A.R.E.A.E.A./Rp-312

هيئة الطاقة الذرية ج.م.ع

ARAB REPUBLIC OF EGYPT
ATOMIC ENERGY AUTHORITY
DEPARTMENT OF ACCELERATORS AND ION SOURCES

SAFETY IN DESIGN AND OPERATION OF LOW ENERGY PARTICLE ACCELERATORS

BY

ISMAIL BADAWY

1991

INFORMATION AND DOCUMENTATION CENTER
ATOMIC ENERGY POST OFFICE
CAIRO, A.R.E.

AREAEA /Rep. 312

ARAB REPUBLIC OF EGYPT
ATOMIC ENERGY AUTHORITY
DEPARTMENT OF ACCELERATORS AND ION SOURCES

SAFETY IN DESIGN AND OPERATION OF LOW ENERGY PARTICLE ACCELERATORS

BY
ISMAIL BADAWY

1991
INFORMATION AND DUCUMENTATION CENTER

ATOMIC ENERGY POST OFFICE

CAIRO, A.R.E.

CONTENTS

ABSTRACT

This paper studies the safety in design and operation of low energy accelerators which produce beams of accelerated charged particles and radiations. As radiation sources, the accelerators are widely used in scientific research, industry, food and medical applications.

The risks to human and environment are considered. The safety in accelerators is discussed- particularly - the shielding against ionizing radiations, overexposure to RF radiation fire hazards and power filures.

Also the paper studies the emergency response at incidents. Emergency procedures are recommended for each type of emergency. Reporting to the competent Authority is also recommended to be prepared for each incident.

The basic principles of regulatory control, licencing and inspections for accelerator facilities are discussed. The relation with the competent authority is pointed out

I. INTRODUCTION

Various types of accelerators for the production of beams of accelerated charged particles and electrons are used in virtually all countries in the world in scientific research (1). The use of accelerators as radiation sources is nowadays wide spread in industry, food irradiation and in medical applications. Loss of control over such facilities may give rise to unnecessary exposure to workers or members of the public, sometimes with fatal results.

The large potential risk of these facilities demands careful and experienced design, manufacture, installation and operation to avoid harmful radiation exposure and other detriments. It is therfore important to achieve high degree of safety and maintain it during the whole life of the accelerator facility (2,3)

This study is limited to low energy accelerators, i.e. of energy below 30 MeV, where the build-up of radio-activity due to secondary or spurious radiations may not be considerable.

II. SAFETY OBJECTIVES

As a matter of principle in any scientific or industrial facility it is essentially required to keep risks to human and environment LOW. The main risk considered for a particle accelerator facility is associated with the potential hazard of ionizing radiation.

The final goal of radiation safety and for safety design of accelerators are:

i) To ensure during operation that radiation exposure of personnel and public remains below prescribed limits, and is kept as low as reasonably achievable "ALARA" (4).

ii) To ensure that accidents are prevented, i.e. to ensure that for all event sequences taken into account in the design of the facility- radiological consequences are SMALL, and to ensure by prevention the accidents with high consequencies are Extremely Unlikely.

In order to achieve the envisaged high degree of safety in an accelerator facility, the following safety philosophy concepts have to be applied (3,5,6):

- Defence in depth
- Safety analysis
- Safety system
- Redundancy
- Diversity
- Independence
- Fail-Safe design

III. SAFETY FEATURES

Safety features of a particle accelerator facility shall be realized either through design or in the construetion and operation. Reviewing and assessing by the competent Authoriy shall recommend whether additional safety measures have to be taken. The following items have to be considered:

i) Shielding

Radiation safety features shall be provided to preclude the emission of radiation in exess of the levels specified in the design (3,4). In order to obtain an appropriate shielding design, experience from existing facilities may be consulted

- In case of self-shielded facilities, the accelerator shall not be operable until all shielding components are in place and all other safety devices are actuated
- In case of facilities with Accessible Radiation Rooms- as schematically represented in Fig. 1a, 1b.

