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PSI

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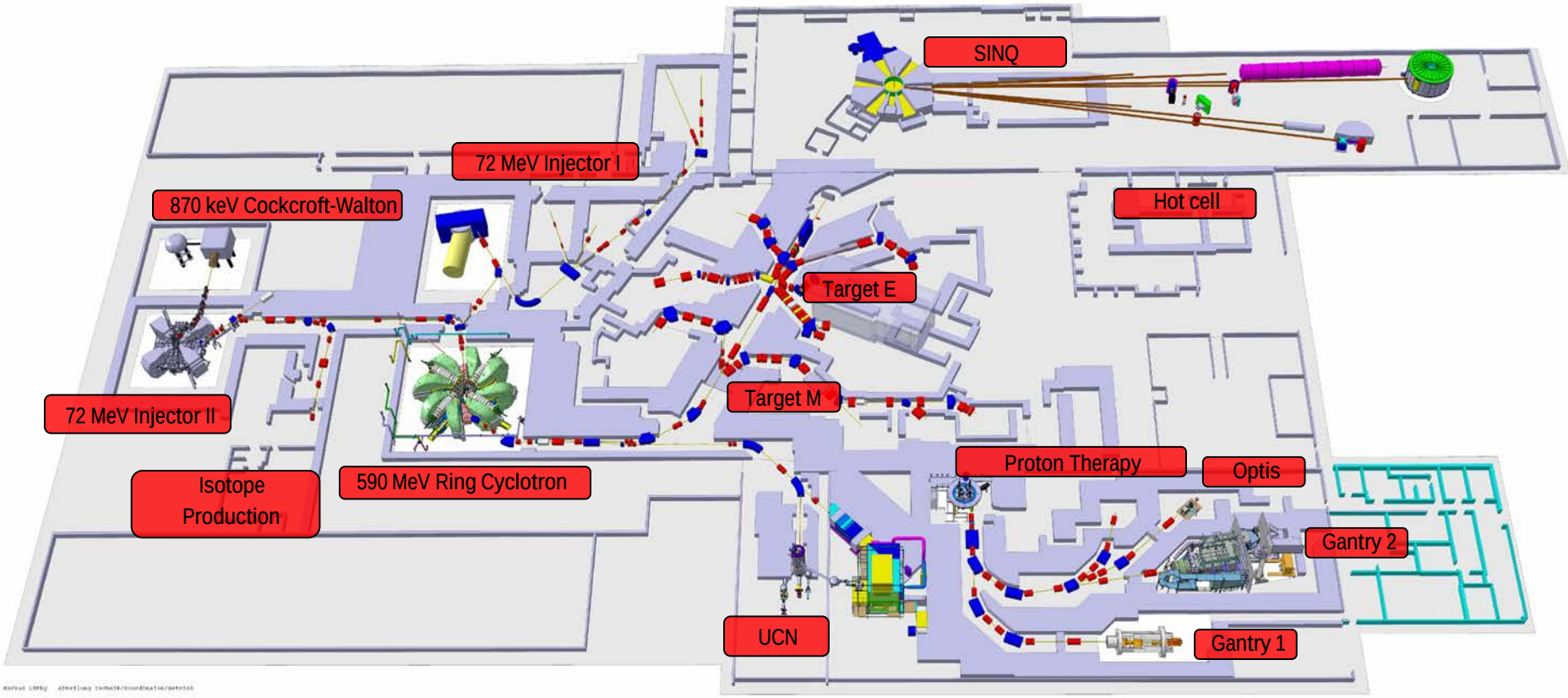
SINQ – A status report

13th International Workshop on Spallation Material Technology, 31.10.- 04.11.2016, Chattanooga, TN, USA

High Intensity Proton Accelerator (HIPA)



- Cyclotron based CW proton accelerator; beam power 1.3-1.4 MW
- Standard operation: 2.2 mA (2.4 mA 2016) 590 MeV protons; downstream of Target E 1.5 mA (1.6 mA 2016) 575 MeV protons
- Multi-user facility: 1 IP station, 2 meson production targets, 2 spallation neutron sources – SINQ and UCN

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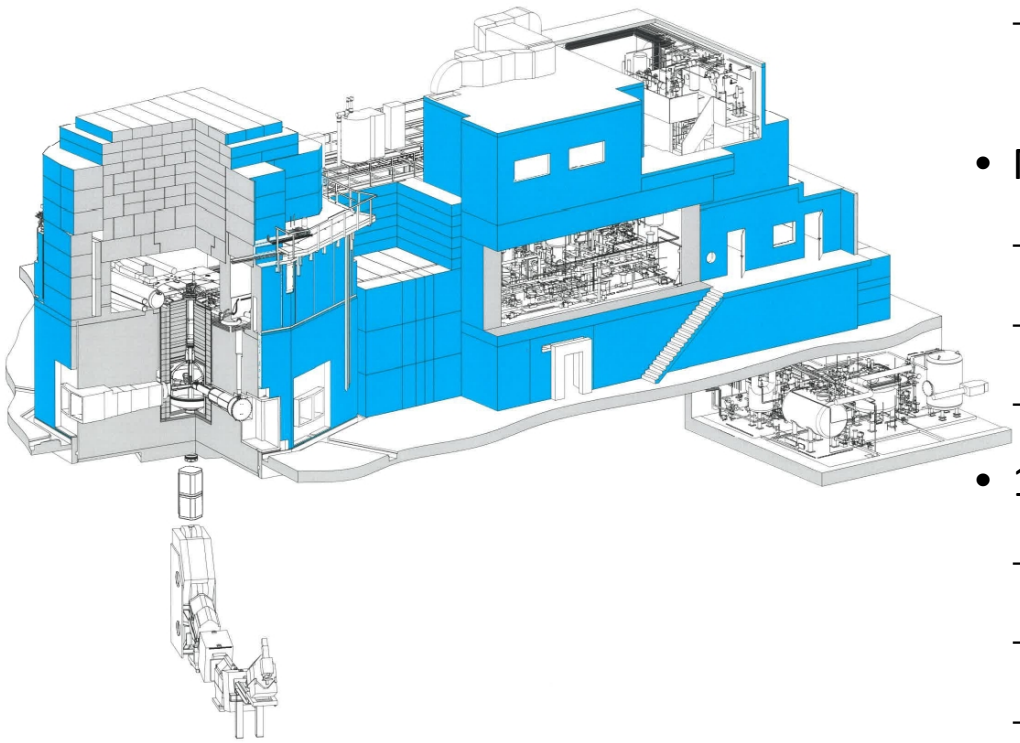
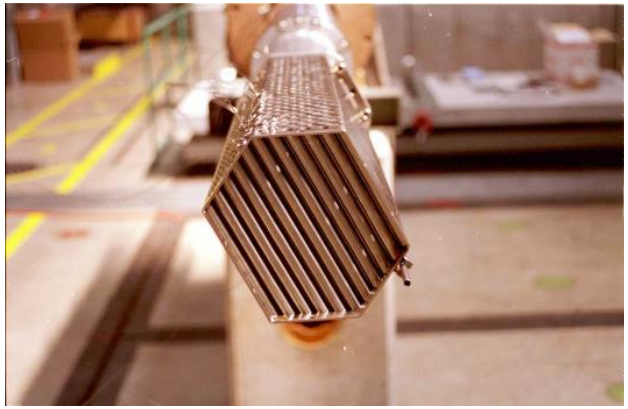
SINQ



