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Problems of radiation protection near the large CERN accelerators

Introduction

The European Organization for Nuclear Research was founded about 10 years ago. The Laboratory was created by a common effort of the European countries to provide facilities and carry out research on the constituents of nuclear matter. Two large particle accelerators were designed and built for this purpose by the Organization; a synchro-cyclotron, accelerating protons to an energy of a maximum of 600 MeV, and a larger proton-synchrotron providing a proton beam with a maximum energy of 28 GeV. The synchro-cyclotron, which usually is called the SC machine, has now been operating for 7 years and the proton-synchrotron, or PS machine, has operated for nearly five years.

The staff of the Laboratory has gradually been built up of scientists, engineers, technicians and other people from the 13 European member states of CERN and now totals approximately 1600 people. About 800 additional staff are working in the Laboratory at present as fellows, visiting scientists, visiting teams and auxiliary staff. Roughly 25% of all the people at CERN are scientists and engineers, 40% are technicians and 10% are administrative staff. About 25% of the staff are auxiliaries.

The Laboratory covers an area of about 40 hectares and is located in Switzerland at Meyrin near the French Border, 8 km from Geneva. Figure 1 shows an aerial view of CERN with the shielding structure of the PS and SC machines as well as the laboratories and the Administration Building. The work of CERN is centered around the two large accelerators, their use for highenergy nuclear physics studies, their operation, maintenance and improvement. A large effort

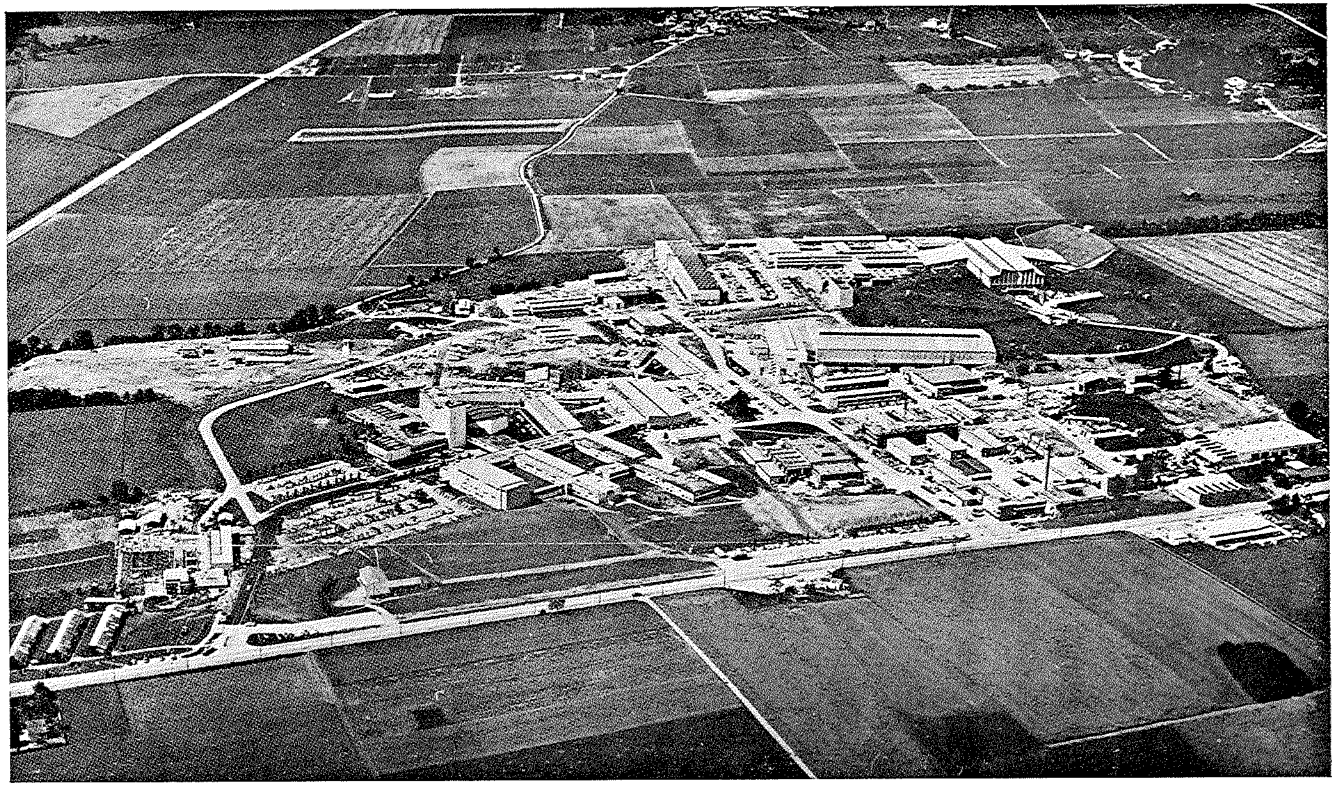

Fig. 1 - *Aerial view of the CERN Site*

is also made to provide and operate facilities for data evaluation for the experiments with the machines. To plan the future, research is also made into still greater accelerators which will presumably be the next stage in experimental facilities enabling us to increase our knowledge about the ultimate structure of matter.