The following systems are provided (2,8):

1. Interlock system for;
   - personnel access
   - Radiation room lock-up sequence
   - Radiation operations
2. Radiation Monitor System (with alarms).
3. Portable Radiation Survey Meters System
4. Emergency Access Capability System for;
   - Stop operation
   - Control console to shut down

5. Warning Signals System for;
   - Visible signals
   - Audible signals

6. Status Indicators System for;
   - Accelerator in preparation
   - Accelator in progress
   - Accelator terminated

7. Noxious Gas Control System for;
   - Ozone and other noxious gases produced by radiolysis
   - Nitrogen oxides

ii) Power Failiures

In case of electrical power failiure of More Than 10 seconds, the accelerator radiation zone shall automatically become fully shielded and it shall be shut down. In cases where short-term electrical power failures of Not More Than 10 seconds occur frequently, it may be acceptable for means to be provided to avoid unnecessary accelerator shutdowns under these conditions (3)

Also, means shall be provided to ensure that failure of nonelectrical power such as pneumatic or hydraulic which is used to control or operate any safety feature or device, the accelerator shall automatically become fully shielded and it shall be shut down

iii) Fire Hazards

Due to malfunction or any other causes, heat build-up to the point of combustion may occur. Provision shall be made to protect the integrity of the accelerator. The following systems shall be provided:

- Temperature and Smoke sensors system
- Fire Extinguishing system
- Personnel Access door system

iv) Natural Features

Factors due to natural features such as Geologic and Seismic features could adversely affect the integrity of the acceletator and its radiation shields. Evaluation of the conditions should take into account the physical properties of the materials underlying the accelerator site and its environments. Area of potential or actual surface or subsurface subsidence, uplift or collapse should be carefully considered when assessing the suitability of a site for an accelerator.

IV. SAFETY CONSIDERATIONS IN DESIGN OF ACCELERATORS

The safety of a particle accelerator facility depends essentially on design features -especially - concerning the design and construction of radiation shields and devices such as interlocks and other controls for assuring acceptably low levels of radiation in the occupied areas and avoiding the entrance or presence of persons in fully restricted areas during operation. It also depends on the overall reliability of facility components to avoid the occurrence of incidents or accidents with abnormal radiation exposure conditions.

It is the objective of manufacturers of industrial accelerators to design the accelerator facility for simplicity and reliability of operation. In fact, it is the inadvertant exposure that may result from hands-on diagnosies and maintenance of working accelerator subsystems with the accelerator stages improperly or partially disabled. As long as the accelerating capability remains, there is possibility of X-ray generation (from dark currents) (2).

Also, designing for ease of trouble shooting is considered a factor in reducing the likihood of hazardous events. Other hazardous occurances such as electric shock and overexpsure to RF radiation will necessary have reduced chance.

The following safety design features may be considered in the design of the accelerator:

1. Positive means of disabling the main acceleration stage.
2. Built-in machine parameter monitoring.
3. Built-in remote machine diagnosies.

The radiation is produced in accelerators by:

i) Primary ion beam or electron beam.

ii) Spurious radiations.

iii) Neutrons, gamma-radiation and X-radiation prodnced as result of nuclear interactions of the primary beam with target materials.

The basic principles in the safety system of an accelerator facility are (3):

i) To verify that <u>No One</u> is in the accelerator hall, or in the irradiation room before the Authorization of Start of the accelerator, or the inlet of the radiation beam. Schematic representation of an "Authorization of Start" system is represented in Fig.2.

ii) Entry of radiation room or target room is Not Allowed with radiation beam on. An example of "Authorization of Access" system is given in Fig.3.

iii) The designed safety system should be of the positive safety type, i.e.; if any anomaly occurs in the circuits, the whole system should function to command the stop of the accelerator.

As an example, a cyclotron accelerator is considered in "STOP" if the following three conditions are applied:

1. No magnetic field.
2. The high frequency is cut-off.
3. The injection is cut-off.

An emergency stop system shall be ready and accessible to actuate in All sections of the accelerator installation. Fig.4. shows a schematic representation of an emergency stop system in a linear accelerator facility.

