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THE PS AS A PHYSICS TOOL AND AS AN INJECTOR

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1. INTRODUCTION

There are at present four experimental areas serving "25 GeV physics" which are supplied with primary and secondary beams directly from the CPS. High energy protons are also delivered to the Intersecting Storage Rings (ISR), in which there are six colliding-beam experimental zones. From 1976, the CPS will also act as injector to the 400 GeV SPS, currently under construction nearby. The problems involved in supplying the various different users with beams of adequate quality, intensity, and stability, and the techniques developed to resolve most of them, are briefly discussed in this paper.

2. "25 GeV PHYSICS" AT THE CPS

With the completion of the Booster Synchrotron (PSB)[1], the CPS can now provide higher intensities (up to 6×10^{12} protons per pulse at the time of writing). The PSB accelerates from 50 MeV to 800 MeV, and the prebunched beam is injected into the CPS during a single revolution. After further acceleration, the protons are distributed between several experiments running simultaneously, using fast and slow extraction and internal targets. Different values of momentum can be supplied to individual users within the same cycle; the usual range is between 19 and 26 GeV/c - hence the term "25 GeV physics". Fast extraction[2] of one or more of the twenty circulating bunches is used for the bubble chambers (at present, three are operational at CERN); slow extraction is shared with an internal target[2,3] for the other experiments. An example of a typical cycle in current use is shown in Figure 2.

The performance achieved up to the present is summarized in

Table 1. Improvements under way should bring these figures closer to the values aimed at. Characteristics of the extracted primary beams are also shown in Table 1. A spill-time of 400 ms is usual for slow ejection, and this can be increased if the number of successive beam-consuming operations in the cycle is reduced. New models of extraction (septum) magnets[4], on the way, will allow improvements in duty cycle. The "effective spill-time" is 90-99% of the overall burst duration if only low-frequency structure is taken into account, and still exceeds 80% if high frequencies are included; it is dependent upon the number of bunches previously extracted. Intensity is not at present limited by the extraction process or equipment, but by the experimental area layout and shielding; after reconstruction (see below), it is planned to use up to 4×10^{12} protons/pulse in the East Hall[5].

There are four experimental areas (see Figure 1) for "25 GeV physics". The South Hall has seven secondary beams derived from two internal targets. One of these targets operates in each alternate running period, sharing with a slow extraction and using about 30% of the accelerated beam. Three of the beams are essentially used as test facilities. The East Hall has two extracted beams, one fast and one slow. In the first of these, one of three possible target positions supplies either a beam with RF separators, or an electrostatically separated beam at medium or low energy. This secondary beam feeds the 2m Hydrogen Bubble Chamber (HBC 200), which can be expanded twice during a single PS cycle, using from 2 to 6 bunches. The slow-extracted beam is divided into three branches by two splitting magnets (steel septum type), with a target in each branch. Sharing between these targets is adjusted by varying the magnet gap size and by altering the optical characteristics of the beam. A feedback steering system corrects for movements due to momentum variation and low-frequency ripple. Secondary beams derived from the targets at present include high energy proton, neutral and $\pi^{\pm}$, and special types such as hyperon and stopped-K. The West Hall is supplied with protons via a beam transfer line some 800 metres long, from an extraction system which can operate in both fast and slow modes during the same PS cycle. A fast kicker magnet directs the proton bunches down one channel to a target which produces the secondary (RF-separated) beam for the 3.5m Big European Bubble Chamber (BEBC); the slow-extracted beam goes down a second channel to a target giving secondary particles of various momenta for the "Omega" magnetic spectrometer.

Finally, the South-East Area houses the neutrino facility (using the heavy-liquid bubble chamber "Gargamelle") and the "g-2" experiment. These operate alternately in successive running periods, both using fast extraction.

The West Hall will become the first experimental area for 200/400 GeV physics with the SPS, and will therefore no longer be available for "25 GeV" experiments after mid-1975. Moreover, it is planned to use reduced intensities on the South Hall targets and employ the beams there mainly as equipment test facilities. Therefore the East Hall beams are in the course of major reconstruction, to allow a more intensive exploitation of this area at higher intensities and with greater flexibility in the secondary beam layout[5].

