Operation of the PSI Accelerator Facilities in 2015

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The Department of Large Research Facilities has responsibility for the operation and development of the three accelerator facilities at PSI. These are: the High-Intensity Proton Facility, the Swiss Light Source and the Proscan medical accelerator. This article covers operational aspects of these facilities, as well as performance highlights and new developments achieved in them. In 2015 the accelerators of both large science facilities, SLS and HIPA, reached record availability numbers over their history of operation.

High-intensity proton accelerator (HIPA)

The user operation in 2015 (KW19) was started as scheduled on May 6 with a production current of approximately 2000 µA. Figure 1 shows the distribution of the weekly availability over the year 2015 as well as the rate of beam trips. Due to an early finish of the yearly shutdown the facility was already in operation two weeks before user operation with approximately 500-1000 µA. In KW18 target M was exchanged due to bearing damages. Over the two weeks of production an average current of 2048 µA and an availability of 97% could be reached. X-Rays, caused by the high RF voltage, were no longer detected at the ionisation chambers thanks to Aquadag coating of the cavity 5 and a better vacuum sealing. KW22 hit back to 81% availability and 1695 µA due to the failure of two quadrupole power supplies in the p-channel and a vacuum leak at the first beam stop leading to approximately 20 hours of interruption. By KW25 the availability stabilised again at 97% with an average current of 2092 µA with minor interruptions. As result of the stable operational performance, it was decided then to proceed with high current test-operation during two shifts (16 hours) with 2400 µA at an interval of two weeks. The first run on June 18 showed a positive outcome with low extraction losses. Also further runs were carried out regularly in spite of high summer temperatures. The RF cooling circuit being at its limit, several high current shifts during this period had to be shortened for several hours. In total 12 high current runs were performed. KW27 was impeded by several failures in Injector2, a vacuum leak in cryo-pump 4 and a defective cooling circuit sensor of resonator 3 resulting into a comparably lower availability of 92%. The SINQ/Beamdump switching power supply, cavity 4, Cockcroft–Walton discharges and a problem with its cooling supply were the main interruptions in KW29&30 followed by almost 6 months of stable operation with an availability 95-99% and a weekly average current above 2000 µA with only few interruptions.