On several points, CERN differs from national European laboratories. It is international, experimental and operated by 13 European nations working in collaboration. The accelerators produce radiation energies above those normally available at other places in Europe. These factors have a considerable influence on the problems of radiation protection.

Radiation protection problems comprise, generally speaking, a scientific and an administrative element. The scientific side is concerned with the evaluation of radiation risks to personnel and is covered by such fields as physics, chemistry biology and medicine. Having established existing radiation risks in meaningful terms, it is then a matter of administration to regulate and influence the working and operating procedures needed to minimize or keep the risk below a certain standard. In the following we shall limit our discussion to some problems of basic knowledge required for radiation protection near the CERN large accelerators.

I) Basis for radiation protection near the CERN accelerators

A. *Radiation at CERN*

The very high-energy proton radiation which results from the operation of the CERN accelerators creates particles such as those listed in Table I. Fortunately, in beams or behind the machine shields, many of these particles do not constitute a protection problem because of their low production cross-sections and short life-times. Of particular concern are high-energy protons, neutrons, pions and gamma rays, as well as electrons and muons. While the machines are operating, such radiation will be found not only in and near the beams in the experimental halls, but also elsewhere outside the main machine shielding. The intensity as well as the mixture of radiation, however, varies greatly from the beam to places outside the shielding. Machine intensity and operation also influence the radiation levels all over the laboratory; naturally the level decreases with increasing distance from the machines.

TABLE 1
ELEMENTARY PARTICLES

Particle	Electric charge	Mass in MeV	Spin	Strangeness	Mean lifetime in seconds	Common disintegration products	Antiparticle
Baryons							
Ξ^- (xi minus)	$-e$	1321	½?	-2	1.2×10^{-10}	$\pi^- + \Lambda$	$\bar{\Xi}^+$ (antixi plus)
Ξ^0 (xi zero)	0	~ 1311	½?	-2	$\sim 2 \times 10^{-10}$	$\pi^0 + \Lambda$	$\bar{\Xi}^0$ (antixi zero)
Σ^- (sigma minus)	$-e$	1196	½	-1	1.6×10^{-10}	$\pi^- + n$	$\bar{\Sigma}^+$ (antisigma plus)
Σ^0 (sigma zero)	0	1192	½	-1	$\approx 10^{-20}$	$\gamma + \Lambda$	$\bar{\Sigma}^0$ (antisigma zero)
Σ^+ (sigma plus)	$+e$	1189	½	-1	0.8×10^{-10}	$\pi^+ + n$ or $\pi^0 + p$	$\bar{\Sigma}^-$ (antisigma minus)
Λ (lambda)	0	1115	½	-1	2.5×10^{-10}	$\pi^- + p$ or $\pi^0 + n$	$\bar{\Lambda}$ (antilambda)
n (neutron)	0	940	½	0	1.0×10^3	$e^- + \bar{\nu}_e + p$	$\bar{n}$ (antineutron)
p (proton)	$+e$	938	½	0	stable	-	$\bar{p}$ (antiproton)
Bosons							
K^0 (K zero)	0	498	0	$+1$	10^{-10}	$\pi^+ + \pi^-$	$\bar{K}^0$ (anti-K zero)
K^+ (K plus)	$+e$	494	0	$+1$	1.2×10^{-8}	$\mu^+ + \nu_e$ or $\pi^+ + \pi^0$	K^- (K minus)
π^+ (pi plus)	$+e$	140	0	0	2.5×10^{-8}	$\mu^+ + \nu_\mu$	π^- (pi minus)
π^0 (pi zero)	0	135	0	0	1.01×10^{-16}	$\gamma + \gamma$	itself
γ (photon)	0	0	1	0	stable	-	itself
Leptons							
μ^- (mu minus)	$-e$	106	½	undefined	2.26×10^{-6}	$e^- + \nu_e + \bar{\nu}_\mu$	μ^+ (mu plus)
e^- (electron)	$-e$	0.511	½	undefined	stable	-	e^+ (positron)
ν_e (neutrino)	0	0	½	undefined	stable	-	$\bar{\nu}_e$ (antineutrino)
ν_μ (neutrino)	0	0	½	undefined	stable	-	$\bar{\nu}_\mu$ (antineutrino)

The CERN PS machine now accelerates more than 10^{12} protons per burst with a frequency varying with the operating energy of the machine. Generally, it is operated with a burst every 2 or 3 seconds. The SC machine has a current of roughly 1,5 μA in the form of a circulating beam of protons. The shielding which surrounds these machines amounts to 5 meters of earth or an equivalent amount of concrete. Extracted secondary beams and also experimental halls are often surrounded by moveable shielding blocks to minimize scattered or secondary radiation.

