PICS IN THE INJECTOR COMPLEX – WHAT ARE WE TALKING ABOUT?

K. Hanke, B. Goddard, B. Mikulec, S. Gilardoni, CERN, Geneva, Switzerland

Abstract

This presentation will identify PIC activities for the LHC injector chain, and point out borderline cases to pure consolidation and upgrade. The most important PIC items will be listed for each LIU project (PSB, PS, SPS) and categorized by a) the risk if not performed and b) the implications of doing them. This will in particular address the consequences on performance, schedule, reliability, commissioning time, operational complexity etc. The additional cost of PICs with regard to pure consolidation will be estimated and possible time lines for the implementation of the PICs will be discussed. In this context, it will be evaluated if the PICs can be implemented over several machine stops.

ASSUMPTIONS

We do not treat in this paper Linac4 and the modifications in the PSB required for the connection of Linac4. Ions will not be treated in this paper either; we refer to the session dedicated on ions.

DEFINITION OF PICS

In this section we will attempt a definition of Performance Improving Consolidation (PIC) items in comparison with pure Consolidation and Upgrade.

Consolidation refers to partial or complete replacement of a system to be performed in order to maintain the present level of performance/availability. Such a 25-year consolidation program was put in place at CERN before the LIU project was launched, and there are numerous items which need to be consolidated in order to ensure reliable operation of the LHC injectors throughout the life time of the LHC, regardless of upgrade scenarios. A typical example is the replacement of the PSB multipole power converters.

Pure upgrade refers to the replacement or addition of a system to improve the performance, which would otherwise not be necessary. Examples are the H^- injection equipment in the PSB, or the modifications of the PS injection for 2 GeV.

Performance improving consolidation (PIC) terms the replacement or upgrade of a system justified by consolidation but with the goal of improving performance. An example would be the change of an ageing PSB power supply by a new one which is more reliable and which can also operate at 2 GeV beam energy.

Using this definition of PICs, there is significant overlap both towards consolidation and upgrade. Items which fall in these grey areas will be highlighted in the following sections.

LIU-PSB

In the following sections we list the PIC items of the LIU-PSB project, we address the risks and give a cost and time estimate.

Magnets

While the modification of the main dipoles (improved water cooling, shimming, retaining plates) is only required for the 2 GeV upgrade and hence a pure upgrade item, some of the magnets in the injection line and in the transfer line to the PS can be considered PIC items. A number of quadrupoles in the BI line are pure consolidation items which need to be changed in all possible scenarios. The partial replacement of magnets in the transfer line to the PS is a combination of consolidation and upgrade and hence a PIC item. The risk of not doing the consolidation consists in magnet failure and unsatisfactory spare situation, in particular for BT.BHZ10. The risks associated with changing the magnets are related to the transport and handling. Presently there is no lifting equipment which can access and handle the heavy dipole magnets. A study is in progress to assess this issue.

RF Systems

The low-level RF of the PSB is at the same time obsolete and inappropriate for future operation with Linac4 and the new high-level RF system. Re-commissioning of the new system will be needed.

The renovation of the high-level RF system consists in replacing the C02 and C04 cavities by new Finemet cavities. The old system is obsolete and will not work with Linac4 intensities and 2 GeV. The new RF system can partially be tested before full installation (prototype cavities in ring 3), but since installation of all required cavities will require removal of the present system, a full test cannot be done beforehand. Further to that technical issues need still to be addressed, e.g. impedance.

Power Converters

The replacement of power converters in the injection line is purely related to Linac4 connection and hence not considered a PIC. However a number of power converters in the rings and notably in the extraction and transfer line can be considered PIC items. Also the main power supply (MPS) can be considered a PIC item, since partial consolidation of the existing MPS would be necessary if it was to continue operation. In particular consolidation of the static VAR compensators (SVC) had been budgeted before the energy upgrade was discussed. Obviously the consolidation part of the budget is small w.r.t. the overall cost of a new MPS (3 MCHF compared to a total of 15 MCHF, see section *Cost*).