V. EMERGENCY RESPONSE

When an accident occurs-depending on its characteristics-workers and members of the public may be exposed. The most significant accidents may occur when a worker enters or remains in the irradiation room (or target room) with the beam of accelerated particles is going on. Very severe injury or death might be expected as a consequence of such an accident.

The possibility of accidental situations due to contamination may be less severe in low energy accelerators than in other irradiation facilities (e.g. gamma irradiation facilities, reactor channels,...) But accidental situations due to contamination cases have to be considered.

Following an accident, it is necessary to do the following:
- Reduce radiation exposure, both individual and collective
- Regain control of the situation in order to restore the site normally
- Treat the injured and overexposed
- Reporting the accident to the competent Authority

Emergency procedures should be written for each type of emergency that can be reasonably encountered. Procedures should be concise, easily followed instructions-specifying the immediate actions to be taken, and include the name (s) and telephone number (s) of the person (s) to be notified to direct remedial actions.

Any incident (or accident) shall be reported to the competent Authority according to a time-schedule which must be fixed in the licence (depending on the severeness of the incident).

The accelerator facility shall be capable of responding in the initial phase to mitigate the consequences of an incident in such a way that:

1. Radiation exposure to personnel and members of the public can be controlled.

2. Accident conditions do not aggrivate further, e.g. by preventing further integrity loss.

Provided these relatively stable conditions can be achieved, the complete restoration can be delayed, allowing for detailed planning of further remedial actions, i.e., the assistance from outside the facility (Competent Authority, accelerator manufacturer, service organization,.....).

VI. REGULATORY CONTROL

A Licencing process and regulatory inspections will be necessary to achieve and maintain control during phases of the operation of accelerator facilities - being considered as radiation faclities (3,9) .

The control over radiation safety in siting, design, construction, commissioning, operation and decommissioning of the accelerator facility is maintained primarily through governmental licences that authorize actions and place conditions on the licensee. Therefore, a primary task of the Competent Authority is to determine whether to approve or not approve the applications for licences on the basis of its review and assessment.

The major stages of the licensing process shall encompass the regulation of:

1. Siting
2. Design
3. Construction
4. Commissioning
5. Operation
6. Decommissioning

The applicant or licensee shall be required to submit and make available to the competent authority in due time all information that it specifies or requests. The format and content of documents submitted by the applicant/ licensee in support of licence applications should be established by the competent authority and he should be aware that the review and assessment of the information is a continuous process.

Other requirements should be imposed upon the applicant/ licensee by the competent authority include:

1. Periodic tests and serveys related to safety.
2. Regular reports to the competent authority including:

   - Senior staff changes
   - Radiological data
   - Operating data
   - Unusual occurences

The competent authority is responsible for regulatory inspections by which it satisfies itself that the licensee is fulfilling the conditions set out in the pertinent regulations and in the licence. The compentent authority is also responsible for enforcement - by which it can require correction of non-compliance with the conditions set out in the licence. Regulatory inspections - both announced and unannounced - shall be performed in all the areas of regulatory responsibility. The competent authority shall carry out -in addition to the normal regulatory inspection activities - regulatory inspections at short notice if an abnormal occurrence requires immediate investigation.

It is essential that the competent authority be given adequate powers to enforce compliance with its regulations and licences. It shall have statutory powers, Also, it should have to impose or recommend penalities, or to institute prosecution through the courts.

The degree of authority to the regulatory inspectors to take enforcement actions shall be determined by the competent authority. The regulatory inspectors are permitted only to inform the competent authority of the situation and it then takes the necessary action. On-the-spot enforcement actions are appropriate only in unusual situations.

VII. CONCLUSIONS

Particle accelerators are widely used facilities in scientific research, industry, food and medical applications. It is then important to achieve a high degree of safety and maintain it during the whole lifetime of the accelerator.