The very high energy of the proton radiation of the accelerators causes nuclear reactions which leave a wide variety of radioactive isotopes in places where the radiation has penetrated. Generally speaking, almost any known isotope below the irradiated element of the material might then be produced. This means that the induced radioactivity of the accelerator components poses another important problem to radiation protection at CERN (1).

B. *The Dosimetry of High-Energy Radiation*

The dosimetry of very high-energy radiation has not been studied in any great detail until recently when the radiation hazard near high-energy accelerators has become a problem. The interest in this field has been greatly stimulated by space research projects, for which an evaluation of hazards from cosmic rays is needed. It is essential for radiation protection in general to bridge the gap between radiation physics and biology by the dose measurments. In fact, only physical measurements having a meaning to the bio-medical field are of any use in evaluating radiation risks to personnel. To carry out such measurements, the concept of radiation dose has been formulated by the I.C.R.U. (International Commission on Radiological Units) and defined for protection purposes as the dose equivalent (DE) (2). It is given by the following formula:

$$(DE) = D\,(QF)\,(DF)\ldots \qquad (1)$$

The dose equivalent (DE) is given in rem is equal to the dose in rads (D) times a quality factor (QF) which is defined as the L.E.T. (Linear Energy Transfer) dependent factor of the R.B.E. (Radiobiological Effectiveness) of the particular radiation in question. Other modifying factors such as distribution factors (DF), etc. might be added to this formula. Although this formula is supposed to give a basis for evaluation of radiation risks from measurements, it is known that several other biological as well as physical factors are involved. Therefore, complete information needed to estimate the hazard from radiation might not necessarily be found from the formula mentioned above.

The difficulty in applying conventional methods of dosimetry to very high-energy radiation arises from the differences in the interaction with matter. Also high local energy deposition and high linear energy transfer (LET) values are associated with product from nuclear interactions. The measurement problem is further complicated by the presence of a wide variety and great energy range of secondary radiation, accompanying the high-energy particle radiation.

The energy loss suffered by high-energy charged particles passing through matter occurs from ionization and from nuclear and electro-magnetic interactions. The primary ionization varies with energy, decreases when energy rises, reaches a minimum and rises again at very high energy on account of relativistic field distortion. For protons passing through tissue, the rate of energy loss can have values between 100 KeV/μ (in the Bragg region) down to 0.2 KeV/μ at minimum ionization. Other charged particles behave similarly.

In addition to the ionization from charged particles, nuclear interactions from charged and uncharged particles have also to be considered. These reactions can vary from more direct nuclear processes in which only a few particles from the target nucleus take part, to reactions in which the whole nucleus disintegrates, emitting a large variety of particles and nuclear fragments (spallation). These reactions involve local energy dissipation of the order of 10 MeV per emitted nucleon for the more direct processes and are as such a source of low-energy secondary particles. The amount of energy dissipated locally in the case of spallation is very high. Apart from escaping neutrons, almost all the available energy contributes to the local dose. The total cross-section for the nuclear interaction is of the same order of magnitude as the geometrical seize of the nucleus. The energy loss per unit path length by very high-energy charged particles when passing through matter, is approximately equally divided between primary ionization and nuclear interaction.

To estimate the radiation dose equivalent (DE) for protection purposes in such a mixed field, the absorbed dose (D), the quality factor (QF) and the build-up factor (BF) will need to be measured. Another approach would be to provide complete knowledge of the radiation types and spectra and to use the knowledge about radiation interaction with matter to calculate the dose. A lack of fany formal method of measuring dose within its definition has made it necessary at present for CERN to adapt the tissue-equivalent ionization chamber reading as a measurement of absorbed dose, independent of radiation type and energy (3). It has not been possible to check this arbitrarily chosen definition of dose for all radiation. The response of this chamber, however, is satisfactory to fast neutrons, gamma rays and primary ionization of charged particles. Having defined the dose in instrument reading, dose distribution factors (DF) are readily measured using water absorbers to simulate tissue. The third quantity necessary is the QF and its variation with depth. This quantity should not be confused with the RBE which is defined entirely by biological effects. The QF depends — as mentioned — only on the average LET and is supposed to cover the most critical effects of radiation, and is therefore considered to express the maximum RBE of the radiation question. The relationship between LET and QF is shown in figure 2.

