswirth are especially acknowledged for their contribution