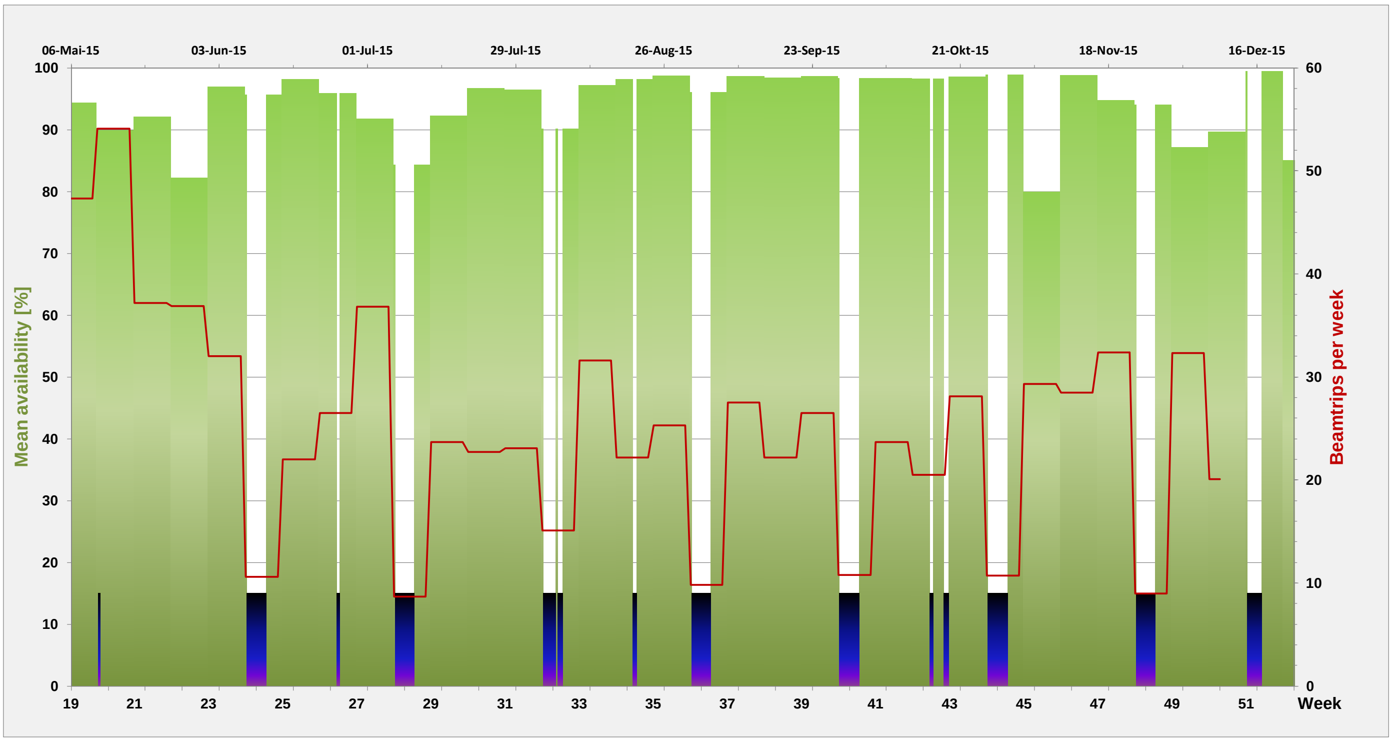

Figure 1: Operation of the Proton Facility: availability and beam trips.

Note that since the beginning of the high current runs the radiation values were still within the allowed limits. During the scheduled outage in KW36 the meson production target E was replaced. However, an unscheduled exchange of target E had to be done in KW46 due to some unknown damage. The target seemed to have already some problem. This led to 32 hours of interruption. In KW42 it was observed that several ionization chambers (MRI3, MRI9, MRI11) in the ring cyclotron showed again an increase of the radiation level, probably due to consumption of the Aquadag coating layer during operation. In KW50&51 the availability dropped due to problems with cavity 4, cooling circuit 9 and the collimator KN4 at Ring's entrance. The operational data of the facility are given in Table 1.

Table 1: Operational statistics for the proton facility.

Beam-time statistics for HIPA	**2015**
Total scheduled user beam time	**4806 h**
Beam current integral To meson production targets To SINQ	 10.21 Ah 6.93 Ah
To UCN	0.075 Ah
To isotope production targets	0.0125 Ah
Outages Total outages (current < 1 mA)	 195 h
Availability (without compensated outage time)	95%

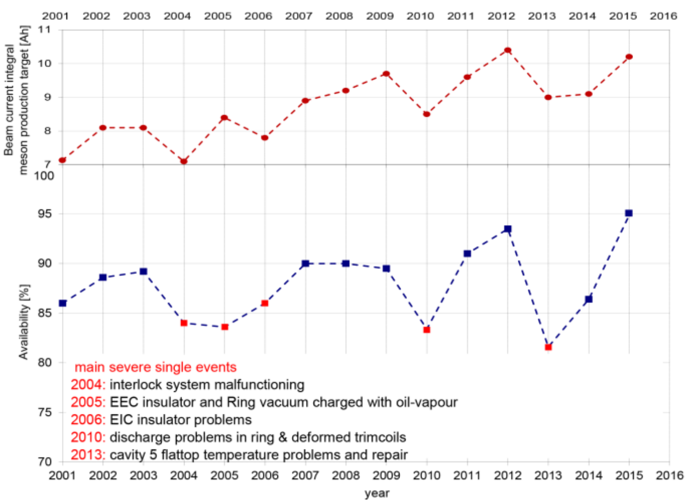

Figure 2: HIPA performance numbers since 2001.