- Vertical setup
- MegaWatt CW Spallation Source
- 575 MeV protons, up to 1.6 mA beam current
- Targets
  - Solid & LM Targets operated (see next slides)
- Moderators & Reflector
  - D_2O tank (reflector) with light water shield
  - Liquid D_2 moderator insert
  - H_2O scatterer
- 17 Neutron Instruments
  - 13 instruments @ cold source
  - 3 instruments @ H2O scatterer
  - 2 instruments @ thermal ports
  - NAA irradiation station
- STIP program (talks of Yong Dai)

SINQ Cannelloni Target Types

MARK I
SINQ Target-1 and 3*
Operation 1996-1999
Full Zircaloy-II rods
Hemispherical BEW



*Remark: SINQ Target 2 is the spare Target

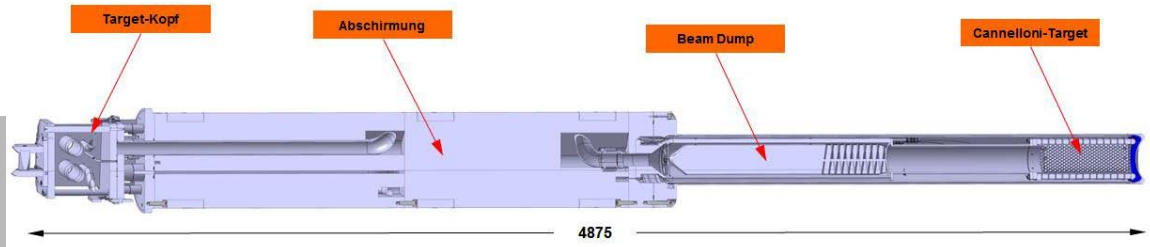
MARK II & III
SINQ Target-4, 5,6 and 7
Operation 2000-2008
Pb Filled Stainless Steel / Zircaloy-II Tubes

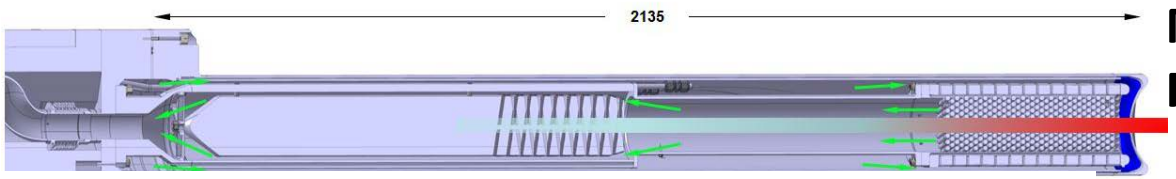
MARK IV
SINQ Target-8, 9, 10 and 11
Operation 2009 - now
Pb Filled Zircaloy-II Tubes (dense packing)
Pb Blanket & inv. BEW

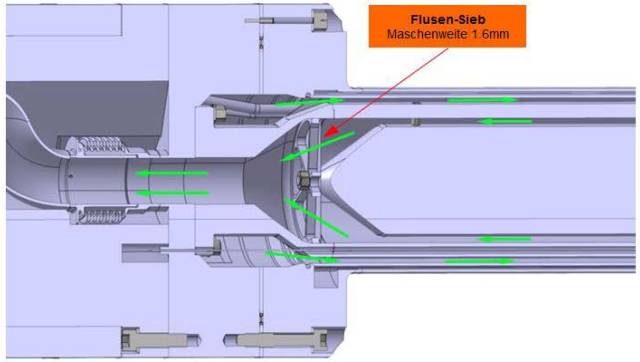
The fabrication of the SINQ targets is done in-house at the PSI main workshop.

Only the three large steel shielding blocks (upper & lower shielding block and „beam stopper“) are fabricated outside of PSI.

SINQ Cannelloni Target

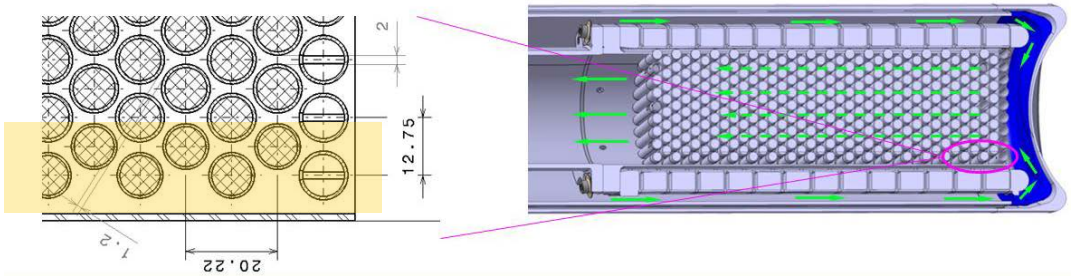






Betriebstemperaturen Targetkühlung:

- Vorlauf	46°C
- Rücklauf	58°C
- Durchfluss	11.5kg/sec



Coolant: D_2O

Mass flow rate: 10 – 12 kg/s

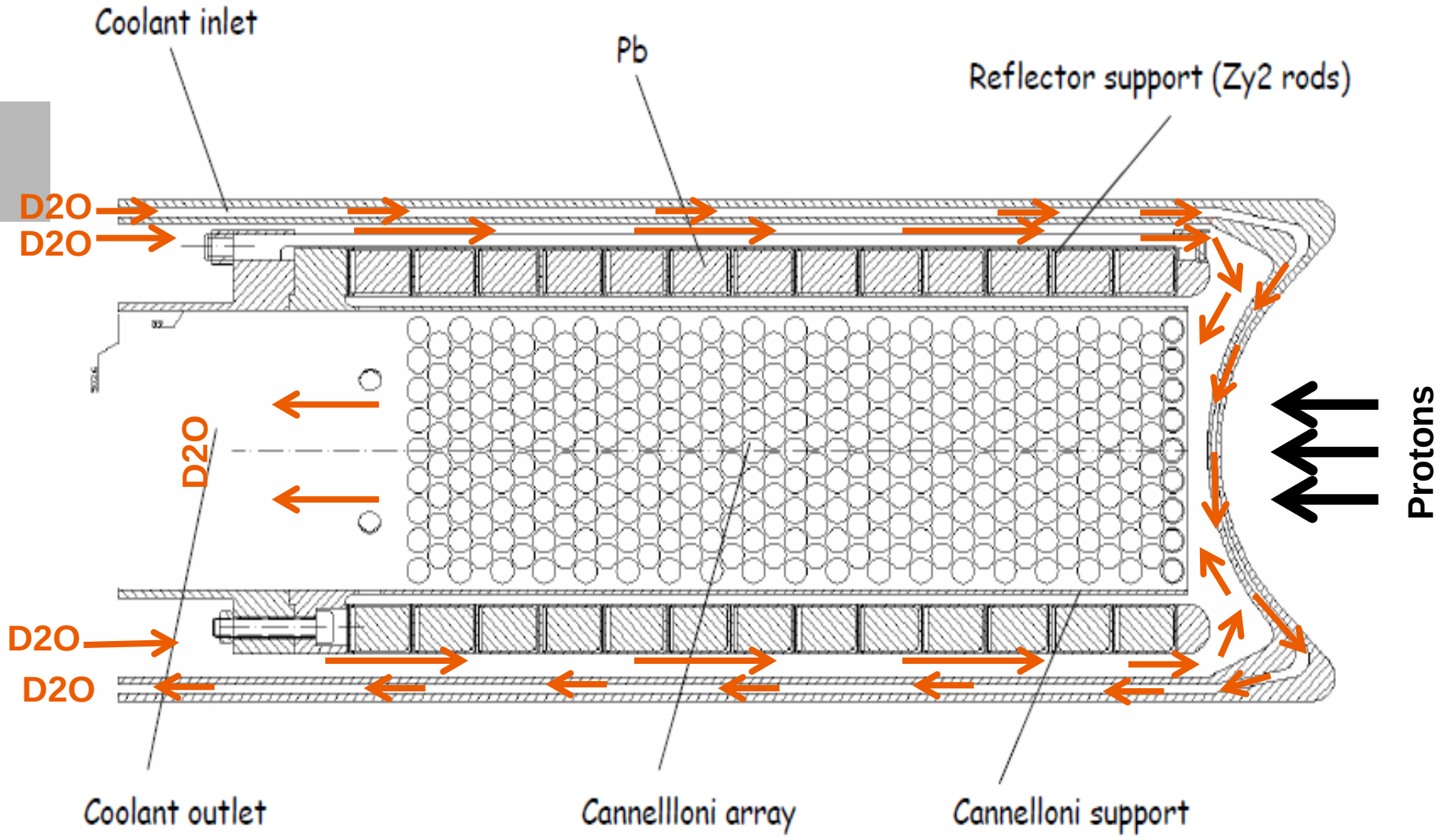
Max. velocity: 5-7 m/s

Pressure drop: ~ 1.5 bar

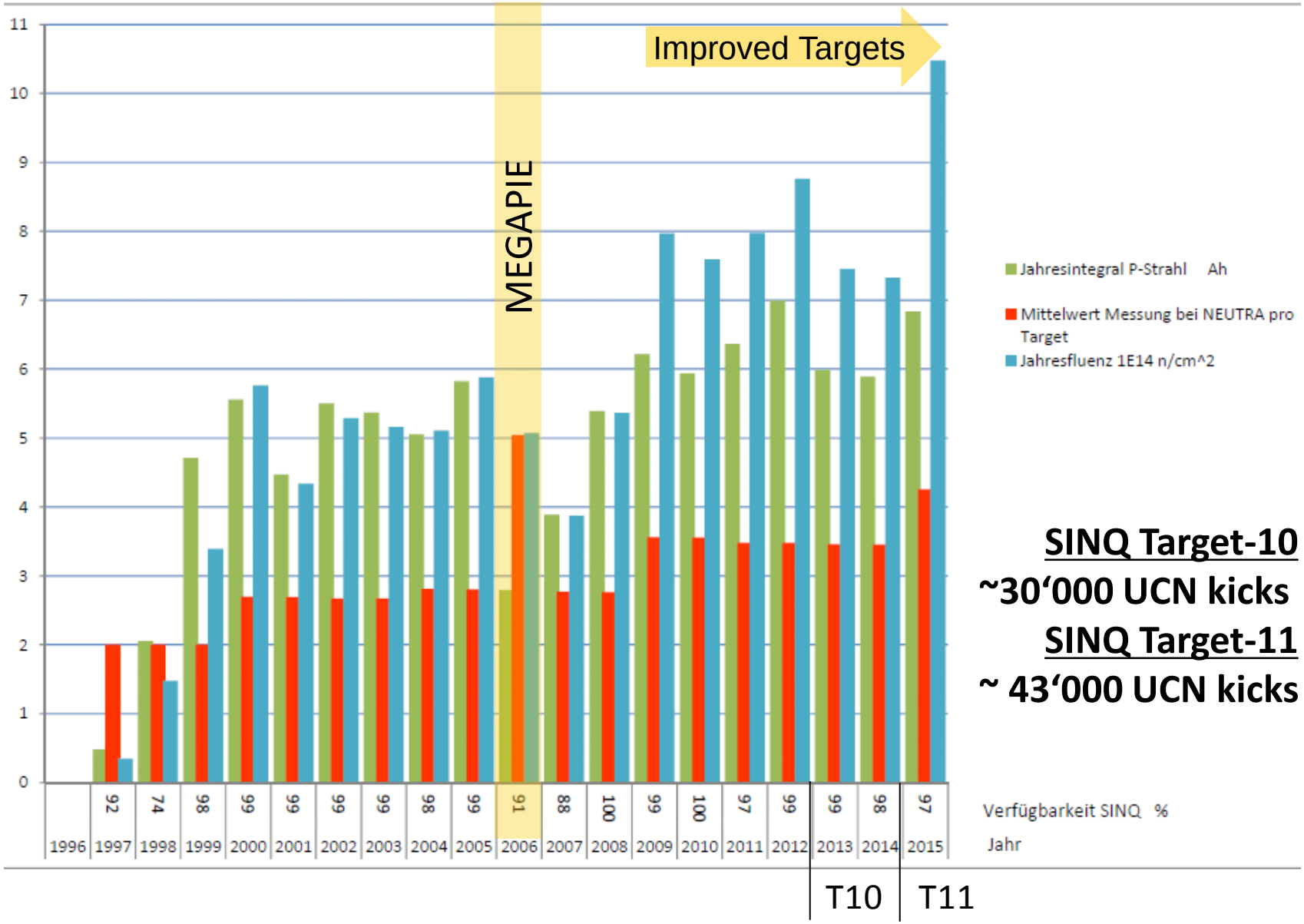
SINQ Target-11

Outermost columns of Target-11 equipped with thinner walled Zircaloy-II Tubes (0.606 mm instead of 0.75 mm wall thickness)

SINQ Target Cooling Scheme



SINQ Performance History



SINQ Target-10
~30‘000 UCN kicks
SINQ Target-11
~ 43‘000 UCN kicks

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SINQ Operation Data - Overview