Attempts have been made to estimate QF by measuring a recombination index, using a parallel plate ionization chamber filled at high pressure with tissue-equivalent gas (4). The

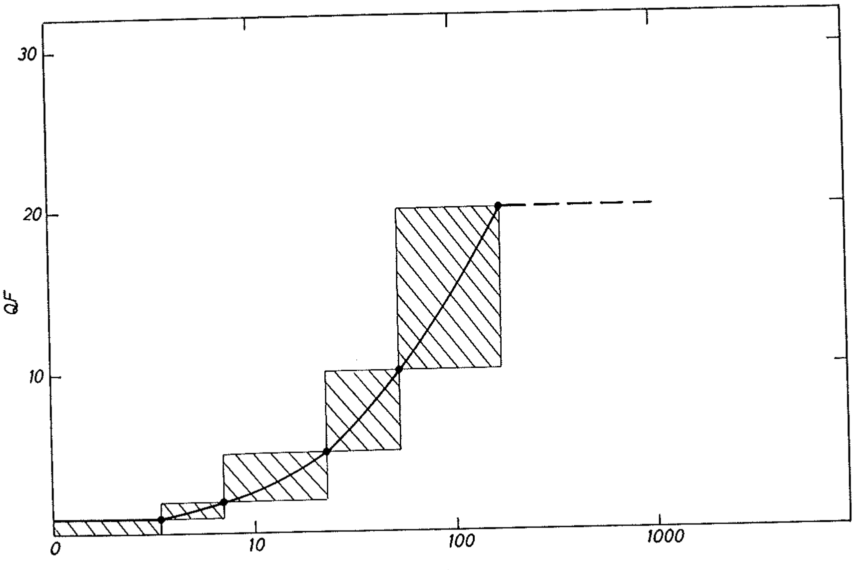

Fig. 2 - *QF as a function of LET*

TABLE 2

SURVEY INSTRUMENTS FOR HIGH-ENERGY RADIATION MONITORING

Radiation	*Energy Range*	*Instruments*	*Quantities Determined*
High-energy particle	E > 20 MeV	Induced Carbon-11 in phosphors	Flux density
Fast neutron	100 keV < E < 15 MeV	Long counter	Flux density
Fast neutron	100 keV < E < 15 MeV	Moderated activation of Indium foil	Flux density
Fast neutron	100 keV < E < 15 MeV	Proton recoil counter	Energy flux
Thermal neutron	0.25 eV	BF_3 chambers	Dose
Gamma and direct ionizing radiation	E > 100 keV	Twin ionization chambers	Gamma dose (+ primary ionization)

function of this chamber is explained by columnar recombination which is a function of the specific ionization and hence of QF. It has been found that the measured index of recombination is proportional to the QF and that this response is independent of dose rate and angular distribution of the radiation. Furthermore, it averages the QF for a mixture of radiation.

This method of measuring dose and dose-equivalent is only practical when the dose-rate exceeds the maximum permissible levels, since the present sensitivity of the instrumentation involved limits the accuracy at low levels. For measurements behind shields where the radiation levels are well below tolerance, conventional health physics instruments have to be used. A system of instruments is therefore employed from which the contribution to the dose of the various types and energy ranges of the radiation are determined seperately (5). The system developed for routine measurements at CERN is shown in Table II.

Up to 6 different instruments are simultaneously needed to evaluate the dose-rate near the machines. Separate measurements of the dose from thermal neutrons, fast neutrons and the high-energy nuclear reacting components as well as the primary ionizing component are made in this way. To convert the readings to dose-equivalent, QFs recommended by the ICRP (International Commission on Radiological Protection), and QFs measured at CERN are applied (5). Behind thick shields, depth dose determinations are not necessary since the radiation can be assumed to be in equilibrium, which will not be significantly disturbed by the presence of the body. The system of instruments already mentioned is thought to give the best analysis of the radiation within the limits of available instrumentation.

From the preceding discussion it is evident that routine dose measurements in the sense of the ICRU definitions become rather complicated near the large CERN accelerators. A reformulation of the concept of the dose equivalent within its definition might therefore be worth-while in order to explore the possibilty of such measurements indepedent of type and energy of the existing radiation (6). Such an approach would necessitate the introduction of a wider knowledge of radiobiology than that existing at present.