The major risks considered in the safety design of a particle accelerator are the potential hazard of ionizing radiation, fire hazard, electric shock, overexposure to RF radiation and noxious gas hazard. Safety features shall be realized either through design or in the construction and operation of the accelerator. Also, power failures, geologic site and seismic features shall be considered.

Safety systems shall include radiation shielding, radiation monitoring, interlock system, emergency access capability system, warning signals system and noxious gas control system

Emergency response must be carefully considered. Emergency procedures must be well established with concise and easily followed instructions. Any incident have to be reported by the accelerator responsible to the competent Authority according to a timeschedule.

The basic principles on regulatory control, licencing and inspections for accelerator facilities are studied. The relation with the competent Authority is pointed out.

ACKNOWLEDGEMENTS

It is the pleasure of the author to express sincere thanks to Prof.Dr. F.W. Hammad, Prof.Dr. M. Sultan, Prof. Dr. M.E. Abdelaziz for interest and encouragement.

REFERENCES

1. M.S. Livingston and G.P. Blewett, Particle Accelerators, MC G.-Hill Book Co . Inc. , New York, (1962) .

2. R. Delsaut, Principes de l'etablissement des securites aupres des accelerateurs, Raport No. D. CEN-S/SPR/SRI/ 81-413, (1981).

3. Safety and radiation protection aspects of the design and operation of gamma and electron irradiation facilities, IAEA Tech. Com. Mtg.- Doc. 2661 t, Draft, IAEA - Vienna, (1988).

4. IAEA Safety Series No.9, Basic Safety Standards For Radiation Protection IAEA - Vienna, (1982).

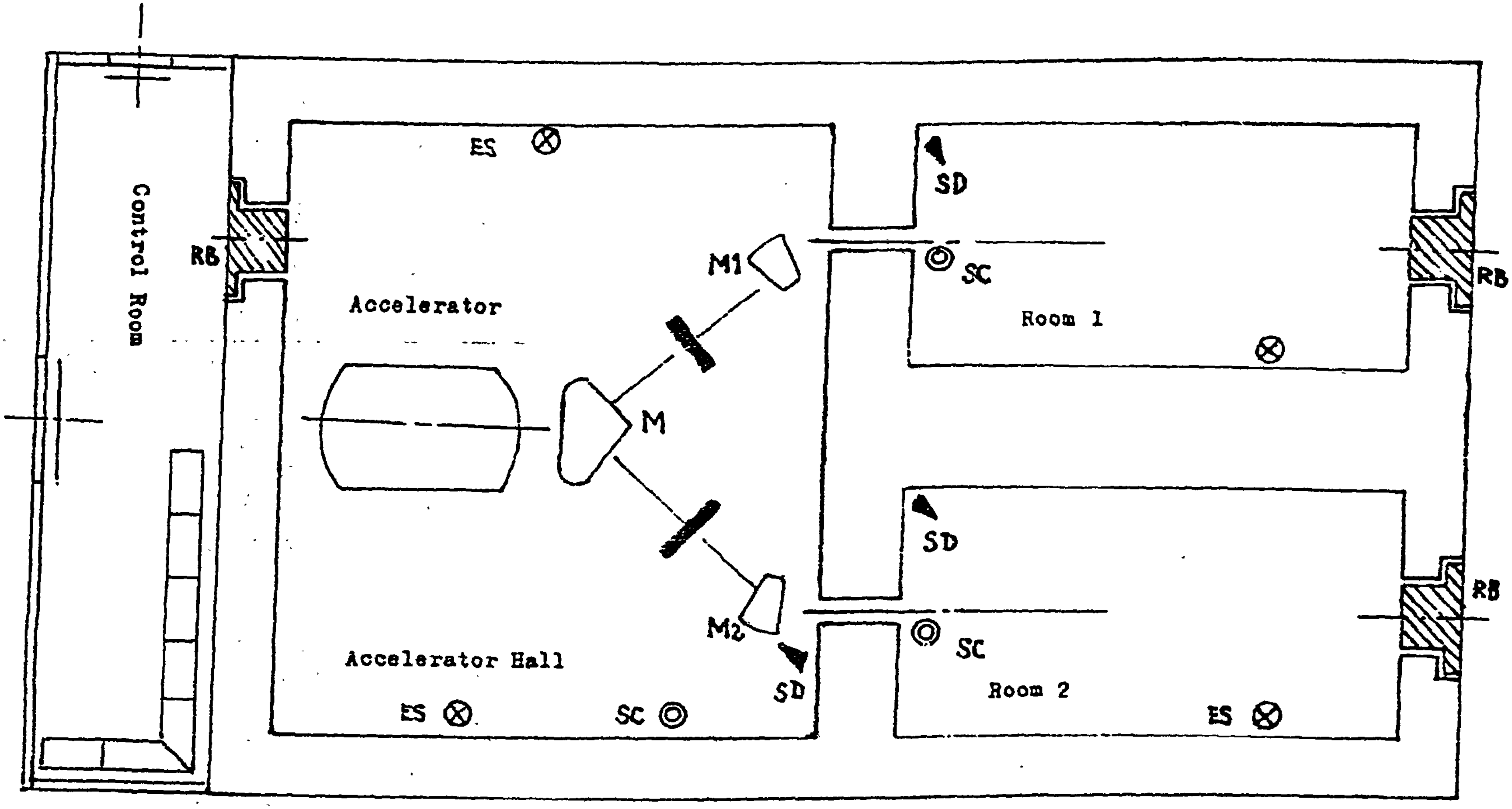
5. Security For Nuclear Power Plants, ANSI- USA, Report No. ANS 3,3, (1982).