3. CPS AS AN INJECTOR

This mode of operation, first tried in 1970 for the ISR and planned from 1976 onwards for the SPS, highlights the importance of beam quality and stability both in the longitudinal and in the transverse phase planes.

3.1. ISR

The projected ISR luminosity (4.10^{30} $cm^{-2}.s^{-1}$, corresponding to 20 A stacked in both rings with a $\Delta p/p$ of 2%) was based upon an extrapolated value for longitudinal density of 8.5×10^3 protons/(eV/c).RF rad. in the bunches to be delivered from the CPS[6]. In 1969 this figure was only 2.6×10^3 p/(eV/c).RFrad. with 10^{12} p/p. A strong blow-up effect, due to space charge and negative mass instability, was taking place at transition energy[7]. This was cured by the "Q-jump" method[8] for rapid passage through transition. However, other longitudinal instabilities developed later in the cycle, during acceleration to higher energies, limiting the density to 5×10^3 p/(eV/c).RFrad., and further measures had to be taken. Firstly, the coherent bunch oscillations were suppressed by a feedback loop in the RF phase-lock[9]. Then the remaining longitudinal instabilities were checked by Landau damping; the RF non-linearity required was achieved by a programmed reduction of RF voltage, adjusted so that longitudinal acceptance continuously matched the bunch emittance[9]. The adjustment was very critical in the early days, but became easier after the reduction of some coupling impedances and with the increased acceleration rate due to the new RF system[4]. It was thus possible to reach and even exceed the ISR luminosity design value.

The increased intensity and density resulting from Booster injection brought new problems. Strong longitudinal oscillations appearing in the Booster itself were suppressed by a controlled longitudinal dilution produced by injecting a signal at the synchrotron frequency into the RF phase loop[10]. New longitudinal oscillations appearing shortly after injection into the CPS were controlled by a further programmed reduction of RF voltage (Landau damping). The "Q-jump" could not cope with the increased density and the "gamma-transition jump" technique[11] was introduced. This produces a rapid γ_{tr}-change an order of magnitude larger, without any modification of the betatron tune. As a result of these measures, it is now possible to accelerate a 6×10^{12} p/p beam to 26 GeV/c with 14 mrad longitudinal emittance (in $\Delta p/p \times$ RF radian units), corresponding to a density of 23×10^3 protons/(eV/c).RF radians.

The ISR luminosity obtained is inversely proportional to the vertical dimension of the beam injected, whilst horizontal size has to remain small enough to avoid losses at extraction from the CPS. Transverse emittance is therefore also a critical parameter.

During PSB running-in, one of the most intractable problems encountered was the large increase in normalized vertical emittance between 50 and 800 MeV. This has been reduced by separating the betatron frequencies by an integer and avoiding 3rd and 4th order stop-bands[1]. Corrections to narrow the stop-bands are also applied at low energy in the CPS to prevent the emittance from increasing[12].

Transverse instabilities of the head-tail type have been observed in both the PSB and the CPS[13], and they have been cured in both machines by using zero-harmonic octupoles to spread betatron frequencies within the bunch. Present emittance values are summarized in Table 2.

At the same time, various machine structures which could provoke these instabilities have been investigated. Whilst resistive wall effects seem to account for this in the PSB, it has been concluded that in the CPS ceramic vacuum chambers and ferrite structures are the responsible elements[14].

3.2. SPS

Whilst the same fast extraction technique already developed for

"25 GeV physics" experiments could be used for the ISR, a new beam transfer scheme had to be developed to fill the SPS, which has a radius eleven times larger than the CPS, in a single shot. This scheme, called "continuous transfer", has been successfully tested up to 2 x 10^{12} p/p and it is described elsewhere[15]. The technique of "peeling" the beam over 11 consecutive revolutions allows uniform filling of the SPS and results in a reduction by a factor 2 to 3 of the horizontal emittance obtainable. It is compatible with any beam structure, bunched, debunched, or even rebunched inside the CPS at the SPS RF frequency of 200 MHz.

In order to preserve longitudinal phase-space density in the SPS, and more specifically to avoid an excessive momentum spread which could be troublesome at SPS transition, it is intended to debunch the beam adiabatically within the CPS. Whilst this process has been tested successfully up to 2 x 10^{12} p/p, at higher intensities it is made more difficult by strong longitudinal instabilities due to beam interaction with surrounding equipment. An active search for potentially harmful structures is being conducted. It has recently been found that vacuum chamber flanges and pump manifolds are likely culprits[14] and it is intended to install RF short-circuits and damping resistors on all these elements.