C. *High-Energy Radiobiology*

It is of little use to apply elaborate methods of dose measurements if a proof of their relevance to the radiation danger does not exist. Confidence in the safety of personnel

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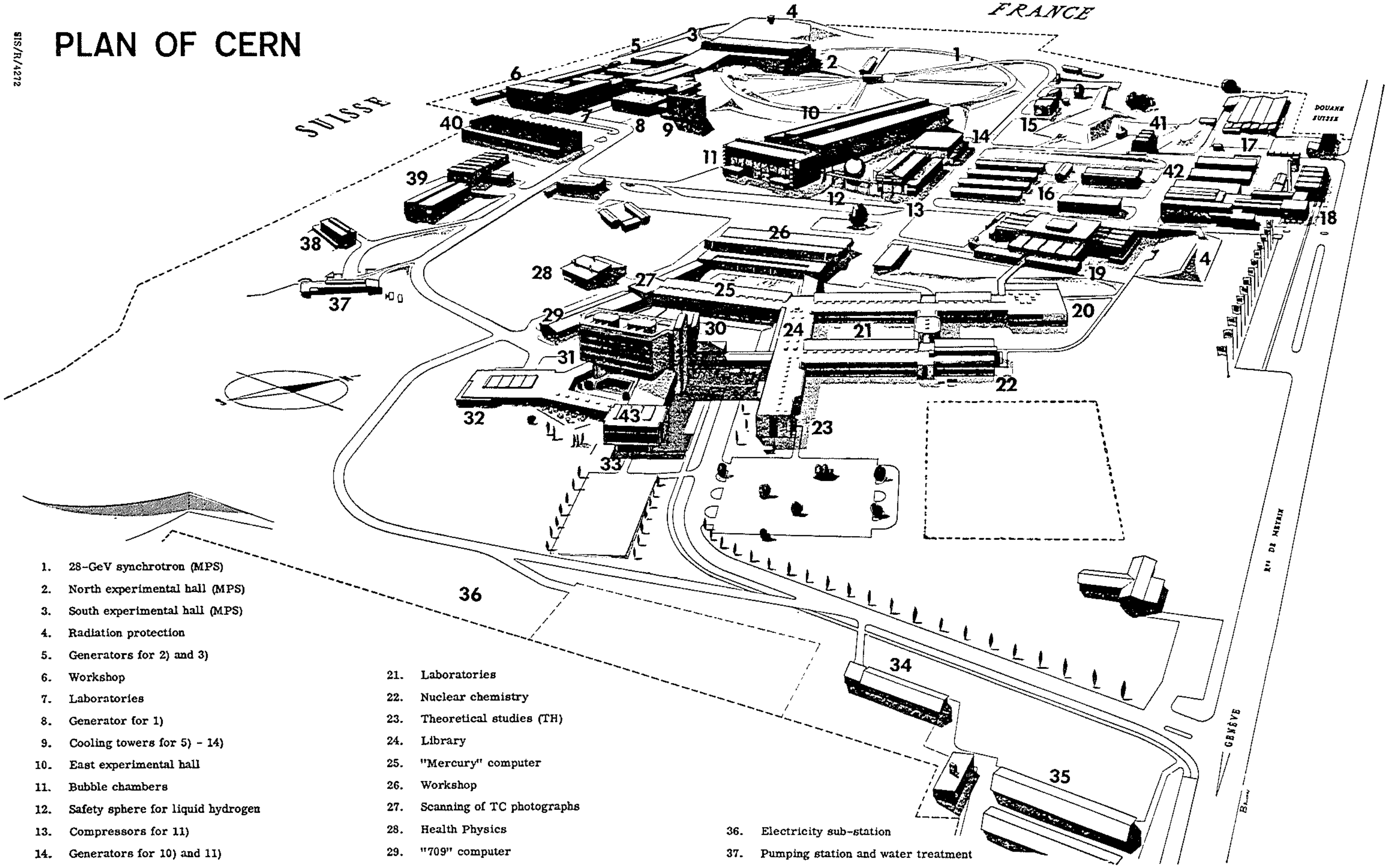
PLAN OF CERN



1. 28-GeV synchrotron (MPS)
2. North experimental hall (MPS)
3. South experimental hall (MPS)
4. Radiation protection
5. Generators for 2) and 3)
6. Workshop
7. Laboratories
8. Generator for 1)
9. Cooling towers for 5) - 14)
10. East experimental hall
11. Bubble chambers
12. Safety sphere for liquid hydrogen
13. Compressors for 11)
14. Generators for 10) and 11)
15. Bubble chambers testing
16. Track Chambers Division (TC)
17. Site and Buildings Division (SB)
18. Power house (SB)
19. 600-MeV synchro-cyclotron (MSC)
20. Control room for 19)
21. Laboratories
22. Nuclear chemistry
23. Theoretical studies (TH)
24. Library
25. "Mercury" computer
26. Workshop
27. Scanning of TC photographs
28. Health Physics
29. "709" computer
30. Main Auditorium
31. Directorate - Administration
32. Canteen
33. Public Information
34. Barrack No. 11 (MSC, etc.)
35. Barracks for outside firms
36. Electricity sub-station
37. Pumping station and water treatment
38. Propane distillation
39. Accelerator Research (AR)
40. Nuclear Physics Apparatus (NPA)
41. Hydrogen liquefier
42. Fire fighting, First Aid
43. Council Chamber