Target	Jahr	von	bis	Target Typ	Target E	Strahl (mAh) / Jahr	Strahl (mAh) / Target	Mittlerer Strahlstrom		Zerlegt	Container Nr.	Abschirmung in Container	Targetbehälter in TL	STIP-Proben	DL bei Ausbau Sv/h in 0,4 m	Defekte Blei-Stäbe	Defekte STIP-Stäbe
1	1996	03.12.1996	04.12.1996	Zirkaloystäbe (Vollmaterial)	6 cm	2						klein		keine			
1	1997	21.03.1997	29.11.1997		6 cm	480	482		KC-T 12	Jul/Aug 2000	423	10009.71.333	In Container	keine			
3	1998	23.06.1998	24.12.1998	Zirkaloystäbe (Vollmaterial)	6 cm	2055		830			(Bombe 103)	klein		ja			
3	1999	18.03.1999	23.12.1999		6 cm 4cm (ab 29.10.99)	4710	6765	850	KC-T 30	Jul/Aug 2000	89	10009.71.333	In Container	ja	21		
4	2000	10.03.2000	20.12.2000	Stahlrohre mit Bleifüllung	4 cm	5559		1100				klein		ja			
4	2001	08.05.2001	21.12.2001		4 cm	4471	10030	1175	KC-T 30	Aug./Sept. 2002	5	10009.71.333	Sep 02	ja			
5	2002	18.04.2002	23.12.2002	Stahlrohre mit Bleifüllung	4 cm	5500		1260				gross		ja			
5	2003	28.04.2003	23.12.2003		4 cm 6cm (ab 31.10.03)	5371	10871	1230	KC-T 30	Okt./Nov. 2004	93	10009.71.326	Dez 04	ja	26		
6	2004	01.05.2004	23.12.2004	Stahl/ZR-Rohr mit Blei	4 cm	5051		1260				gross		ja			
6	2005	11.04.2005	23.12.2005		4 cm	5822	10873	1260	KC-T 30	Okt./Nov. 2006	117	10009.71.326	Nov 06	ja		Stahlrohr 1 x Kappe ab 2x Rohr geplatzt	
MEGAPIE	2006	14.08.2006	21.12.2006	**MEGAPIE** Flüssigmetall Target	4 cm	2795	2795	1320		Jun./Dez. 2009				keine	2.9		
7	2007	12.04.2007	21.12.2007	Zircaloyrohr (0.725) mit Blei	4 cm	3885		1330				extra gross		ja			
7	2008	12.05.2008	23.12.2008		4 cm	5390	9275	1350	KC-T 30	Jun./Jul. 2010	84	10009.71.358	Jul 10	ja	25		Zr-Rohr 3 x Gebaucht
8	2009	09.04.2009	22.12.2009	Zircaloyrohr (0.725) mit Blei, rund, Bleiblanket aussen, Kalotte invers	4 cm	6218		1490				extra gross		keine			
8	2010	21.04.2010	23.12.2010		4 cm	5933	12151	1550	KC-T 30	Mai/Juni 2012	8	10009.71.347	Jun 12	keine	16	Zr-Rohr 1 x Rohr geplatzt	
9	2011	13.04.2011	02.11.2011	Zircaloyrohr (0.725) mit Blei, rund, Bleiblanket aussen, Kalotte invers	4 cm	6366		1500				extra gross		ja			
9	2012	24.04.2012	21.12.2012		4 cm	6994	13360	1520	KC-T 30	Jul/Aug 2014	111	10009.71.347		ja	16		Zr-Rohr 1 x Gebrochen 2 x Kappe ab 1 x Loch 1 x Gebaucht
10	2013	06.05.2013	23.12.2013	Zircaloyrohr (0.725) mit Blei, rund, Bleiblanket aussen, Kalotte rund "alt"	4 cm	5986		1575				extra gross		ja			
10	2014	12.05.2014	23.12.2014		4 cm	5891	11877	1450	KC_T 30 KC-T088 (Alu)	Juni/Juli 2016	106	10009.71.347		Ja	12		Zr Rohr 2 x Gebrochen 5 x Kappe ab 5 x Rohr geplatzt
11	2015	27.04.2015	23.12.2015	Zircaloyrohr (0.725) mit Blei, rund, Bleiblanket aussen, Kalotte invers, aussen je 2 neue Zr-Rohre (0.61)	4 cm	6301		1500						keine			
11	2016	04.05.2016	25.06.2016		4 cm	1100	7401	1500									
12																	
					Total Strahl @ SINQ	88479											

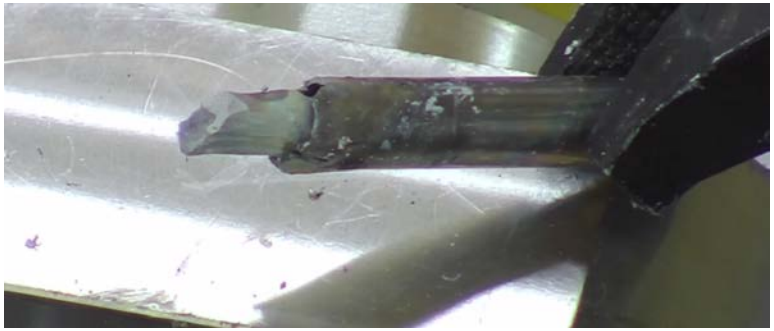
Until 2016 all SINQ Targets have been operated for their expected life-time without major incidents.

However, smaller defects of single Cannellonis were encountered for several targets.

SINQ Target-11 (2015 & 2016) prematurely had to stop operation on June 25th 2016.

SINQ Target-10 Inspection

W STIP Sample Tube #6



Erosion of Tungsten ?
High dose rates in D_2O

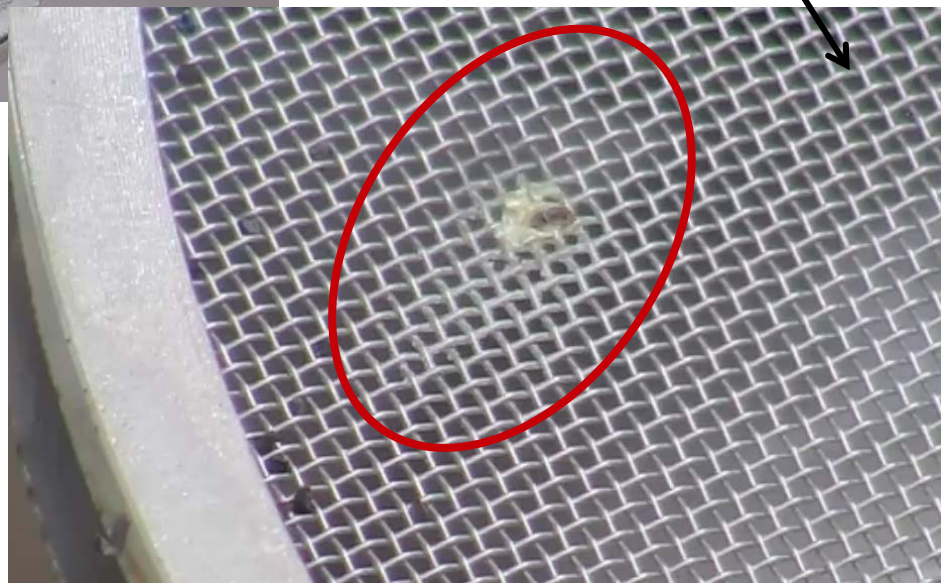
- Operation 2013 & 2014
- High dose rates measured at the piping in the coolant plant room
- Indication for broken Cannelloni tubes
- Visual inspection in ATEC (Hot cell PSI West)

W STIP Sample Tube #8

9 STIP sample tubes showed damage/ were damaged during extraction

SINQ Target-10 Inspection

Sieve made from SS 1.4401
Mesh-Size 0.88 × 0.88 mm²



«Flusensieb» (fluff sieve) contained particles

Main D_2O cooling loop had to be continuously filtered during shutdown(s)