4. OPERATIONAL ASPECTS

The implications of the multiple use of the CPS have led to the concept of interleaved supercycles. Their duration will vary from 3.5 to about 10 seconds according to the SPS maximum energy and the experimental areas in use. A possible example is given in Fig. 3. The main magnet power supply regulation is being modified to suit this type of operation, aiming at the same field reproducibility as with single identical consecutive cycles.

In order to minimize induced radio-activity and component damage, it is intended to accelerate only the intensity needed by each user[16]. Pulse-to-pulse intensity modulation will be achieved by changing the number of turns injected into the Booster at 50 MeV (operational tests have already been successfully conducted). Complementary means such as longitudinal acceptance reduction and vertical beam shaving at injection and attenuation by "sieves" are also envisaged.

Another area of permanent concern is the maintenance of a high degree of reliability (i.e. availability). Irradiation of the main magnet

has recently become a serious problem; several units have failed and have had to be replaced, and many others show signs of serious damage. A detailed survey of the present status (Fig. 4) and its probable evolution has been made, and preservation measures are under way[17]. Induced activity is another problem [18], and stringent operational procedures have been adopted to stabilize its level in spite of the rise in intensity[19]. With all these measures, it has been possible to keep the overall CPS failure rate down to between 8 and 9% since 1969[20].

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TABLE 1

CPS PERFORMANCE

Item	Theoretical or design* Efficiency (%)	Measured Efficiency (%)	Intensity ($\times 10^{12}$ protons/pulse)		
			Design	Present	Best
Linac beam (50 MeV)			60	28	50
PSB Multiturn Injection	37-43(60**)	34-40	24	9	15
PSB RF Trapping	90-95	90-95	19	8.5	
Acceleration to 800 MeV	100	95	17	8	12
PSB Ejection and Recombination	95	90	15	6.5	11
Injection and acceleration in CPS	99	90-97	10	6.0	9.3+
Fast extraction from CPS	100	93-98		6.0	8.5++
Slow extraction from CPS	98	93***		1	6
Transfer to ISR	100	98		1.8	
Transfer to SPS (test)	95-97	91	10		

* Design efficiencies based on design emittances in the 3 phase planes.

