DESIGN CONSIDERATIONS FOR THE PS2 BEAM DUMPS

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Abstract

The different beam dump functionalities required for the proposed PS2 machine and its transfer lines are briefly described, followed by first estimates about the expected beam loads. This data has been taken as input for comparing the different technical options for the dump systems, in particular to simulate the radiological impact for internal or external beam dump options. The numbers derived have been used to help decide which of the feasible technical alternatives are preferred.

FUNCTIONS AND BEAM LOADS

The PS2 accelerator is proposed to replace the existing PS, to provide more reliable operation and improved basic beam parameters for the foreseen LHC luminosity upgrade and other users. Beams with very high intensities above 10^{14} p+ will be accelerated, providing a totally new challenge concerning the disposal of unwanted beam.

A 200-day nominal operation year is assumed for the calculations. The relatively short PS2 cycle (minimum 2.4 s) combined with the assumed maximum intensity of 1.5×10^{14} p+ results in about $7x10^6$ cycles per year with about 10^{21} accelerated particles. This is several orders above the current PS level. The increase in energy (50 vs. 26 GeV) also raises the challenge of handling operational beam losses. Table 1 shows an overview of the basic PS2 parameters [1].

Table 1: PS2 - Basic parameters

Injection energy (kinetic)	GeV	4
Extraction energy (kinetic)	GeV	50
Maximum beam intensity	p^+	1.5×10^{14}
Minimum cycle period to 50 GeV	s	2.4
Maximum norm.emittance (H-V)	π.mm.mrad	15-8
Cycles per year		7,200,000
Protons accelerated per year	p^+	1.08×10^{21}

The calculations assume maximum beam intensity at all times and no unforeseen losses. Loads were calculated for dump functionalities which were identified as necessary. Eight such functionalities were identified for the PS2:

Setting up of the injection transfer line

A dump will be required for the injection transfer line, to enable setting-up and re-optimisation after changing the injection foils. Safety beam stoppers will also be required to allow downstream access. For setting-up it is assumed that 4 days per year are needed at 10 % intensity. This gives 0.2 % of the yearly total, or $2x10^{18}$ particles. Foil changes are assumed to imply one hour at 20 % intensity, and twenty foil changes p.a. gives 0.08 % of the yearly total, or $9x10^{17}$ particles. The sum of the two loads is 0.28 % or $3x10^{18}$ particles at 4 GeV.

Fast injection setting-up and injection failures

For setting up the fast injection of p^+ (4 GeV) an internal beam dump is proposed which can also localise losses in case of injection kicker failures. The yearly start-up is assumed to give a beam load of 20 % intensity over 24 hours (0.1 %; $1.08x10^{18}$ p+ p.a.) The load due to the few injection kicker failures per year will be negligible.

H^- injection

A charge-exchange H- system will be used to inject at 4 GeV [2]. The stripping efficiency of a 500 µg/cm^2 foil is about 95 % giving ~2 kW of unstripped H^0/H^- to be extracted and dumped. During nominal operation about $1.5x10^{14}$ H^- ions will be injected per cycle. A total of $5.4x10^{19}$ particles are then dumped p.a. Start-up will cause an additional beam load over the first 10 days, estimated at 30 % of the produced beam, or 0.75 % of the yearly production ($8.1x10^{18}$ ions p.a.). Around 20 interventions due to foil exchanges are expected per year, causing an additional load at lower intensity (20 %) onto the injection dump for about 2 hours, giving 0.16 % or about $1.8x10^{18}$ particles p.a. The beam load for the H^- dump is therefore 5.92 % of the annual production ($6.4x10^{19}$ p+ at 4 GeV).

Emergency beam abort

An emergency abort system is needed to safely dispose the 1.2 MJ of beam energy in case of equipment failures. It is assumed that 0.5 % of all cycles are aborted. This corresponds to about $5x10^3$ emergency aborts p.a., or $5.4x10^{18}$ dumped particles. Half of this beam ($2.7x10^{18}$) is assumed to be dumped below 20 GeV. An external dump would require a fast extraction channel, but the aperture must be large enough to accept the beam at injection energy. An internal dump is easier to implement, cheaper and more compact but potentially generates more problems in terms of radiological protection due to local activation.

Machine setting up

Six days of setting-up (two for each beam) with an average of 20 % of full intensity gives a total of 0.6 % ($6.5x10^{18}$ p+) p.a. This must be sent to an internal dump at low energy and until the ramp and extraction is commissioned; at high energy an external or transfer line dump could be used. 50 % of the load is assumed to be below 20 GeV.

Setting up of the extraction transfer lines

A dump will be required for the extraction transfer line, to set up the line and stop the beam from the PS2. Safety beam stoppers will again be required. The annual load will be 0.3 % or $3.25x10^{18}$ particles at 50 GeV (assuming 2 days a year at 30 % intensity on average).