Decision: No STIP Sample Tubes in Target-11

Operation SINQ Target-11

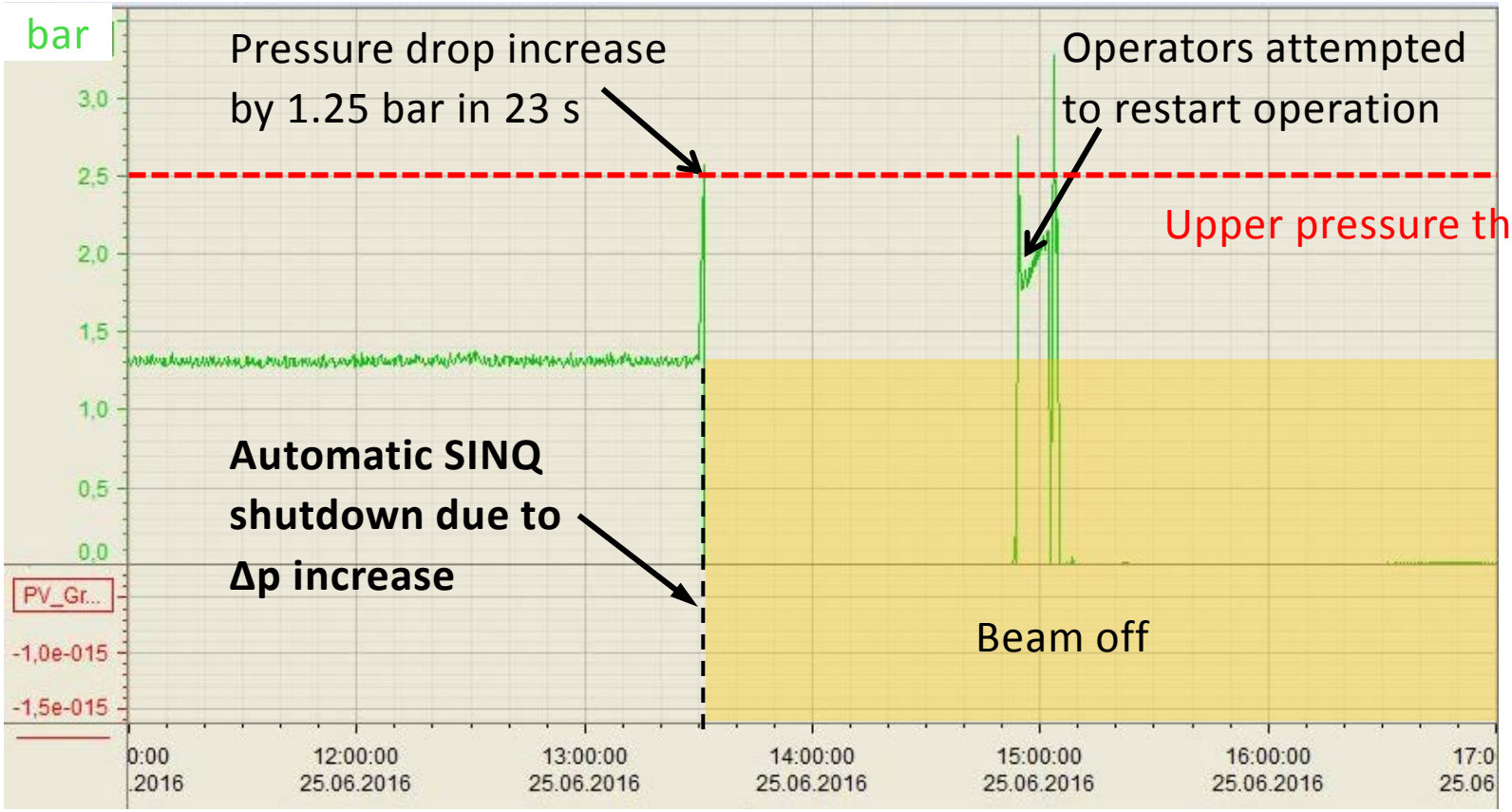
From May 2015 until June 23th 2016 the SINQ Target-11 had been operated without major incidents.

- On June 23rd 2016 a dose rate increase at the D_2O piping in the SINQ coolant plant room was observed, after a VIMOS triggered beam shutdown.
- On June 25th 2016 at ~ 13:30 the SINQ operation was automatically stopped due to abnormally high pressure drop.
- Within 23 s the pressure drop of the D_2O target main cooling loop rose to more than 2.5 bar (normal operation Δp = 1.3 - 1.5 bar).
- At the same time elevated D_2O temperatures measured in Row 2 of SINQ Target-11.
- After beam switch-off the D_2O pressure rose to more than 10 bar, the pressure relief valve opened.

Attempts to restart SINQ target main cooling loop after some waiting time failed due to repeated pressure drop increases. No radio-activity was released from SINQ; all inventory was contained in the Target, the main cooling loop and its filters.

It was decided to let the activity further decay and to prepare for a per-mature SINQ Target exchange. Authorities agreed to this approach.

Operation SINQ Target-11 – Pressure drop

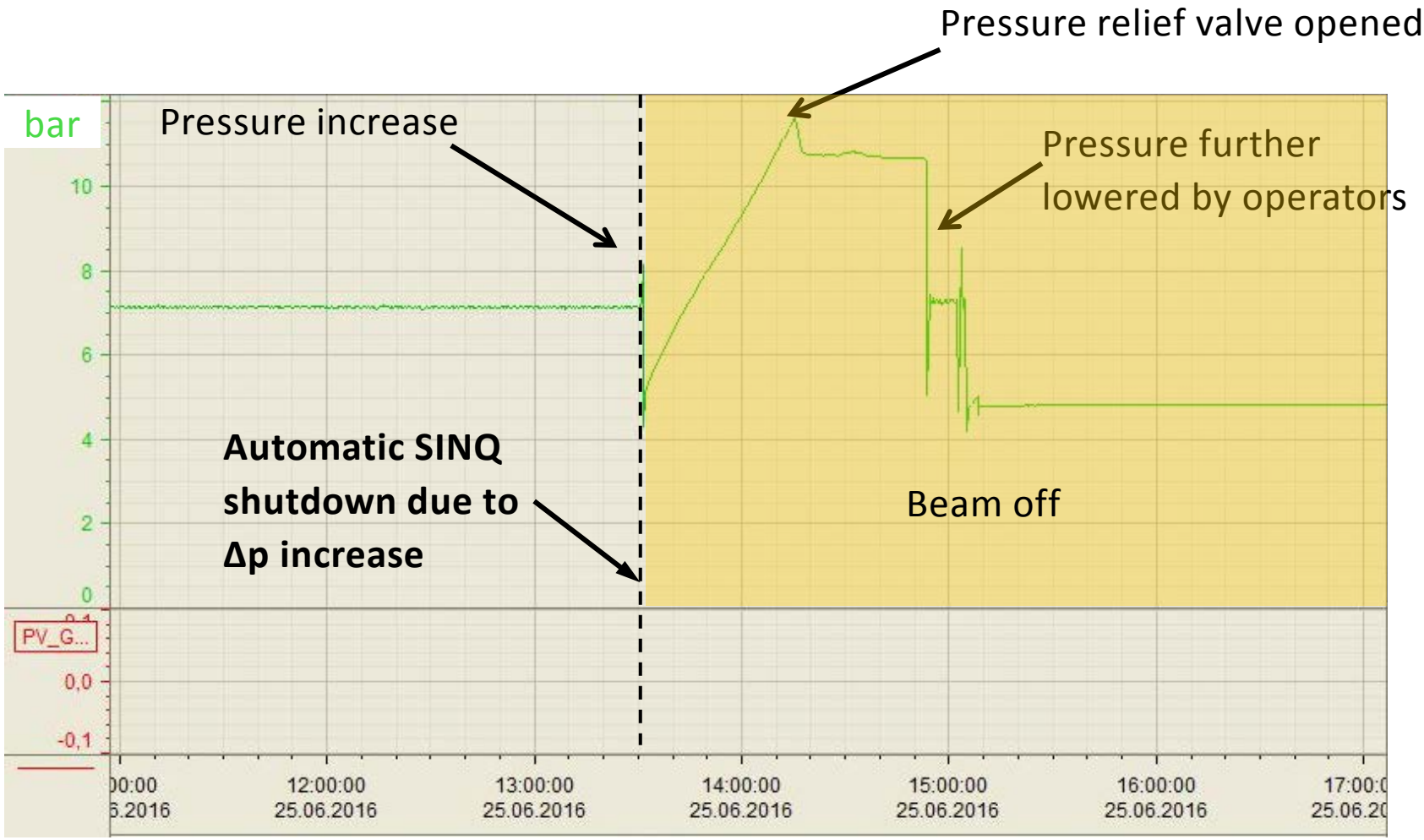


25. June 2016 SINQ operation was automatically stopped by SINQ safety system due to an abnormal high pressure drop in the main cooling loop