Beam Instrumentation

Beam instrumentation is also widely a PIC item, since consolidation needs and increased requirements in the frame of the upgrade project are almost inseparable. Main items are the new wire scanners, the new orbit system and replacement/increased number of BLMs. The shortcomings of the present systems are the insufficient transverse emittance diagnostics (improved precision needed for future high brightness LHC beams) and insufficient BLM coverage for operation with Linac4. As any new development the new systems need to be commissioned and tested, where possible before Linac4 connection. The main risk is that this will not be fully possible, which can impact the commissioning time after LS2.

PSB Dump

While the injection dumps are only required for Linac4, and therefore a pure upgrade item, the main dump of the PSB can be considered a PIC. The old dump was in place since the construction of the Booster, and is inappropriate for the intensities expected with Linac4 and 2 GeV beam energy. The dump was replaced by a new one during LS1, this item is therefore completed. There is no risk identified for the operation with the new dump.

Extraction and Transfer

There are reliability and spare issues with some of the extraction and transfer line equipment. This will be addressed at the same time as doing the upgrade to 2 GeV beam energy. The new systems will need to be commissioned, and potential issues with the rise time of the extraction kickers are being addressed.

Cooling and Ventilation

The present system is obsolete and a complete renovation is planned, taking into account the new requirements of an upgraded Booster. This comprises cooling for the new MPS, the new dump, and increased cooling of the main magnets. The CV system is also closely related to RP issues (evacuation of irradiated air). The renovation of the cooling and ventilation system is a potential time driver for LS2.

Transport and Handling Equipment

The entire transport and handling equipment must be renovated in order for it to be ready for the upgrade work planned in the PSB. If the renovation is not done, delays are to be expected for LS2. Studies are needed for removal/installation of the new dump (completed), and for the lifting of some equipment e.g. the large bending magnets in the BTM and BT line. In particular for these dipole magnets presently no handling equipment exists, and studies are underway.

Cost

Table 1 shows the cost overview of the beforehand mentioned LIU-PSB PIC items.

Table 1: Cost of LIU-PSB PIC items

PIC	**Cost [kCHF]**
Magnets	2696
LL RF	1566
HL RF	11732
Power Converters	18451
Beam Instrumentation	2954
Dump	460
Extraction and Transfer	3515
Cooling and Ventilation	6994
Transport and Handling	644 t.b.c.
Total	49012

It is interesting to note that the total cost of PIC items equals approximately the budget of LIU-PSB without the Linac4 related items (total budget 60.8 MCHF). In other words almost all items addressed in the frame of LIU-PSB can be considered PICs. The weighting of what fraction of these items can be associated to consolidation, and which fraction is associated to performance improvement has been done based on the budget figures. The result is that 50% of the total cost can be considered the consolidation part, and the remaining 50% is related to performance improvement. This result is in agreement with the budget estimate performed in the frame of the feasibility study [1], where a total cost of 53502 kCHF was estimated with 27320 kCHF already budgeted in the existing CONS project and 26182 kCHF to be added for the 2 GeV upgrade. The modifications related to the connection of Linac4 were not included at the time.

Time Lines and Increments

In this section we attempt to estimate the time needed to implement the PICs. The implementation of PIC items is constrained by the LHC shutdowns. It is therefore important to assess whether the time needed to implement a given item is needed as a single block, or whether it can be broken up and distributed over several shutdowns. Wherever that is the case, intermediate, shorter shutdowns could be used to advance work and release some pressure from LS2. In Table 2 we summarise the total duration needed to implement each item, the possibility to break up the activity, the minimum single block needed and the earliest start date.

