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CPS HIGH INTENSITY RUNNING

IMPLICATION ON MAGNET IRRADIATION AND RADIOACTIVITY

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This note is a summary and a synthesis of the informations contained in four previous reports (1,2,3,4) on statistics and previsions of irradiation and radioactivity of the CPS magnet.

1. CPS Operation Programme

Presently the CPS, using actual Linac as 50 MeV injector, accelerates generally $2 \cdot 10^{12}$ p every 2 to 2.4 s depending upon the flat top length used. In some special runs, using the PSB as injector, $5 \cdot 10^{12}$ p/p have been reached. The injection system is designed for a future accelerated intensity of 10^{13} p/p.

Since no definite long term programme exists until now, we use here the same assumptions as in (4) and consider the following variants of operation :

Acceler. protons for 25 GeV physics	Allocation to internal targets # 1 # 8		
	no int. target	$5\cdot10^{11}$p/p on int. target	10^{12} p/p on int. target
A=$5\cdot10^{12}$p/p accel. f. phys.	A_o	A_1 (10%)	A_2 (20%)
B=10^{13}p/p acceler. f. phys. after 1976	B_o	B_1 (5%)	B_2 (10%)

TABLE 1

The case A_1 is assumed to last up to end 1975. The other proton uses are summarized below :

Year (end)	1973	1974 to 1977	1978 to 1983
Σ proton/year (NP)	$1.4\cdot10^{19}$	A=$3.5\cdot10^{9}$;B=$7\cdot10^{19}$after 76	A=$2.8\cdot10^{19}$;B=$5.6\cdot10^{19}$
Cycles/year (25 GeV/c)	$7\cdot10^{6}$	$7\cdot10^{6}$	$5.6 \cdot 10^{6}$
I p/p average	$2\cdot10^{12}$	A=$5\cdot10^{12}$;B=10^{13} after 76	A=5.10^{12},B=10^{13}
Internal targets	25% ($5\cdot10^{11}$p/p)	A_1 = 10% B_1 = 5% A_2 = 20% B_2 = 10%	A_1= 10% B_1 = 5% A_2= 20% B_2 = 10%
Slow ejections	50%	A_1 = 65% B_1 = 70% A_2 = 55% B_2 = 65%	A_1= 75% B_1 = 80% A_2= 65% B_2 = 75%
Fast ejections	25%	25%	15%
Dump (internal, non protected)	5%	5%	3% (?)
SPS injection 10 GeV/c	0	0	10^{13}p/p=$2.8\cdot10^{19}$/year

TABLE 2

(We ~~have~~ neglected the starting up transitory period of SPS in 1977)

2. Magnet Irradiation

2.1 Radiation Damages

The PS magnet blocks are made of steel sheets glued together with araldite. This epoxy resin is destroyed by radiation and the front steel sheets get loose, breaking the araldite pole face windings already weakened by radiation.

Looking at past experiences we have estimated the reliability f of the original magnet unit as $f = 1 - p$, where p is the breakdown probability. We consider the radiation dose R (in rad) absorbed by the iron at the entrance of the first block 5 cm below beam axis. This location will always be used as a reference point because it is the most exposed and the weakest region. We could now consider that

$$f \simeq - 0.83 \log (R/8 \cdot 10^8)$$

which means that there is no old unit in good condition for doses above $8 \cdot 10^8$ rad and that the f reliability starts to decrease somewhere between 3 and $5 \cdot 10^7$ rad.

Furthermore, we could expect, though we have not yet any precise information about it, that the main coils could support more than 10^9 rad where they are; this dose corresponds to $\simeq 5 \cdot 10^9$ rad at the reference point because there is a factor 4 between the maximum dose on the coil closest to the beam and the reference point dose.

In order to improve the resistance of the PS magnet units, four possible actions have been envisaged by the "CPS Magnet Working Group" (5) :

a) Circling the two extreme steel blocks with insulated bars in order to refrain the sheets from getting loose.

b) Installing more radio resistant pole face windings (so-called BBC - PFW).

c) Changing the two extreme blocks by new blocks glued with a more radio resistant araldite (so-called Siemens block).

d) Exchanging damaged main coils.

Operation c) is limited to a few units because the quantity of these Siemens blocks is limited due to the short stock of magnetic steel. Operation b) could be coupled with a complete exchange of pole face windings for a more powerful type. Operation a) requires some PS shut down periods.

The reliability limit could probably be pushed up to $5 \cdot 10^9$ rad by operation a) and b), but operation a) alone, leaving the old ACEC pole face windings on could probably not push the limit above 2 to $3 \cdot 10^9$ rad. This is just a guess based upon values given by manufacturers.