Pressure drop in target cooling loop increased from 1.3 to >2.55 bar within 23 s.

This corresponds to a reduction of the effective hydraulic cross section of 40 – 50%.

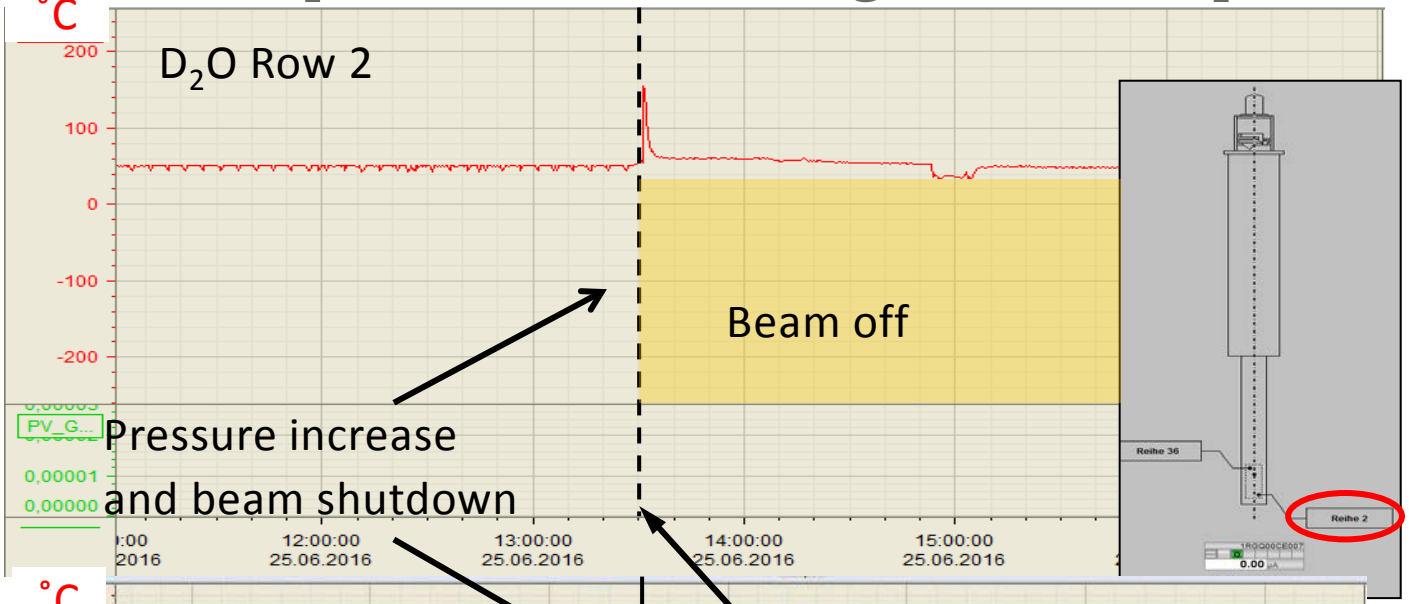
Operation SINQ Target-11 - Pressure

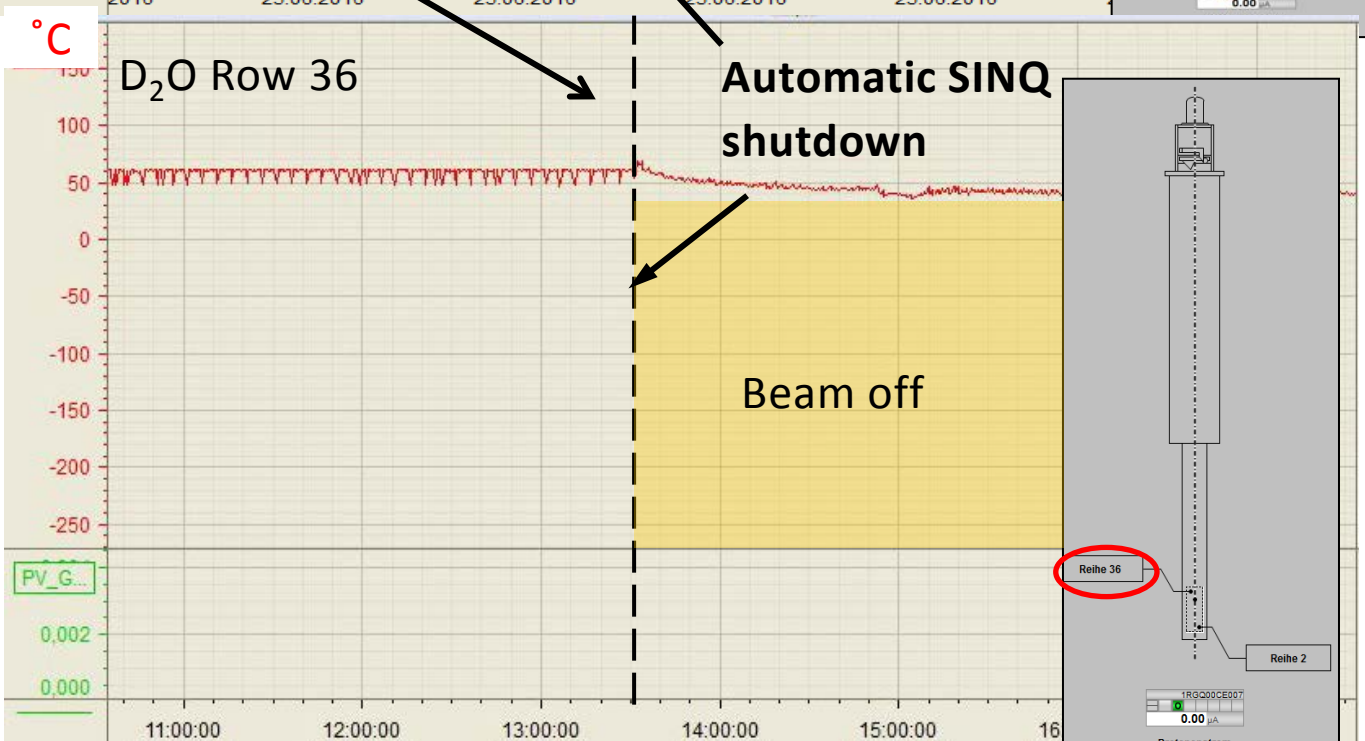


Static D_2O pressure in SINQ Target-11 increased, even in beam-off state

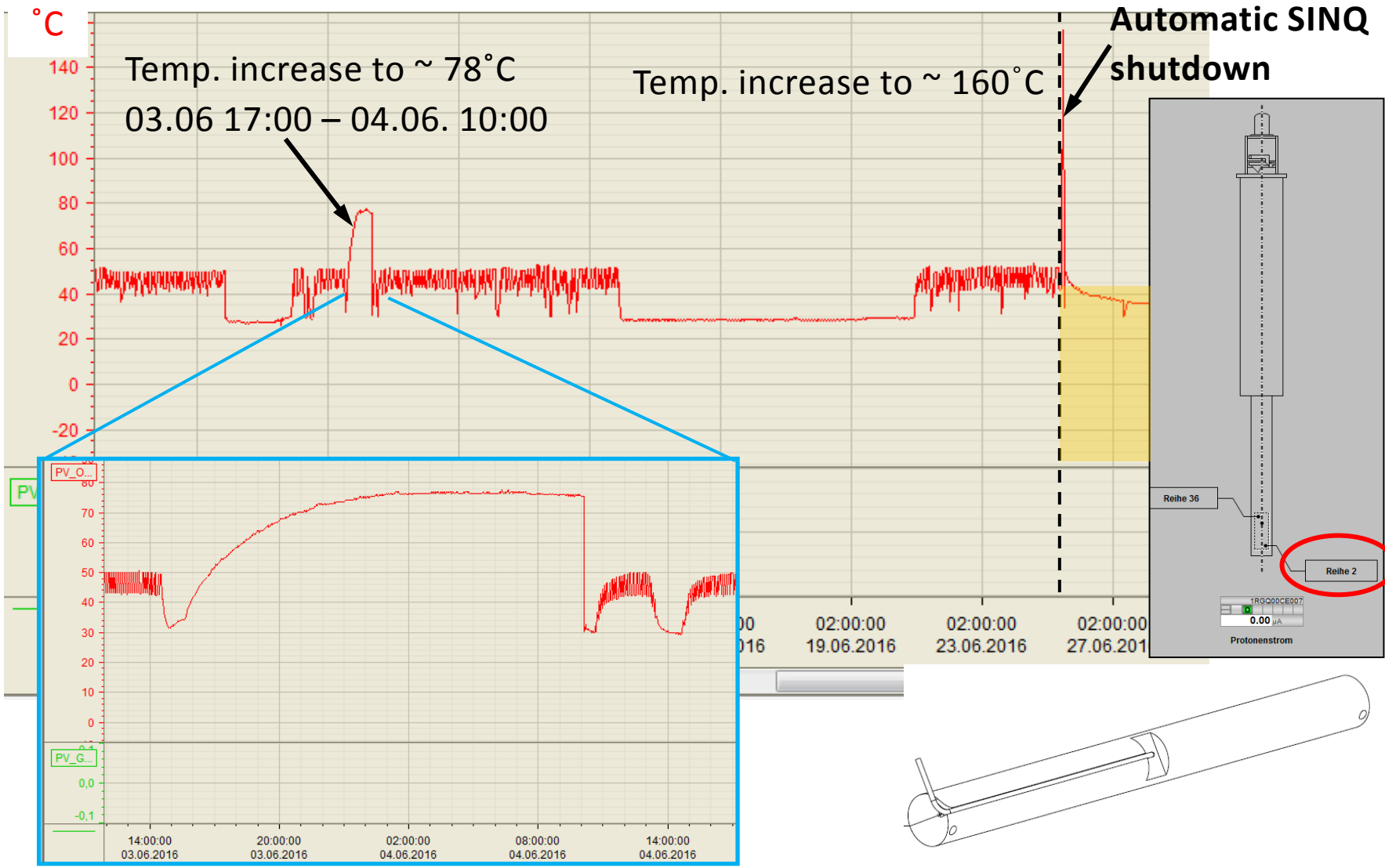
Pressure relief valve opened & further pressure release by operators