** Close to coupling resonances and using skew quadrupoles.

*** With 30% of the beam shared with an internal target.

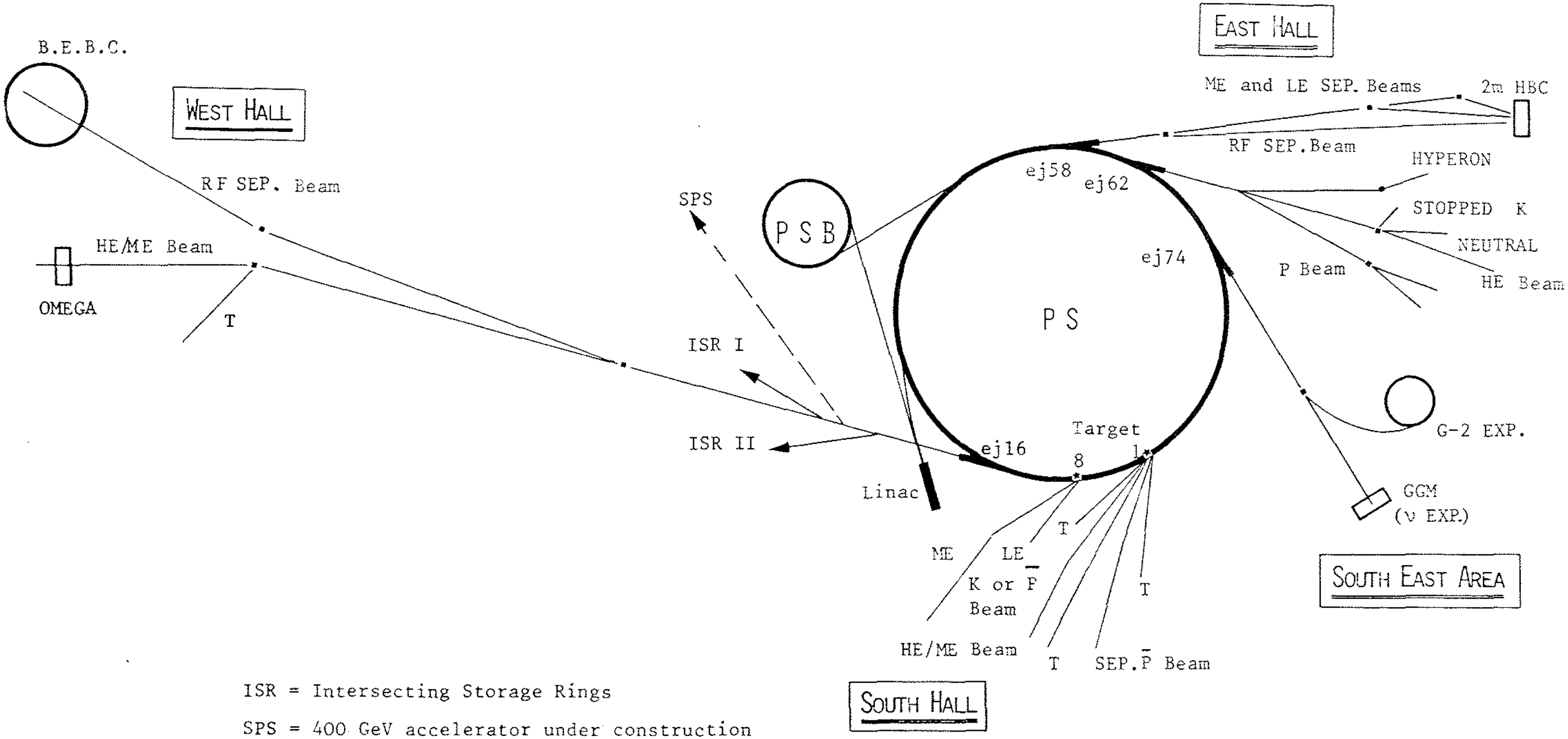
\+ At transition

\++ At 10 GeV/c

TABLE 2

BEAM PROPERTIES (Typical Values)

Item	Linac	Booster	CPS			
			Before SPS Transfer		Before ISR Transfer	
Energy	50 MeV	800 MeV	10 GeV/c		26 GeV/c	
CPS Injection energy			50 MeV	800 MeV	50 MeV	800 MeV
Intensity (10^{12} p/p)	(55 mA)	6.5	2	6	2	6
Transverse emittance						
(95% of beam; H	32	30	1.5	5.5	0.65	2.5
10^{-6} π rad.m) V	32	14	2.0	3.3	0.9	2.2
Normalised transverse emittance H	10.5	47	16	60	18	70
(10^{-6} π rad.m) V	10.5	22	21	35	24	60
Normalised transverse						
density H	2.1	1.4	1.25	1.0	1.1	0.85
(10^{17}p/(π rad.m))V	2.1	3.0	1.0	1.7	0.8	1.0
Longitudinal emittance						
-($\Delta p/m_o c$ x RF radians)	-	0.01	0.01	0.014	0.01	0.014
-(eVs)	-	0.16	0.16	0.22	0.16	0.22
Longitudinal density						
-(10^{12} p/eVs)	10.0	2.5	-	-	0.65	1.4
-(10^{3} p/(eVs)·RF rad)	160.0	40.0	-	-	10.0	23.0