2.2 Contribution from Operation to Magnet Irradiation

We call TIR (Total Irradiation of the Ring) the sum of the 100 doses measured at the reference point. Below we find the total contribution of an operation to TIR, including all the corresponding losses integrated around the PS ring. More details about specific straight sections and measurement can be found in (2).

a) Internal targets : $3.5 \cdot 10^{-10}$ rad per allocated proton

b) Slow ejections :

    with no internal target $2.12 \cdot 10^{-11}$ rad/alloc. proton
    cases A_1 and B_1 $3.18 \cdot 10^{-11}$ " " "
    cases A_2 and B_2 $4.24 \cdot 10^{-11}$ " " "

c) Fast ejections : $3.4 \cdot 10^{-11}$ rad/alloc. proton

d) All remainders at 25 GeV/c (dumps, injection, slow ejection tails, various losses, miscellaneous etc...) : 4 to 5, then 3 to $4 \cdot 10^{-11}$ rad per accelerated proton. The reason of this uncertainty comes from the fact that we do not know exactly how much of the "various and miscellaneous losses" are finally created by target operation. In spite of the dose measurements it is difficult to separate accurately the losses created by target, and an uncertainty of 10 to 20% still remains. For our previsions we took an average.

e) All at 10 GeV/c (injection, acceleration, ejection towards SPS) : $1.7 \cdot 10^{-11}$ rad/accelerated proton.

From this list we see that internal target operation generates at least 10 times more doses than any other operation.

2.3 Dose Distribution Among Units

The histogramme of the dose distribution has its peak around $6 \cdot 10^{7}$ rad at the end of 1972, for 104 units (because 4 units had been changed at that time). It extends up to $1.4 \cdot 10^{9}$ rad. Only 20 magnet units had received more than $1.6 \cdot 10^{8}$ rad at that time and 4 more than $8 \cdot 10^{8}$ rad (the reliability limit).

The accumulated TIR on these 104 units since the PS start was $1.49 \cdot 10^{10}$ rad. This same TIR was at that time $1.07 \cdot 10^{10}$ rad for the 100 units present in the ring.

If we multiply each bin of the histogramme by its corresponding reliability, we find that the most probable amount of damaged units should be around 20, which corresponds to reality.

2.4 Prevision of Irradiation

Though it does not show the fate of individual units, the evolution of TIR could be taken as a description of eventual damages. The Table 3 shows the expected TIR for the proposed variants.

Accel. prot. at 25 GeV/c	Variants	up to end 1975	end 1977 (+ 2 years)	end 1983 (+ 6 years)
$5 \cdot 10^{12}$p/p	A_o= no inter. target after 1975	$2.0 \cdot 10^{10}$	$2.48 \cdot 10^{10}$	$4.03 \cdot 10^{10}$
	A_1= 10% on internal targets	$2.0 \cdot 10^{10}$	$2.76 \cdot 10^{10}$	$4.98 \cdot 10^{10}$
	A_2= 20% on internal targets	$2.0 \cdot 10^{10}$	$3.02 \cdot 10^{10}$	$5.89 \cdot 10^{10}$
10^{13}p/p	B_o= no inter. target after 1975	$2.0 \cdot 10^{10}$	$2.97 \cdot 10^{10}$	$5.49 \cdot 10^{10}$
	B_1= 5% on internal targets	$2.0 \cdot 10^{10}$	$3.23 \cdot 10^{10}$	$6.29 \cdot 10^{10}$
	B_2= 10% on internal targets	$2.0 \cdot 10^{10}$	$3.62 \cdot 10^{10}$	$7.76 \cdot 10^{10}$

TABLE 3 (TIR in rad)

To illustrate the damages, let us take a TIR around $5 \cdot 10^{10}$ rad end 1983 (variant A_1). The corresponding histogramme is peaked at $2 \cdot 10^8$ and extends up to $5 \cdot 10^9$ rad for the most exposed unit. Looking at the reliability of individual units we find that 60 units would have to be repaired. As 24 units will have been repaired after the January 1974 shut down, 36 units more would have to be repaired according to the following rhythm : 2.5/year in the first years, to reach 4/year after 1978 (approx.) And also a few sets of coils would have to be changed.

It is highly probable that all the repairs and all the pole face windings exchanges will be done on one or two long PS shut-downs. These points will be discussed in (5). Though the necessary money for such repairs and exchanges is not negligible, it appears that the most important problems lie in the time needed to do the job and in the corresponding radioactive dose received by the working staff.