Table 2: Time lines for PSB PIC items

PIC	total duration [m]	split (y/n)	minimum single block [m]	earliest start date
Magnets	4-5	y	3	partly before LS2
LL RF	7	n	7	LS2 digital RF control compl.
HL RF	10.5	n	10.5	LS2
Power Converters	MPS: 1/8.5/2 TL: 12	n	12	LS2
Beam Instr.	9	y	3.5	LS1
Dump	compl.	n		compl.
Extraction and Transfer	7	n	7	LS2
Cooling and Ventilation	7 exclusive +12	n	7/12	LS2
Transport and Handling		y		LS1

The largest time increments are needed by Cooling/Ventilation, Power Converters and RF. The time estimate for CV assumes that the present cooling equipment is dismantled and the new equipment is installed in the same location. As a consequence, during an estimated duration of seven months, no cooling would be available. Therefore presently plans are being worked out to include the CV equipment in the building for the new MPS, which would allow installation while the old system is still operational. The time estimate for the commissioning of the new MPS is composed of one month installation work, 8.5 months of commissioning in the new building (parallel to other work) and two months of final commissioning. The overall duration cannot simply be derived from Table 2. It is not driven by a single intervention, but by the combination of CV, cabling and RF work.

LIU-PS

In the following sections we list the PIC items of the LIU-PS project, we address the risks and give a cost and time estimate.

Magnets

In the frame of the energy upgrade new low-energy correctors are needed. This concerns vertical steerers, quadrupoles and skew quadrupoles. The magnets are considered PIC items. In particular the skew quadrupoles suffer from low reliability due to large thermal heating. The new magnets will need to be recommissioned.

RF Systems

The low-level RF renovation consists in an upgrade of the transverse feed-back amplifiers, in new 1-turn delay feedbacks for the 10, 40 and 80 MHz systems and in a new digital beam control.

On the high-level RF side the renovation of the 10 MHz system is planned. The limitations of the present RF system result in insufficient longitudinal beam stability and degradation of the beam quality. Recommissioning of the new hardware is the only risk identified.

Power Converters

The power converters of the low-energy quadrupoles are planned to be renovated, as well as the ones of the orbit correctors and skew quadrupoles. The same type will be used for newly installed skew sextupoles. Another item is the power amplifiers of the 40/80 MHz RF systems. The present system needs to be consolidated as the number of failures due to large RMS current and old thermal protections is increasing. The new power converters will require recommissioning.

Beam Instrumentation

Items to be renovated are the wire scanners and the BLMs. The present wire scanners are inappropriate for the emittance diagnostics of future high brightness beams. The BLM system is obsolete and a longstanding consolidation item. The new systems will need to be recommissioned.

PS Dumps

The internal dumps of the PS will be exchanged, as the present mechanics is prone to vacuum leaks. Furthermore the precision with which it acts on the trigger is insufficient. The new dumps will need to be recommissioned.

Transverse Damper

The transverse damper of the PS needs new power amplifiers in order to function up to specifications, and eventually a second kicker to separate the function for the two transverse planes. The present system is limited in DC power and bandwidth. No risk has been identified for the new system.

Longitudinal Damper

It is planned to install a Finemet cavity to damp longitudinal and coupled-bunch instabilities. Presently the bunch intensity is limited and incompatible with the HL-LHC parameters. No risk has been identified for the new system.

Radiation Shielding

It is planned to increase shielding on top of extraction septum in straight section 16 and above the route Goward. The situation is already at present not conforming to radiation protection standards. No risk has been identified for the new installation.

Cost

Table 3 shows the cost overview of the beforehand mentioned LIU-PS PIC items.

Table 3: Cost of LIU-PS PIC items

PIC	**Cost [kCHF]**
Magnets	1000
LL RF	900
HL RF	4200
Power Converters	3065
Beam Instrumentation	1062
Dumps	850
Transv. Damper	350
Long. Damper	1500
Rad. Shielding	3150
Total	16077

The cost drivers of the project are the RF and Power supplies. Radiation shielding is a cost driver as well, but it may be considered a 100% consolidation item. The overall split between what is pure consolidation and what is performance improvement is more difficult than in the case of LIU-PSB. An approach based on weighting yields approximately 40% consolidation and 60% for the performance part.

Time Lines and Increments

Table 4 summarises the time needed to implement the PICs as far as they are known.