Machine development (MD)

MD sessions will cause additional beam loads on a beam dump, which again may be internal or external. It is supposed that an average of 100 MD hours (with 20 % of full intensity) will cause 4.3×10^{18} dumped particles or 0.4 % of the yearly production. The beam load is assumed to be 50 % at 4-20 GeV and 50 % at 20-50 GeV.

Particles remaining after slow extraction

Some particles remain in the machine at the end of each slow extraction cycle and must be dumped. A transfer line dump is difficult as the line will be needed for the slow extracted beam. It is assumed that 1 % remains and that slow extraction is used for 50 % of the time, giving a total of 3.6×10^{18} p+ or 0.33 % of the production at 50 GeV.

DUMP CONCEPTS

Where possible, within operational boundary conditions, the functionalities were then combined into dump devices. The figures are summarised in Table 2 together with the possible beam destinations. Some combinations of dump configurations are defined, and the expected loads are calculated. Some cases are complicated – to dump the remaining slow extracted beam on an external beam line dump would require a fast switch magnet system in the transfer line, which raises issues of machine safety to avoid sending beams to the wrong destination

Due to the very high beam load the H^- injection requires an external beam line dump, necessitating an extraction septum and a large acceptance beam line. The injection systems would also require a dedicated transfer line dump and an injection dump, as in the SPS.

For setting up and MD a dedicated external dump or transfer line dump may only be feasible above a certain energy due to limited acceptance of the extraction channel [1]. In the preferred scenario the PS2 would contain an internal emergency dump (as used in the SPS) which would work from 4 to 50 GeV for emergency aborts, for 'cleaning' the machine after slow extraction and MD beams below 20 GeV. A separate beam line-type dump (as used in the PS) would be used for machine setting-up at high energy and for MD above 20 GeV.

The resulting loads are shown in Table 3. It is assumed that no external movable dump is needed for the SPS injection line, as it should be possible to use either the beam line dump or the existing SPS dump.

Table 2: Dump functionalities, calculated beam loads and possible dump locations

Function	E [GeV]	Load [p+]	% of total	Possible beam destinations					
				Int. or ext. emerg. dump	Ext. beam line or TL-dump	Inj. transfer line dump	Int. fast inj. dump	Int. or ext. H- dump	Int. or ext. emerg. dump
Emergency abort	20-50	2.7×10^{18}	0.25	X					
Machine development	20-50	2.2×10^{18}	0.2	X	X				
Machine setting up	20-50	3.3×10^{18}	0.3	X	X				
Extr. line setting up	50	3.3×10^{18}	0.3		X				
Slow extraction	50	3.6×10^{18}	0.33	X	X				
Inje. line setting up	4	3.1×10^{18}	0.28			X			
Fast inj. setting up	4	1.1×10^{18}	0.1				X		
H^- injection losses	4	6.4×10^{19}	5.92					X	
Emergency abort	20-50	2.7×10^{18}	0.25						X
Machine development	20-50	2.2×10^{18}	0.2						X
Machine setting up	20-50	3.3×10^{18}	0.3						X

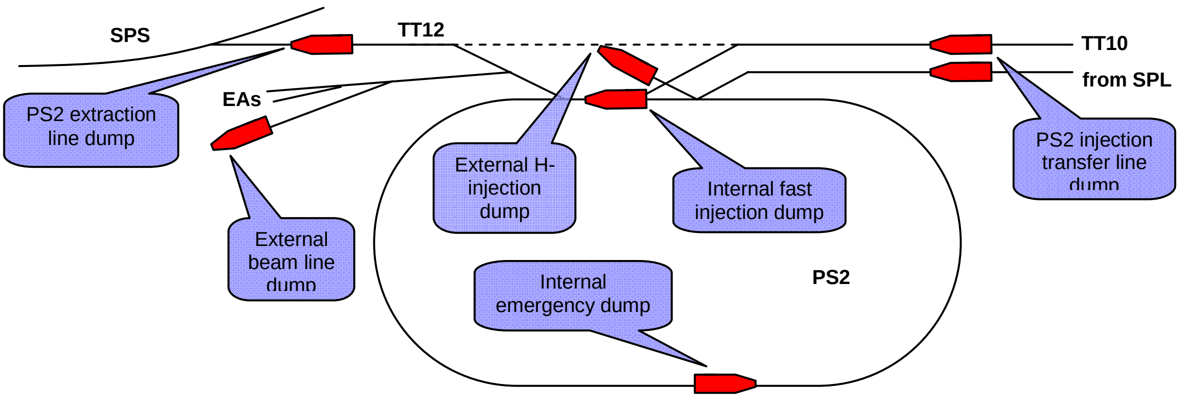

Figure 1: Schematic overview of the proposed PS2 dump concepts.