6. Radiological Safety in the Design and Operation in Particle Accelerators, American National Standard N.43.1, (1969)

7. Reactor Shielding For Nuclear Engineers, Editor N.M. Schaeffer-National Technical Info. Service, Spring Field-VA, TID 25951, (1973).

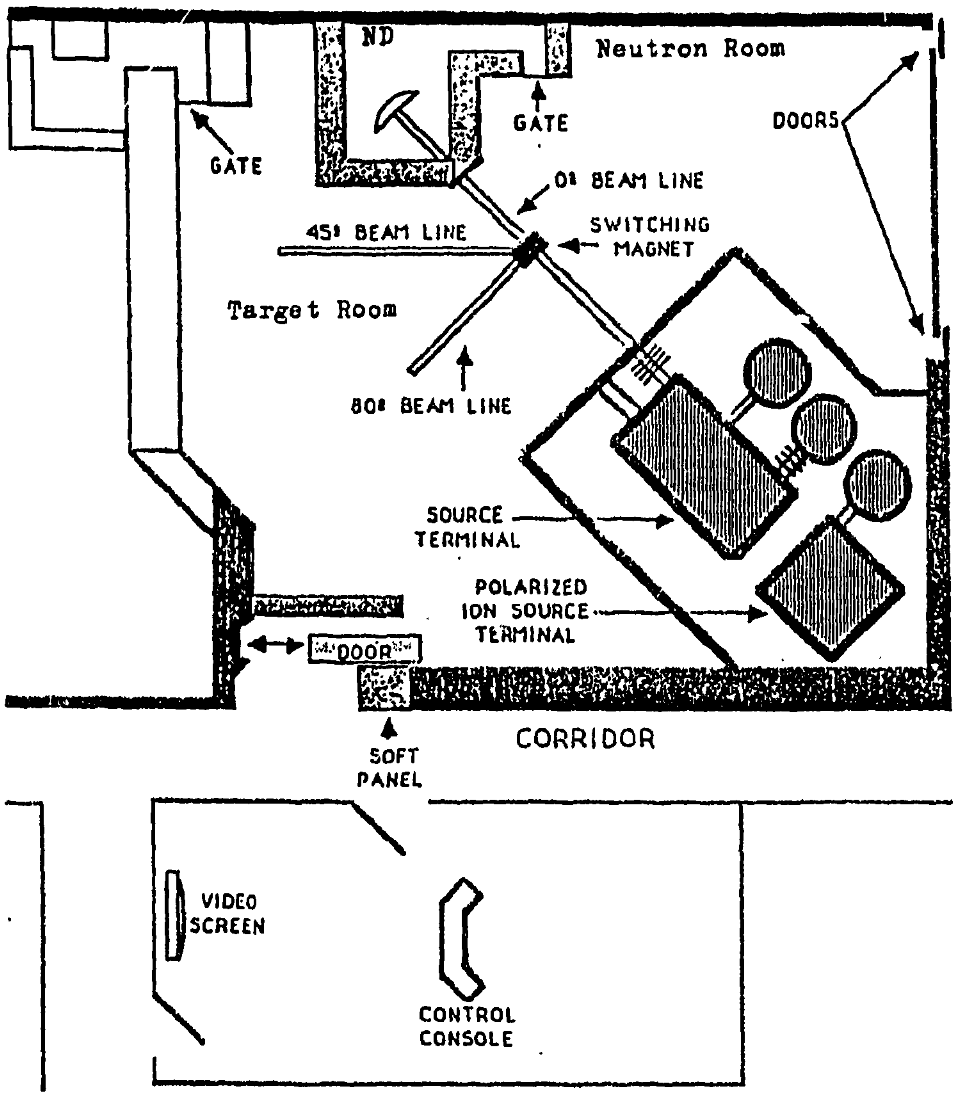
8. Radiation Alarms and Access Control, National Council on Radiation Protection and Measurements-USA, Rep. No 88, (1986).