ISR = Intersecting Storage Rings

SPS = 400 GeV accelerator under construction

HE, ME and LE = High, medium and low energy beam

T = Test beam

▪ = External target

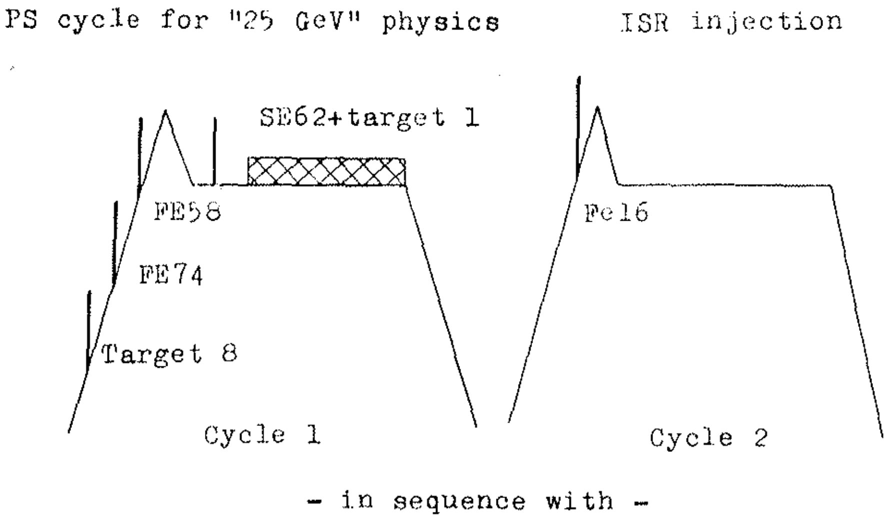
SEP = Separated beam

ej = Straight section location of extraction magnet for fast or slow ejection

FIG. I

SCHEMATIC DIAGRAM OF EXTERNAL AND SECONDARY BEA

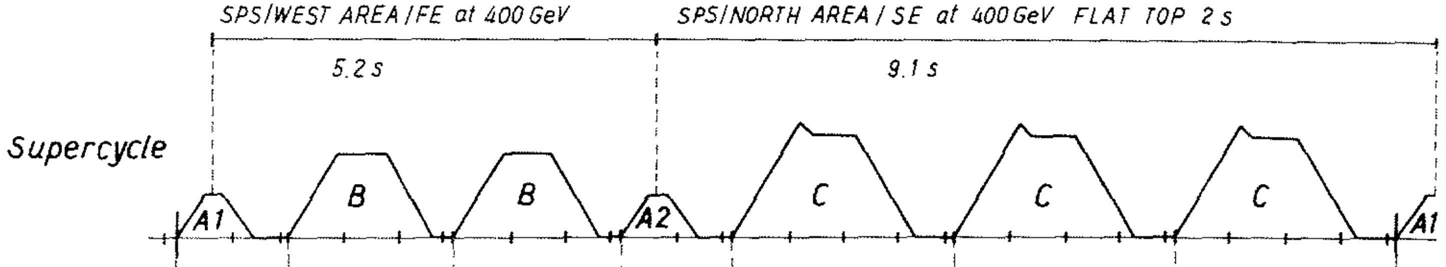
(SECOND HALF 1974).



Maximum momentum	26.3 GeV/c
'Flat top' momentum	24 GeV/c
'Flat top' length	540 ms
Repetition time	2.6 sec.
Cycle 1/cycle 2	1 : 1

	Operation	GeV/c	Area	Users	Remarks
cycle 1	Target 8 (parasitic)	16	South	Counter tests	5 ms burst with RF structure < 5 % intensity
	Fast ejection SS74	19	South-East	g-2 experiment	1-2 bunches
	Fast ejection SS58	24	East	2m HBC	2 shots with 1-3 bunches
	Slow ejection SS62	24	East	6 counter experiments + tests	30-40 % of protons ~ 400 ms
	Target 1	24	South	2 counter experiments + tests	15-20 % of protons ~ 400 ms
cycle 2	Injection to ISR	10-26 variable	ISR	Counter experiments	20 bunches

FIG. 2 A Typical CPS Cycle Sequence



USER	SPS	"25 GeV" PHYSICS		SPS	ISR	"25 GeV" PHYSICS	ISR
OPERATION AND FRACTION OF BEAM USED	CT 100 %	FE 74 5 % SE62 75 % TO 8 20 %	FE 74 5 % SE62 75 % TO 8 20 %	CT 100 %	FE 16 100 %	TO 1 1 % 2x FE58 20 % SE62 64 % TO 8 15 %	FE 16 100 %
TOTAL INTENSITY (P/P)	10^{13}	4.10^{12}	4.10^{12}	5.10^{12}	3.10^{12}	5.10^{12}	3.10^{12}

KEY:

CT = CONTINUOUS TRANSFER
FE n = FAST EJECTION STRAIGHT SECTION n
SE62 = SLOW EJECTION STRAIGHT SECTION 62
TO 8 = INTERNAL TARGET STRAIGHT SECTION 8
TO 1 = INTERNAL TARGET STRAIGHT SECTION 1
P/P = PROTONS PER PULSE