Table 3: Proposed dumps and their beam loads

PS2 dumps	**Beam loads [p+ /y]**			
	4 GeV	4-20	20-50	50 GeV
TL (injection)	3.1E18	-	-	-
Fast inj. (I)	1.1E18	-	-	-
H- inj. (E)	6.4E19	-	-	-
Emergency (I)	-	8.2E18	2.7E18	-
Beamline (E)	-	-	5.5E18	6.9E18

RESIDUAL DOSE RATE ISSUES

With the load information derived above a preliminary study using FLUKA [2] was made to get information about the order of magnitude of residual activation to be expected for the various dumps. This study was based on activation calculations made for an SPS-type beam stopper (TED), Fig. 2, which is in widespread use in the SPS beam extraction lines to the CNGS/LHC, and also as the basis for the SPS internal beam dump.

Although this type of dump is often used, it is not the ideal choice to minimize the production of residual dose rate, since the design can further be optimized to reduce the residual activation. However well-tested simulations and benchmarks exist, which provide a good basis for a first comparison.

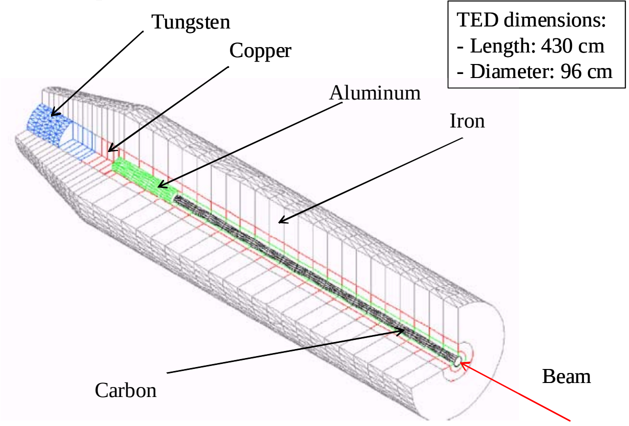

Figure 2. Geometry of SPS dump used for simulation.

The simulations assumed 10 years of operation, each of 200 days of beam operation and 165 days of shutdown. Residual contact dose rates were calculated for 5 different cool down periods after the last 200 days of irradiation. Note that the dose rate at 1 m distance (perpendicular to the TED axis) is approximately a factor three below the indicated values.

The results are shown in Fig. 3, along with the measured values from the SPS internal beam dump. It can be seen that the radiation levels in the surroundings of the external beam dumps and the internal emergency dumps are higher than those seen around the SPS beam dump, while operation of the two other internal dumps will cause lower dose rates than seen around the SPS dumps.

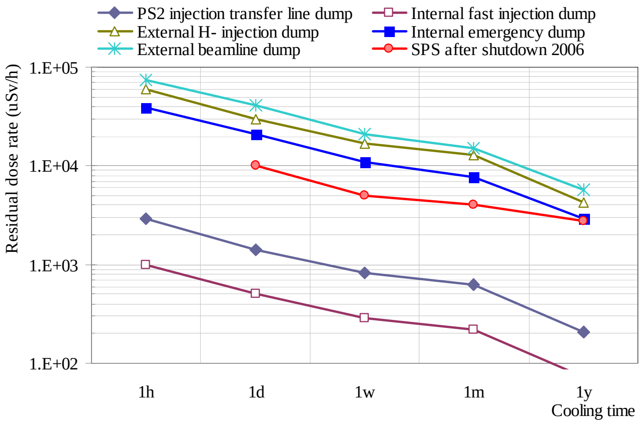

Figure 3. Results for preliminary residual dose rate calculations for PS2 beam dumps, assuming an SPS-type TED geometry. The SPS value for a cool down of 1 year was measured during the long shut down in 2004/2005.

CONCLUSIONS

Beam loads for the PS2 and its transfer lines were estimated and beam dump concepts developed, to have a first look at the potential radiological impact. The results confirm that the H- dump will have to be an external system, with an extraction septum and a large acceptance beam line. An internal emergency dump is also required but must only be used for beam which can not be extracted to an external dump, located in a well shielded area. This scenario is preferred since it presents fewer difficulties for the beam dump system design while optimising the loss locations, and simplifies operation.

The systems finally proposed are: 1) an external movable transfer line dump for PS2 injection line setting-up, 2) an internal dump block for fast-injection setting-up and errors, 3) an external H^- dump system, 4) an internal 4-50 GeV dump system for emergency aborts, low-energy setting-up and low energy MDs, and 5) an external beam line dump (20-50 GeV) for all other beams.

The activation analysis confirms that significant efforts have to be put into the design of dumps and their surroundings. External dumps must be designed with a larger graphite core surrounded by heavy shielding, since the TED-like beam dump design is not adequate. The design of internal beam dumps needs to be optimized in terms of reduction of residual radiation (e.g. using marble layers), or by considering bypass tunnels or larger tunnel sections allowing to place shielding between the dumps and the passage.

REFERENCES

[1] B. Goddard et.al., “PS2 Beam Transfer Systems: Conceptual Design Considerations“, AB-Note-2007-001-BT, Geneva, January 2007.

[2] A.Fassò et al., “The FLUKA code: description and benchmarking”, AIP Conf. Proc. 896 pp. 31-49, 2007.