Operation SINQ Target-11 - Temperatures



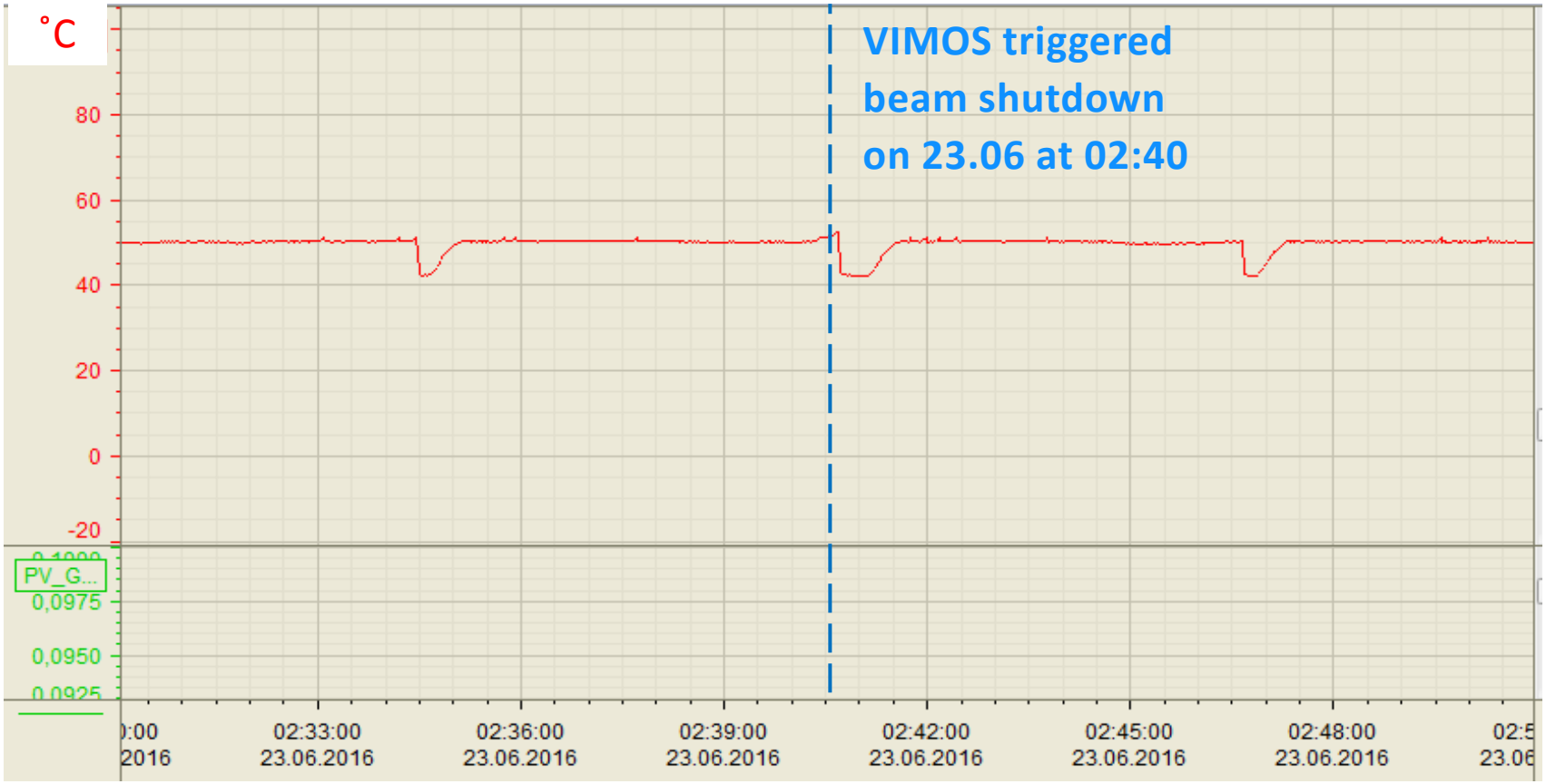


Operation SINQ Target-11 - Temperature



D_2O Temperature data in Row 2 of SINQ Target-11 from 03 - 27. June 2016

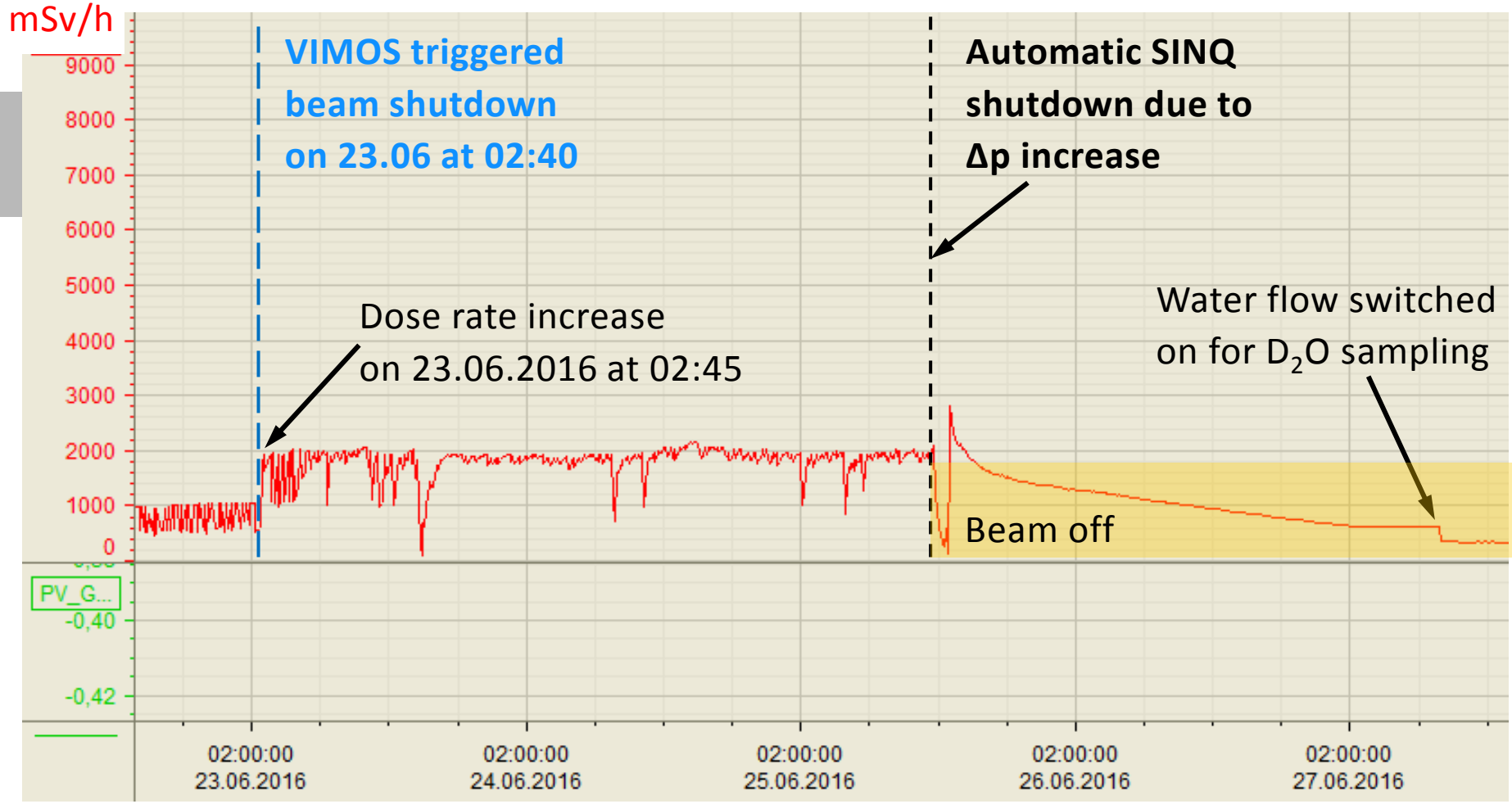
Operation SINQ Target-11 - Temperatures



In Row 36 an increase in temperature of 3˚C was observed at the time of the VIMOS triggered beam shutdown.

Dose rate in SINQ cooling plant room increased ~ 5 minutes later.

Operation SINQ Target-11 – Dose rate data



Dose rates (mSv/h) at the D_2O piping in the cooling plant room increase at 02:45
Dose rate increase indicates failure of (a) Cannelloni(s); at ~02:40 D_2O temperature increase in Row 36 of Target by 3˚C, in coincidence with VIMOS triggered shutdown

SINQ Target-11 - Aftermath

- SINQ Target Exchange needs license from Authority
  - Authority wants to have detailed information on causes of the incident asap
  - License to exchange, install and operate Target-12 granted

- New SINQ Target-12 installed; operation shall start 31.10.2016
  - Reduced beam current – 1700 µA on Target-E ➔ ~ 1150 µA on SINQ
  - Less UCN kicks – max. 30'000 kicks
  - Broader beam footprint – max. of 30 µA/cm^2
  - Limited integrated charge on target – 5000 mAh

- Visual inspection SINQ Target-11 earliest May 2017
  - Samples will be taken for analysis in Hot Laboratory of PSI