9. Governmental Organization For the Regulation of Nuclear Power plants, A Code of Practice, IAEA-Safety Series No 50-C-G/ Rev.1. (1978).



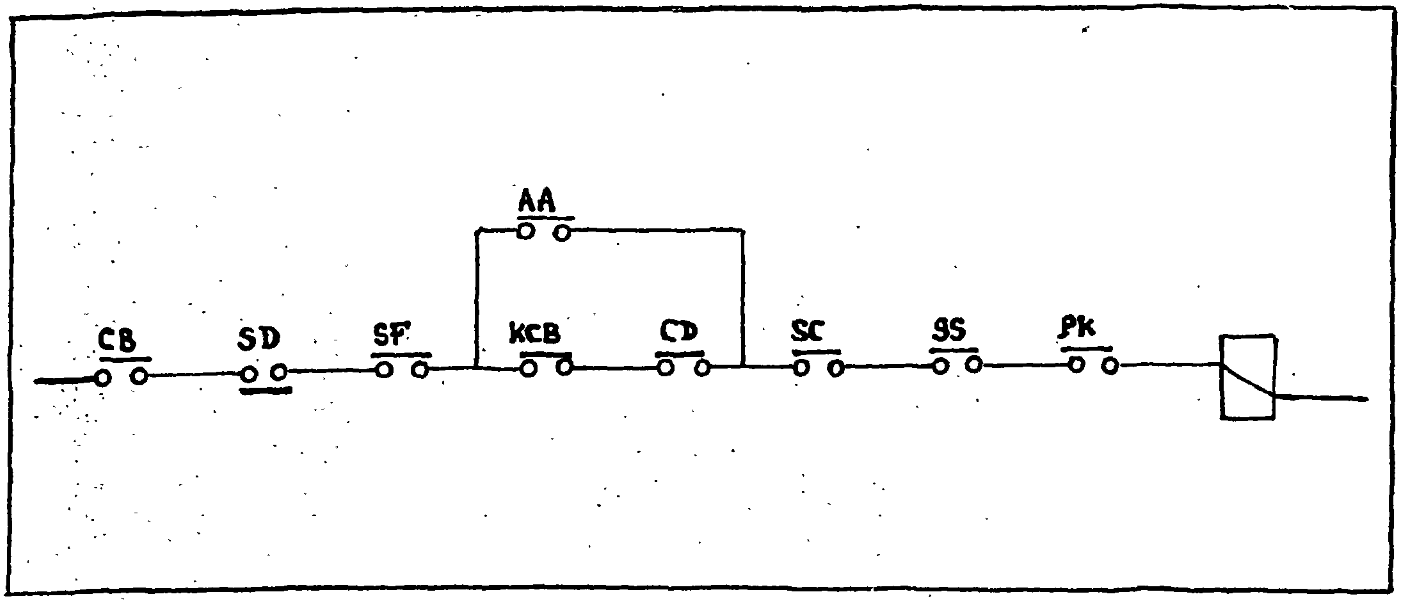
NB: ES Emergency Stop , RB Radiation Mobile Block
RS Radiation Screen, M Magnetic Deflector
SD Safety Detector , SC Safety Check Point