The average availability in 2015 was 95%, 8.6% better than in 2014. Thus, HIPA's operational performance in 2015 in terms of availability was the best achieved for the last 15 years. The various relative contributions to the downtimes in 2015 are shown in Fig. 3. The distribution differs from the previous years. Major contributions came this year from power supplies due to of QHG21&22 failures (18.7%), RF failures (16.5%), target E replacements (16.3%) and water cooling issues (15.2%).

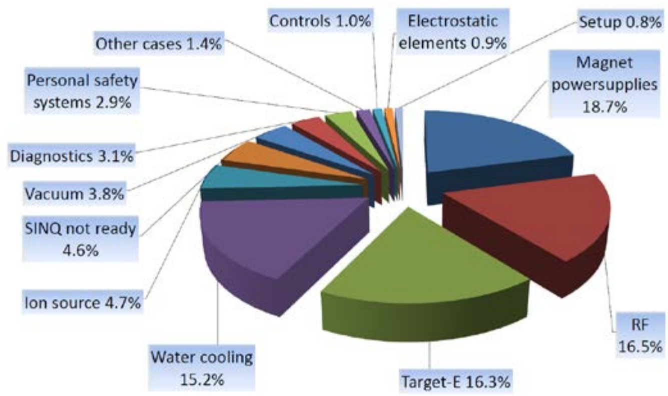

Figure 3: Downtime characterization by category of HIPA outages longer then 5 minutes (ca. 195 hours).

Proton Therapy PROSCAN

In 2015 the cyclotron and beam lines for the proton therapy facility at PSI have been operating without major problems. With more than 7100 hours of operation, a high availability of 98.3% has been achieved. This figure reflects the time that cyclotron and beam lines have been in the status "ready for beam delivery" . Down times due to interlocks from the patient treatment side have thus not been included in these statistics. During 2015 most of the equipment and extensions of the control and safety systems related to the new Gantry-3 have been taken into operation and tested. The increased number of interlocks at the cyclotron is due to these activities and is the reason for the <1% decrease of the availability compared to 2014. No exceptional system problems have occurred in 2015. In the cyclotron operation, some hours were lost due to problems with the encoders in the short-plates mounted at the Dee-stem in the RF system. The problems with the cryo-systems were consisting of a bad contact between the 50 K heat shield and its cryo-cooler, due to mechanical problems when mounting the cryo-cooler after a service. There were no other specific components contributing to the unscheduled down times in 2015.

A system has been developed that prevents too frequent shut down of the ion-source when in full operation, since we expect that fewer switching at full power will increase the life time of the ion source. The system has been installed and will be taken into operation in 2016, when it has passed the necessary safety procedures at the proton therapy.

A system is being developed to allow small adjustments of the radial position of the extraction elements in the median plane.