Table 4: Time lines for PS PIC items

PIC	**total duration [m]**	**split (y/n)**	**minimum single block [m]**	**earliest start date**
Magnets	12	y		LS2
LL RF	parallel	y		LS2
HL RF	3	n		LS2
Power Converters	3	n	3	end 2015
Beam Instr.	5	y	1	LS2
Dumps	1	y	0.5	LS2
Transv. Damper	not critical	n		ongoing
Long. Damper				completed
Rad. Shielding				completed

Not all time lines for the PS PIC items are fully defined, but none of them is a time driver. As we will see in the summary, the intervention times are entirely driven by the PSB.

LIU-SPS

In the following sections we list the PIC items of the LIU-SPS project, we address the risks and give a cost and time estimate.

800 MHz Upgrade

The upgrade of the 800 MHz RF system consists in the replacement of the analogue control with a digital one, in a new 1-turn feedback and feed-forward (essential for beam control) in the low level and in the consolidation of the existing power system and the doubling of the available power (needed to match the 200 MHz upgrade). The shortcomings of the present 800 MHz system result in beam instabilities at higher intensity. The voltage is considered insufficient, there is a reliability risk and extra resources are needed to keep obsolete low-level running. The risk of implementing the upgrade lies in the readiness for operation end 2014.

200 MHz Low-level Improvement

The upgrade of the 200 MHz RF system is considered a pure upgrade item, while the improvement of the low-level is a PIC. The present 200 MHz RF system causes extra cost, resources and reliability risk to keep the obsolete systems running. The beam control is performing insufficiently. No risk has been identified for the case that the PIC is implemented.

Beam Instrumentation

Items to be consolidated are the replacement of the obsolete MOPOS electronics and adding a new fibre backbone, the replacement of obsolete BLM electronics using MOPOS fibres, the replacement of the existing wire scanners with new devices and the improvement of the BGI, BSRT, IMM and Head-Tail monitors. The existing systems cause extra cost, resources and reliability risk to keep obsolete systems running. There is presently no reliable transverse beam size measurement, the resolution is insufficient and there is no bunch-by-bunch capability for LHC beams. While no risk has been identified for MOPOS and BLM (deployment in parallel with existing system), HOM heating could be an issue for the new wire scanners.

Dumps

The TIDVG core needs to be replaced with an improved version in order to make it robust against present and future LHC beams. If not done, there is potential damage to the TIDVG for repeated dumping of intense/bright LHC beams. This would result in long (months) recovery in order to condition it with beam. Upgrading the dump will also require a long beam conditioning time.

Scrapers

Construction of additional spares and improvements to local shielding are planned. The present system suffers from insufficient spares, and a breakdown could cause reduced LHC performance (unable to clean transverse tails in SPS). No risk has been identified in case the improvements are done.

ZS Improvement

In order to consolidate the electrostatic septum ZS it is planned to improve the pumping, to reduce the impedance, to improve the ion trap connections and to short-circuit the anodes. The present ZS suffers from sparking, it imposes limitations on other beams and requires longer switch to an LHC cycle. No risk has been identified for the case that the renovation is done.

Kicker Impedance Reduction

The addition of transition pieces in the MKD kickers and a serigraphy of the MKQ kickers are planned. Presently the intensity is limited with high duty cycle beams. This imposes also a limitation on the scrubbing beam time. No risk has been identified for the case that the renovation is done.

Transverse Damper Improvement

The planned renovation of the transverse damper consists in the improvement of the low-level control, in the addition of dedicated pickups and in the consolidation of damper cables. The present system features extra cost and resources to keep obsolete systems running and represents a reliability risk. Furthermore it is not able to properly damp Pb ion beams. No risk has been identified for the case that the renovation is done.

Machine Interlocks (WIC)

It is planned to replace the obsolete electromechanical relays with a PLC solution compatible with the other SPS TL and CERN systems. The aim of the renovation is better reliability and easier maintenance, as well as standard supervision and diagnostics. If not done there is a possible reliability issue, extra maintenance costs, and need for extra resources for keeping obsolete system operational. No risk has been identified for the case that the renovation is done.