Fig. 12. Schematic representation of an accelerator installation with accessible radiation rooms.



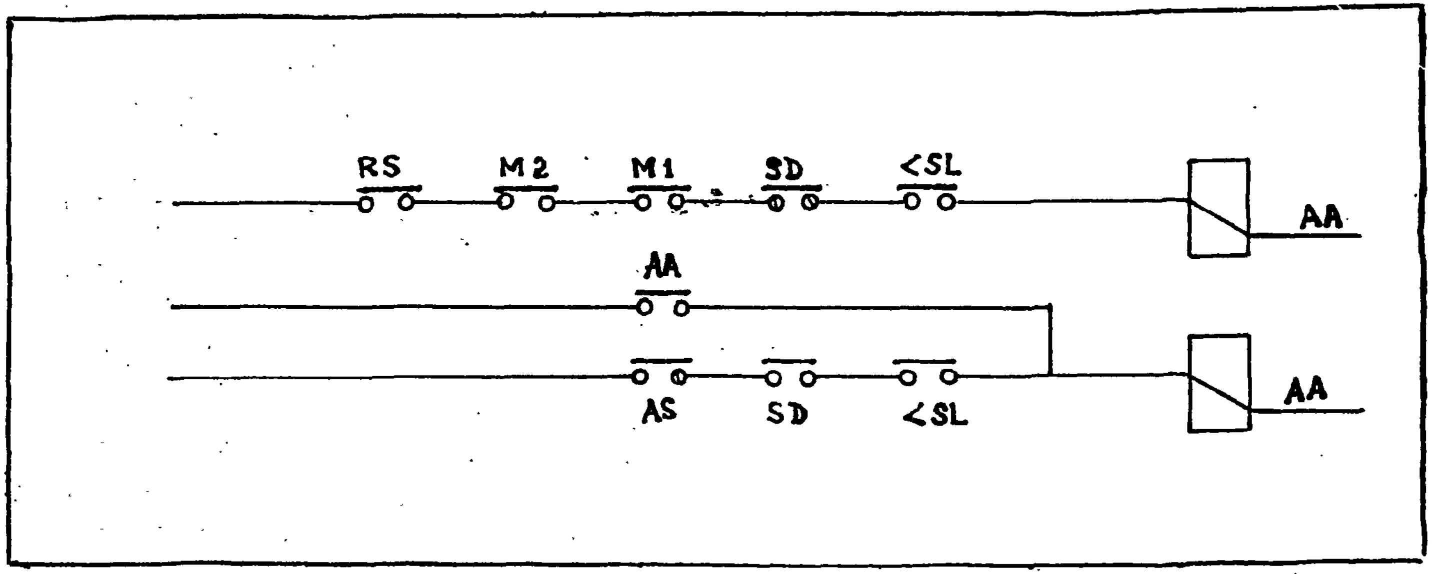
NB: ND Neutron Detection System

Fig. 1b . Layout of a low energy accelerator (350 KV) as a neutron generator facility and for applications.