- Simulation efforts further intensified → improvement of cooling efficiency implemented in Target-12

- PIE of structural materials - Zircaloy-II and Steel - is being intensified
  - Zircaloy-II samples from tubes irradiated in SINQ Target-9 are being prepared for analyses in the Hot Laboratory of PSI
    + Crack Propagation Testing
    + Hydrogen and Helium measurements
    + Corrosion
  - Zircaloy-II samples from STIP-II will be tested

SINQ Target-11 – Search for failure mode(s)

- Proton beam distribution narrower than for previous Targets → higher power densities & particle fluxes in central region of Target-11 → higher damage rate
- During beam development operation up to 2.4 - 2.5 mA (@Target-E) → 1.6 – 1.7 mA on SINQ
- Thin walled Zircaloy-II tubes at outer radii (two outermost columns); up to now untested for in-beam operation
- Increased number of kicks to the UCN spallation source; 30'000 kicks during operation of SINQ Target-10 & ~ 43'000 kicks experienced by SINQ Target-11 ➔ full thermal cycles for SINQ and UCN Targets → Cyclic Fatigue
- Corrosion effects on the inside of the Zircaloy-II tubes in the front rows (up to ~ row 20); Embrittlement due to Hydrogen and Helium → Post Irradiation Examination in the Hot Laboratory of PSI by Yong Dai and others

Thank you for your attention!