LSS1 Vacuum Sectorisation

It is planned to add sector valves around the TIDVG and MKP/D in order to reduce the personnel dose, to protect sensitive equipment and to reduce the pump-down time. Present risks are venting and damage to sensitive or very radioactive equipment, and an increased radiation dose to personnel. No risk has been identified for the case that the renovation is done.

Arc Vacuum Sectorisation

The aim is to reduce the length of the arc sectors by a factor of 2 in order to reduce pumping times. This would also improve the protection against loss of electron cloud scrubbing. If not done the scrubbing times for electron cloud mitigation are longer. No risk has been identified for the case that the renovation is done.

Cost

Table 5 shows the cost overview of the beforehand mentioned LIU-SPS PIC items.

Table 3: Cost of LIU-SPS PIC items (on LIU budget)

PIC	**Cost [kCHF]**
800 MHz Upgrade	
200 MHz Low Level Consolidation	3700
Beam Instrumentation	5600
Dumps	2900
Scrapers	200
ZS Improvement	1000
Kicker Impedance Reduction	4100
Transv. Damper Improvement	1300
Machine Interlocks (WIC)	600
LSS1 Vacuum Sectorisation	800
Arc Vacuum Sectorisation	2500
Total	22700

A tentative split up in “consolidation” and “performance” part of the PIC items has been done on a basis of weighting (not on pure budget figures as in the case of LIU-PSB) and interestingly yields a ratio of 50%/50%.

Time Lines and Increments

Table 6 summarises the time needed to implement the SPS PICs as far as they are known.

Table 6: Time lines for SPS PIC items

PIC	**total duration [m]**	**split (y/n)**	**minimum single block [m]**	**earliest start date**

800 MHz Upgrade	12	n/a	n/a	Completed in LS1
200 MHz Low Level Cons.	6	y	3	2016/17
Beam Instr.	24	y	3	LS1
Dumps	3	n	3	LS2
Scrapers	0			
ZS Impr.	3	y	2	2015/16
Kicker Impedance Reduction	3	y	2	2015/16
Transv. Damper Improvement	9	y	6	Completed in LS1
Machine Interlocks (WIC)	6	n/a	n/a	Completed in LS1
LSS1 Vacuum Sectorisation	6	n/a	n/a	Completed in LS1
Arc Vacuum Sectorisation	6	y	3	2015/16

As compared to Table 2, it becomes apparent that none of the interventions is exceeding in length the ones imposed by the PSB upgrade.

CONCLUSION

The classification of what is considered a PIC item is often ambiguous, and there are many borderline cases. The same is true for the accounting of what the "performance improvement" part and what the "consolidation" part in a PIC item is. However it is interesting to notice that a 50%/50% split seems to be the average across all machines. It has to be said that this split has been calculated strictly based on the budget figures for the PSB, but it has been estimated for PS and SPS. This estimate tries to weight what the performance and what the consolidation part in each item is, which is not necessarily reflected in the budget figures of the LIU-PS and LIU-SPS projects.

The time lines to implement the PIC items have been analysed with the goal of determining the minimum shutdown length needed for their implementation. The LIU-PSB project includes the time drivers with a minimum shutdown increment of 12 months, determined by CV, Power and RF in combination with the related cabling. The time estimates of PS and SPS are fully in the shadow of the PSB interventions. All time estimates depend strongly on available resources (manpower).

The cost of the PIC items can be summarised as

- LIU-PSB: 50'000 (total budget 60.8 MCHF)
- LIU-PS: 16'000 (total budget 20 MCHF baseline, including all options 32 MCHF)
- LIU-SPS: 23'000 (total budget 77 MCHF)

This corresponds to almost the entire budget of LIU-PSB (without the Linac4 related items), for the PS it corresponds to 80% and for the SPS to 30% of the respective total budgets.

Several items (e.g. beam instrumentation) need to be done in all possible scenarios in order not to compromise performance over the coming years.

REFERENCES

[1] K. Hanke et al, "PS Booster Energy Upgrade Feasibility Study", CERN EDMS 1082646 v.3 (2010).