"Plan of CERN", ref. PIO/5262/2

Fig. 3 - *Location of the Laboratories at CERN*

with regard to radiation hazard is dependent on an adequate knowledge of the biological effects of high-energy particles. Owing to the pioneer character of high-energy physics at CERN, the biological hazard is inevitably to a large extent an unknown quantity. Direct information about biological effects at higher radiation energies would help to check the physical measurements and make a substantial contribution towards improving radiation protection. Protection problems related to high-energy radiation are greatly influenced by the considerable lack of experimental results of such studies (7).

To meet some of the need for knowledge of biological effects from high-energy radiation, a few preliminary experiments have been performed at CERN exposing rats, mice and drosophila to a 600 MeV proton beam. These experiments were carried out thanks to laboratories in the CERN member states (Prof. Bonet-Maury, Institut du Radium, Paris, Dr. Bührer, University of Geneva; Dr. Legeay, Saclay; Prof. Pasinetti, University of Milano; Prof. Pasinetti, University of Palermo and Dr. Purdom, Medical Research Council, Harwell).

Although the results were not directly aimed at protection, they have so far shown no substantial deviation from health physics dose measurements. LD_{50} of mice and rats for 600 MeV protons show RBE values of 1 and 1.25 respectively (8, 9). Lethal mutation of drosophila using the same beam also gives RBE values close to 1 (10).

Much more work in this field needs to be carried out to enable us to make a better evaluation of radiation hazards to personnel near the CERN machines.

II) The radiation hazard at CERN

The radiation hazard at CERN is caused by the high-energy radiation existing when the accelerators are in operation and by beta and gamma radiation and contamination risks from induced radio-activity during the shut-down of the accelerators. Isotopes and special radiation producing equipment, such as the 1.7 MeV electron storage ring model and electrostatic separators are also sources of radiation which must be controlled.

Figure 3 shows the position of the laboratories on the CERN Site. A major radiation protection problem is to possess sufficient data to evaluate the risk at any time and any place on the Site. The dose-rates during operation of the accelerators vary greatly according to the way in which the machines are used. Dose-rates in secondary beams have usually values of

TABLE 3

ANALYSIS OF SURVEY RESULTS NEAR THE CERN AND PS MACHINES

Location of Measurements	*High Energy Part. Carbon*-11		*Fast Neutrons*			*Gamma Dose*	*Thermal Neutrons*	*Total Dose*	*T. E. Dose*	*Apparent Quality Factor*
	Flux *part/cm²/sec*	*Dose* *mrem/h*	*Flux* *n/cm²/sec*	*Average* $\overline{E}$ *MeV*	*Dose* *mrem/h*	*mrad/h*	*mrem/h*	*mrem/h*	*mrad/h*	
At large distances while the 600 MeV SC external proton beam is operating	< 0.8	< 0.08	25	0.6	2.5	0.02	—	2.6	0.9	2.9
	< 1.2	< 0.12	1	1.1	0.1	0.03	—	0.25	0.04	6.2
	2.0	0.2	48	1.3	6.9	0.3	—	7.4	0.62	12
	< 0.8	< 0.08	22	0.9	3.0	0.5	—	3.1	0.28	11
Near SC neutron hall while internal target is in operation	< 0.8	< 0.08	3.8	1.5	0.54	0.06	—	0.7	0.07	10
	1.5	0.15	5.4	0.9	0.72	0.03	—	0.9	0.07	13
	3.3	0.33	7.3	4.4	1.05	0.42	—	1.8	0.5	3.6
	15.6	1.6	7.5	11.6	1.1	0.83	—	3.6	0.9	4
Near PS target region (bridge)	5.2	0.52	26.2	2.8	3.9	0.36	0.9	4.32	1.0	4.3
	22.8	2.28	64	3.4	9.2	1.26	1.85	15.59	3.8	4.1
	27.0	2.7	39	4.9	5.6	0.85	1.7	11.3	1.9	6.0
	4.4	0.44	22.8	1.9	3.3	0.31	0.69	4.74	0.8	5.9
Near PS north hall when internal target in operation	< 0.8	< 0.08	2.2	1.1	0.3	0.05	0.12	0.54	0.04	13
	< 0.8	< 0.08	3.0	0.7	0.4	0.05	0.15	0.68	0.06	11
	< 0.8	< 0.08	4.3	1.0	0.6	0.04	0.16	0.87	0.11	8
	< 0.8	< 0.08	3.7	1.2	0.53	0.01	0.12	0.71	0.05	14

several rems per hour, and consequently local shielding arrangements make beam regions inaccessible. This also nearly reduces the dose-rates to tolerance level (2.5 mrem/h).