A complete repair of the CPS with some coil exchanges could cost nearly 3 MSF, excluding any change or any improvement of the PFW system.

3. Magnet Radioactivity

3.1 Measurements

If this is not specially pointed out, the dose rates we talk about are measured at 40 cm from straight section vacuum chambers after 2 days cooling, as usually measured by the Health Physics Group. More details can be found in (3). This dose rate for straight section i is given by

$$D_i\ (T,t) = K_i \cdot I_i\ (p/s) \cdot \log\ (1 + \frac{T}{t}) \tag{1}$$

where T is the time of irradiation during which I proton/s have interacted on the source causing the irradiation at i. t is the cooling time (in days as T), and K_i is a constant to be specified.

3.2 Contribution to Radioactivity from Operation

As for TIR we consider TAR (Total Activity of the Ring, as already quoted by J.H.B. Madsen) as the sum of the 100 straight section dose rates at 40 cm. Below, we give the total contribution of an operation to TAR after 2 days cooling, including all the straight sections in correlation with the source considered (for details see (3)). The values quoted here are the K_i to be put in equ. 1.

a) Internal Targets : $9 \cdot 10^{-12}$ rem/h per allocated proton per second. We have assumed that a specific target could be used one monthly period over two. So the cooling time up to a PS shut-down oscillates between 30 and 2 days. We have taken account of this possibility by averaging the above value. But we must keep in mind that the shut-down remanent radioactivity level depends very much on the type of PS operation used just before this shut-down.

b) Slow Ejections :

With no internal target : $0.75 \cdot 10^{-12}$ rem/h per alloc. p. s^{-1}

Cases A_1 and B_1 : $0.96 \cdot 10^{-12}$ rem/h per alloc. p. s^{-1}
Cases A_2 and B_2 : $1.36 \cdot 10^{-12}$ " " " " "

c) Fast Ejections : $2 \cdot 10^{-12}$ rem/h per alloc. p. s^{-1}.

d) All the remainders at 25 GeV/c (dumps, injection, slow ejection tails, various and miscellaneous losses etc...) : $1.5 \cdot 10^{-12}$ rem/h per accelerated p. s^{-1}, then $1.3 \cdot 10^{-12}$. Here we have the same remark as in 2.2 d) about the difficulty of knowing the origins of the "miscellaneous losses".

e) All at 10 GeV/c (injection, acceleration, ejection towards SPS...), $8 \cdot 10^{-13}$ rem/h per accel. p. s^{-1}.

Again we find this factor 10 between the target and the other operations.

3.3 Previsions of Radioactivity

It could be interesting to follow the TAR evolution through time according to the proposed variants (the detailed activity distribution can be found in (3)).

Accel. prot. at 25 GeV/c	Variants	up to end 1975	end 1977 (+2 years)	end 1983 (+6 years)
$5 \cdot 10^{12}$ p/p	A_o = no intern. target after 1975	10.	8.1	7.7
	A_1 = 10% on internal targets	10.	10.7	9.8
	A_2 = 20% on internal targets	10.	13.4	12.1
10^{13} p/p	B_o = no intern. target after 1975	10.	13.7	13.3
	B_1 = 5% on internal targets	10.	16.3	15.9
	B_2 = 10% on internal targets	10.	19.5	19.1

TABLE 4 (TAR in rem/h, after 2 days cooling)

This TAR decreases on an average by a factor 0.7 ten days after the PS stop and on an average factor 0.5 after 30 days cooling. The above values could be used for a normal short shut-down, but they should be multiplied by 0.6 average for a long post christmas shut-down. So, considering variant A_1, one of the most probable, the long shut-down TAR could be around 6 rem/h.

For comparison, at the end of 1972 the TAR, after 2 days cooling, was 5.2 rem/h. So a factor 2 could be expected in the future.

3.4 Real Doses Received by Maintenance Staff

We have shown in (3) that the dose received by the personnel working h hours in region i is, on average

$$D = h \cdot \frac{1}{f_e} \cdot \frac{1}{f_p} \cdot \frac{1}{2} \cdot \log (1 + 200/t) \cdot D_i$$

where D_i is the dose rate per hour measured at i at 40 cm after 2 days cooling, t is the cooling time in days, f_e and f_p are respectively the "equipment reduction factor" and the "presence reduction factor". f_e is on average 2, when straight section and vacuum chamber have been taken away, but it could vary (see (3)). f_p varies from job to job and depends upon the place where the worker has to stand. It is between 1 and 5.