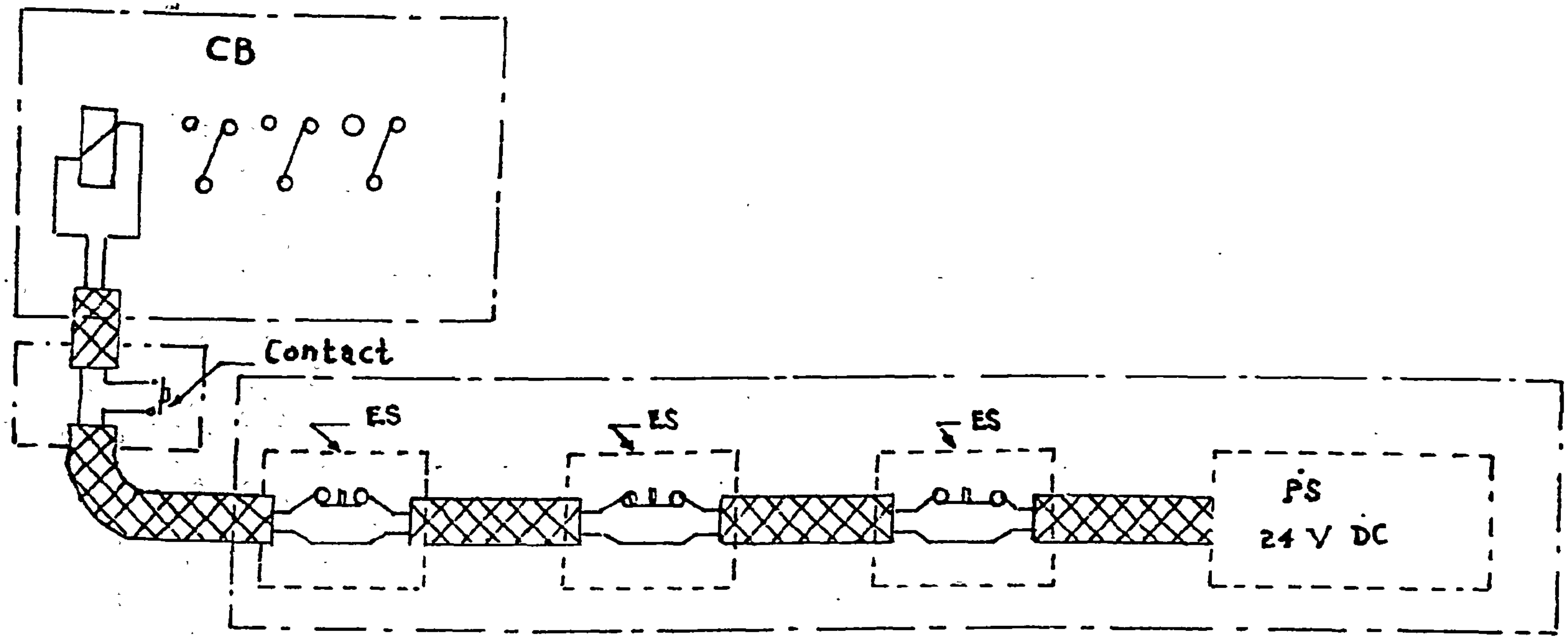
NB:	AA	Access Authorization	,	CB	Control Board
	CD	Contact of Door	,	KCB	Key to CB
	PK	Presence Key	,	SC	Safety Check
	SD	Safety Detector	,	SS	Sound Signal

Fig. 2. Symbolic representation of a safety " START " system in an accelerator.



NB: AA Access Authorization , AS Accelerator in STOP
M1 Magnetic Deflector-1 , M2 Magnetic Deflector-2
RS Radiation Screen , SD Safety Detector
SL Safety Limit of Radiation

Fig. 3. Authorization of access to a radiation room.



NB: CB Cotrol Board , ES Emergency Stop
PS Power Supply of System

Fig. 4. Schematic representation of an emergency stop system for an accelarator.