The dose-rates decrease with the distance from the machines. It has been found that the CERN PS machine creates a yearly dose of about 60 mrem/year at a distance of 400 m from the machine when operating 120 hours per week. The CERN SC machine with an operation of 140 hours per week creates a yearly dose of 100 mrem at a distance of 100 m. In both cases only internal targets have been used. When high-energy protons are extracted, radiation doses increase by orders of magnitude. In spite of this, it must be concluded that the CERN machines are quite well shielded considering their use.

Typical distribution of the radiation outside shielded areas of the CERN PS and SC machines is shown in Table III. It is interesting to see that the major component of the dose is fast neutrons which contribute more than 50% of the total dose. In some regions, for example along the beam path, even behind very thick shielding, muons dominate showing that the gamma radiation or charged particle component can contribute up to 85% of the total dose. The quality factor of the radiation varies, but seems to keep to within values of 5 to 10.

The maintenance during shut-down of the accelerators presents particular protection problems because of the induced radioactivity. The highest dose-rates are found near target regions close to the vacuum chambers where the dose-rates might reach 10 to 15 rem per hour. The induced radioactivity which causes this dose-rate decays with time, but in a complex way because of the composition of the radioactivity (12). The exposure to people maintining the machine is considerable and require strict control.

About 250 smaller radioactive sources are scattered around the site, so creating other sources of radiation needing control. A nuclear chemistry laboratory using chemical methods on irradiated materials from the accelerators produces radioactive liquids and other waste requiring regular inspection and control.

A 1.7 MeV electron storage ring model produce bremsstrahlung which has to be shielded and kept inside regions inaccessible to unauthorized persons.

The general policy on radiation protection followed by CERN is based on the ICRP recommendations. Shielding is used and other radiation studies are currently made to keep accessible places within the 40-hours-per-week total, and regions with higher dose-rates must be under strict control.

III) The personnel radiation control

The radiation exposure of personnel is controlled by gamma and neutron film-badges. About 1400 people were controlled last year for gamma exposure and 400 for neutron exposure also. Due to the particular radiation existing near the accelerators, special reading of neutron film-badges is made to enable us to include the high-energy component in the results (14). The use of neutron films is based on observation of nuclear stars in the emulsions. The star production represents a new phenomenon for dose interpretation and its biological significance is not easy to evaluate.

The distribution of the doses received by people at CERN in 1963 is shown in Table IV. About 950 people were under control the whole year and 78 of these received a dose above 1 rem. It is also intersting to note that the relation between neutron dose and gamma dose to personnel varies between 0.08 and 1.125, where the higher values are found for people working near the accelerators.

In addition to the film-badge control, all people exposed professionally to radiation have a yearly blood test and those exposed to neutrons and high-energy radiation are also given an eye inspection. These examinations are made by a medical consultant attached to the Health Physics Group. Of the 925 people who were given a blood test last year, 92 people were suffering from slight anomalies of the blood. In most of these cases, the anomalies were of a transint character. Slight anomalies of the eyes were observed in 16 of the 325 people who had their eye lenses tested in 1963.

TABLE 4

DISTRIBUTION OF DOSES

Dose	*Number of persons*		*Total*
	Group I	*Group II*	
	Gamma only	*Gamma+neutron*	
0 - 1	688	183	871
1 - 2	38	7	45
2 - 3	18	—	18
3 - 4	7	5	12
4 - 5	2	—	2
> 5	1	—	1

A serious question to be considered is whether the medical side of the radiation protection problem at CERN is satisfactorily solved. The fact that so little is known about biology of very high-energy radiation might justify close observation of people subjected to these extraordinary radiation conditions. On the other hand, it would also be very difficult to reach a decision as to what particular symptoms to look for. The most rewarding approach would be to organize a major research project on fundamental biological problems, to run in parallel with progress made in physics of fundamental particles.

Conclusion

Because of the pioneer character of the nuclear physics studies carried out by the CERN machines, and the lack of biological knowledge about effects from high-energy radiation, the whole basis for personnel radiation protection near high-energy machines is subject to particular problems. A greater effort put into dosimetry, as well as the radiobiology of high-energy radiation might contribute substantially to placing the radiation protection problems in perspective, and to deciding whether we are oxer-emphasizing or neglecting this kind of activity as it is carried out at the present time at CERN.

REFERENCES

(1) *J. Baarli,* « Induced radiactivity in the CERN accelerators ». Premier Colloque International sur la Protection auprès des Grands Accélérateurs, Orsay. P. 123-128, 1962.