To these specific doses we should add a "general dose" received globally in the ring by any person and which is on average : TAR (rem/h after 2 days cooling) x $3.5 \cdot 10^{-3}$ rem per day in the ring for a person not doing any specifically located job. We could illustrate these formulae with two examples :

a) Vacuum Section: These last years, this section has done, per year, on average : 100 complete straight section dismantlings, 80 minor interventions on vacuum chambers plus some minor interventions in the inflection region. The time for dismounting and mounting a straight section, including vacuum tests, is on average 12 hours for 2 persons, with fp $\simeq 2.5$. Therefore, to do this job after 2 days cooling in a section where the dose rate is D_i at 40 cm, the worker will get a dose $D(\text{rem}) = \frac{12}{4.5} \cdot D_i(\text{rem/h}) = 2.66 \cdot D_i$.

If the 100 straight sections have to be changed in a long shut-down, a person participating in the whole job will receive TAR $\cdot \frac{12}{4.5} \cdot 0.5 \simeq 1.6$ TAR, or 16 rem if TAR = 10. To this one should add the general dose for perhaps 30 days of global presence in the ring, which is, in this case, 0.5 rem per person.

This means that this job should be shared by 8 teams of two persons each because we admit that in one shut-down a worker should not receive more than 2 rem. The same job done at the end of 1972 would have required half these people, because the TAR averaged over a long shut-down was only 3.1 rem/h.

b) <u>Magnet Section :</u> To repair a magnet unit upstream and downstream with PFW exchange, requires 9 hours with fp $\simeq 2$ and fe $\simeq 2$. So the dose received by the staff operating in a region where the measured reference dose is Di, is after two days cooling :

$$D(\text{rem}) = \frac{9}{4} \cdot Di = 2.25\ Di\ (\text{rem/h}).$$

If the unit has to be displaced, one should add a dose

$$D(\text{rem}) = 1.33\ (\text{or } 1.83)\ Di\ (\text{rem/h}).$$

The figure in bracket corresponds to the case where a bus bar should also be displaced.

Therefore, in order to repair 100 units (the whole ring), in one long shut-down, a man participating in the whole job will receive TAR $\cdot$ 2.85 $\cdot$ 0.6 = 1.7 TAR, or 17 rem if TAR = 10. Taking into account the general dose of 0.5 rem, here too we see the necessity to share this dose between 9 teams. The same job done at the end of 1972 would have required half these people, as already mentioned.

Doing this computation we should keep in mind that 40% of the units contribute to 86% of all the radioactivity. This means that 60% of the repairs described above can be done with only 14% of the calculated dose. Furthermore 15% of the units contribute to 60% of the whole ring dose. We could consequently expect that work on the, let us say, ten most exposed units could be done with an increased care and a precisely detailed preparation. A reduction by 15% of the total dose described above could then be expected, and consequently the 2 rem limit for the two jobs described above should not be overpassed by too much. We can therefore conclude that maintenance jobs could be done in future, but only if one envisages some drastic solutions as :

a) More or less doubling.the presently most exposed staff $\simeq$ 15 people), or

b) Hiring extra staff for special non repetitive work, or

c) Reducing the quantity of "interventions" in the ring, or

d) Diminishing the time in the ring (equipment improvement and rigid discipline), or

e) Planning the CPS operations according to the work to be done in order to get a sufficient cooling in the most active region before a planned "intervention", etc...

4. Conclusions

It seems that, as far as the main magnet is concerned, there is no apparent irreducible risk in running the PS at high intensity. A magnet could eventually be repaired, equipment be changed, maintenance be done*). But one should be ready to face :

a) higher expenditures for new radio resistant material

b) an adequate maintenance organization, in order to avoid hiring of extra staff for radioactive maintenance. such as:

c) lengthening of PS shut-downs and slight constraints in the planning of the PS use for physics in order to facilitate maintenance.

References

1. Irradiation of CERN PS Magnet Steel Blocks; R. Gouiran; MPS/MU-Note/EP 72-14

2. Taux d'Irradiation des Unités de l'Aimant. Statistiques et Prévisions; R. Gouiran; MPS/MU-Note/EP 72-15 Rev.

3. La Radioactivité de l'Aimant du CPS et son Influence sur la Maintenance de l'Anneau. Statistiques et Prévisions; R. Gouiran; CERN/MPS/SR 73-5

4. Report of the Working Group on the Implication of the Future Use of Internal Targets; R. Gouiran, L. Hoffmann (Chairman), W. Kubischta, Ch. Steinbach; MPS/MU/LH/gm, 29 August 1973

5. CPS Magnet Working Group. Report to be issued.

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* These are preliminary conclusions. The exact policy will be described in (5).