Fig. 3 : EXAMPLE OF A POSSIBLE SUPERCYCLE

16.8.74

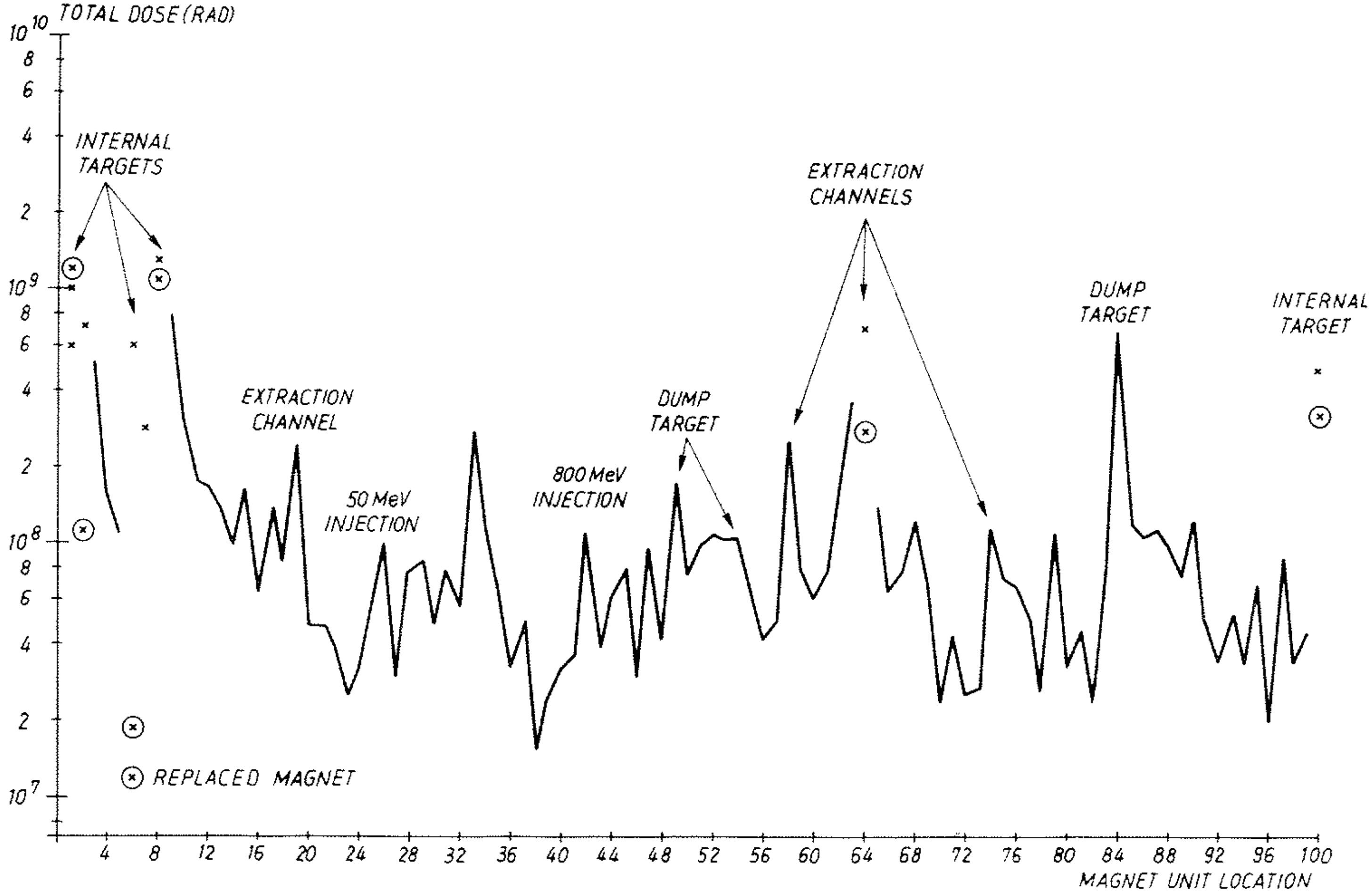


Fig. 4: CPS MAGNET IRRADIATION STATUS (January 1974)

29 7 74 C.