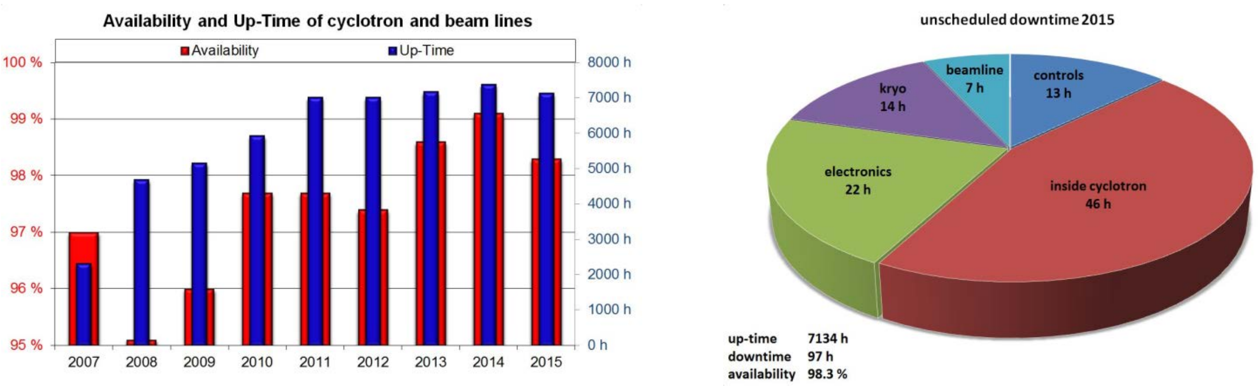

Figure 4: Operating hours per year, availability of PROSCAN (left) and unscheduled downtime by causes.

We intend to use a similar system of piezo-motors as planned in the new design of the phase slits in the cyclotron. We expect that this can be used to further minimize the beam losses at extraction during beam development.

In 2015 the new experimental facility (PIF, Proton Irradiation Facility) behind a bending magnet just before the coupling point of the new Gantry-3, has been used frequently (on average once a week) and extensive beam tests have been performed successfully in the beam line to the coupling point of the new Gantry-3.

A test with boron carbide as degrader material has shown that the use of this material instead of the currently used graphite will increase the transmission of low energy (70-80 MeV) beams from degrader to treatment room by more than 30%. This can be used for a major improvement of the treatments and we have decided to build a new degrader with this material.

Development and Operation of the SLS

The Swiss Light Source had very smooth user operation in 2015. The beam availability was at an excellent 99%, the highest value in the history of the SLS. The mean time between failures was again more than four days, a value better than for most other synchrotron light sources world-wide.

The longest unscheduled beam outage of 12 hours had been caused by a PSI wide power outage of about 10 minutes. This outage had been triggered by a hardware failure during the commissioning of a new transformer for the medical facilities of PROSCAN. In the process a voltage sensor of a gear switch exploded, which in turn set off the global power cut. All other unforeseen beam interruptions in 2015 were shorter than five hours.

Figure 5 shows the number of beam outages split by their failure category for the past years. The total number is very low as well, the second best value in the history of the SLS.

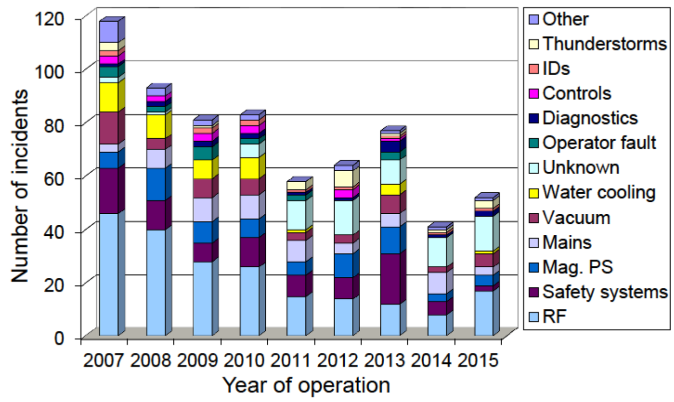

Figure 4: Beam outage count per failure category

A slight increase of the number of beam outages caused by the RF is visible; this was to be expected, since two of the cavities had been exchanged last year. Figure 6 shows the number of the different beam distortions over the years.