(2) *International Commission Report* 10a on *Radiological Units* and *Measurements* (*ICRU*), Handbook 84, 1962.

(3) *H. H. Rossi* and *G. Failla,* Nucleonics 14, 32, 1956.

(4) *A. H. Sullivan* and *J. Baarli,* « An Ionization Chamber for the Estimation of the Biological Effects of Radiation ». CERN Report 63-17, 1963.

(5) *J. Baarli* and *A. H. Sullivan,* « Radiation Dosimetry for Protection Purposes near High-Energy Accelerators ». Health Physics (in the press).

(6) *A. H. Sullivan,* « A Formulation of Radiation Dose-Equivalent and Quality Factor in Terms of Radiation Effect ». DI/HP/41, 1964.

(7) *A. Pasinetti,* « Radiological Problems in Protection, Prevention and Therapy of High-Energy Radiation Injury ». CERN DI/HP/39, 1964.

(8) *P. Bonet-Maury, J. Baarli, T. Kahn, G. Dardenne, M. Frilley* et *A. Deysine,* « Biological Effects of Neutron and Proton Irradiation ». I.A.E.A., Vol. 1, pp. 261-277, 1964.

(9) *G. Legeay,* Private Communication.

(10) *C. E. Purdom,* Private Communication.

(11) *A. H. Sullivan* and *T. R. Overton,* « Time Variation of Dose-Rate from Radioactivity in a High-Energy Particle Accelerator ». CERN DI/HP/45, 1964.

(12) *J. Baarli* and *J. Dutrannois,* « The Nuclear Stars in Personnel Neutron Track Films carried at CERN ». Symp. on Personnel Dosimetry Techniques for External Radiation; pp. 283-301, 1963.

INTERVENTI SULLA RELAZIONE

F. ELLIS

I should like to ask Prof. Baarli about the abnormalities he mentiens. About 10% of the 925 people given blood tests and 5% of the 325 having lens examinations showed anomalies.

Were these anomalies developments after starting work at CERN and were thay considered to be due to the radiation hazard at CERN or were they thought possibly to be due to other causes?

If they might be due to the radiation hazard they are surely relatively larged than might be expected from the more usual types of radiation and therefore suggest that effects are the results of the very high energy radiation and probably due to induced radioactivity in the body since the doses received are as very small as indicated by Dr. Baarly's measurements. The implication is so strong that we are ignorant of the biological effects that theprogramme of research into this problems should be given considerable priority.

It would be helpful to follow up the workers from CERN for a long time when they leave the site to work elsewhere so as to find out of any late developments might occur in connection with the health of these individuals which might be related to their exposure. Are such follow up arrangements in hand or are they considered necessary?

Furthermore have any effects been absorved in connection with pregnancies which have developed at CERN in the children of worken either in the form of abnormalities or as long term developments of any kind such as malignant deseases.

J. F. FOWLER

I was surprised by the high figures for abnormalities of blood and eyes mentioned by Dr. Baarli. How significant are these abnormalities? Are they found continually in the came people? Whether they are or not, it seems, necessary to have a programme of foundamental biological work with the strange particles produced by these machines. The relationship of absorbed dose to biological effect is very poorly known at high LET's, and of course the measurement of LET distributions, and the biological significance of any such measurements, needs a great deal more work.

RISPOSTA DEL RELATORE

J. BAARLI

In connection with the possible future use of pi-minus mesons for radiation therapy as mentioned by Prof. Fowler, in his extremely inspiring talk, I could mention that we at CERN already have conducted some preliminary studies. The studies consisted of an experimental investigation of depth and isodose distribution in water of a 65 MeV pi-minus meson beam from our 600 MeV Syncrocyclotron. The pi-minus mesons of this energy ionize very similarly to fast electrons, but when they come to rest at the end of their range in the absorber they interact with the nuclei present. Interactions with oxygen in water result in the emission of 3 alpha-particles per interaction, each alpha-particle having an energy of about 8 MeV.

Our depth and isodose distribution measurement in water for the pi-minus beam at CERN showed that the average range was about 14 cm.

Furthermore we found that the ratio between the maximum dose in rads as measured at the 14 cm depth, and the dose in rads at the surface was about 2, a ratio which did not vary appreciably rapidly with depth between 1 and 12 cm. The rate however increased to a maximum of 3,4 in the peak at around 14 cm.

The dose rate of the beam we used for this purpose was quite low but sufficient for physical measurements which we plan to continue at CERN. Attempts have also been started to increase the pi-minus beam intensity, but our type of syncrocyclotron can probably barely achieve a dose rate in which biological experiments are feasible.

Argomento precedente
Indice
Argomento successivo