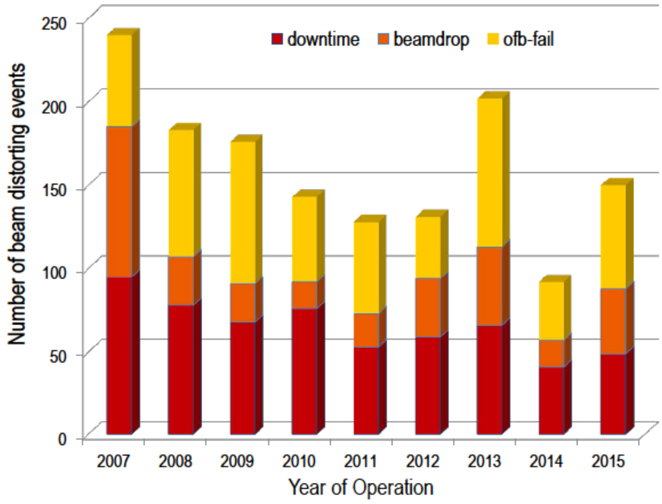

Figure 5: Number of beam distorting events of the past years

While the number of beam outages remained very low, the total number of beam distortions was slightly increased. The increase in the number of beamdrops was mainly driven by water flow interlocks of the Linac and Booster RF. The flow in those cooling systems had been reduced in order to avoid cavitation. The interlock limits had been adjusted accordingly. But now small pressure fluctuations in the cooling water circuits can trigger flow interlocks. The origin of these pressure fluctuations are currently under investigation. Another problem was the lifetime of the focussing power supplies of the klystrons of the Linac. Condensers in these power supplies had reached the end of their lifespan and had to be replaced. The number of orbit-feedback outages was similar as the average value of the past eight years. Figure 7 shows the duration of the beam outage events in 2015 assigned to the different failure categories.

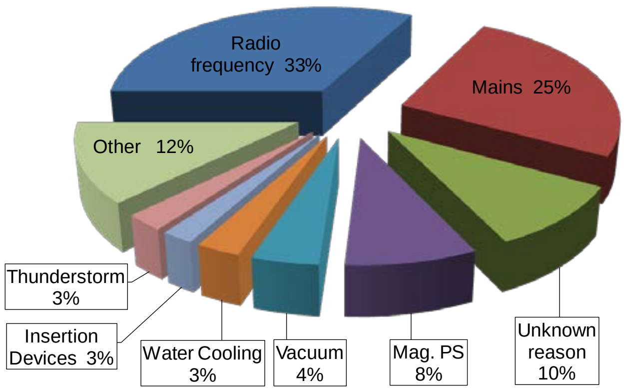

Figure 7: Beam outages per failure category in 2015

Trips of the RF amounted to a third of the total beam downtime; the single incident with the mains caused another quarter.

The operational data is summarized in Table 2. In January 2016 the last 500 MHz cavity of the storage ring will be replaced. The exchange of the first three cavities went very smoothly and all problems related to the exchange were handled in due time.

The development of a new BPM system is progressing well. The new hardware is expected to be ready by mid 2017. Unfortunately this will be the same time period where the BPM system of the SwissFEL is expected to go into operation. It has been decided to schedule the commissioning of the new BPM and Fast Orbit Feedback system in the second half of 2017: a long summer shutdown of three weeks will be scheduled to install the new hardware and about two weeks commissioning time after the shutdown to get the system into operation. It will be reassessed in April 2017 if the hardware and the required manpower will be actually available in August 2017. If this is not the case, the commissioning of the new system will be scheduled for 2018.

Table 2: SLS Operation Statistics

Beam Time Statistics	**2015**		**2014**	
Total beam time	6872 h	78.6%	6888 h	78.6%
• user operation	5056 h	57.7%	4984 h	56.9%
- incl. compensation time	160 h	1.8%	160 h	1.8%
• beamline commissioning	728 h	8.3%	832 h	9.5%
• setup + beam development	1088 h	12.4%	1072 h	12.2%
Shutdown	1896 h	21.6%	1880 h	21.5%
User operation downtimes	46		37	
• unscheduled outage duration	49 h	1.0%	124 h	2.5%
• injector outage (non top-up)	11 h	0.2%	9 h	0.2%
Total beam integral	2497 Ah		2455 Ah	
Availability	99.0%		97.5%	
Availability after Compensation	102.3%		100.8%	
MTBF	107.6 h		131.2 h	
MTTR (mean time to recover)	1.1 h		3.3 h	
MTBD (mean time between distortions)	35 h		55 h	