REACTOR MODEL, SITING AND ENVIRONMENTAL PROBLEMS: A CASE STUDY OF A NUCLEAR RESEARCH REACTOR PROPOSED FOR AHMADU BELLO UNIVERSITY

by

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ABSTRACT

The prospect of acquiring and siting a nuclear research reactor at the Ahmadu Bello University is assesed in this thesis. The reactor proposed is relatively cheap, easily constructed and operated, safe in terms of reactor accidents, common to users operating research reactors in developing countries, and uses low fuel enrichments which conforms with the International Atomic Energy Agency requirements.

The siting criteria examined includes considerations such as: reactor zones, topography, soil characteristics, meteorological conditions, and transport systems that will reduce traffic hazards. It is suggested that a research reactor of low power (1 MW), could be located at the proposed site because of the suitable siting conditions.

The environmental problems such as: dispersal of airborne radionuclides, anticipated ecological problems, aircraft crashes, flood, forest fires, radiation monitoring and site security were also considered. The most virile problem of the nuclear industry - waste management was also considered in the context of the rather low suspect waste that will be generated from the reactor. A low power reactor, like the one proposed for the university will not cause serious environmental problems, if safeguards and monitoring of radiations are performed effectively.

Finally, it is concluded that a low power Triga Mark II research reactor rated 1 MW (th), could be sited and operated safely at the proposed site with radiologically insignificant environmental problems.

DEDICATION

DEDICATED

TO

BASSEY AND ABASSI

DECLARATION

This thesis is an original work carried out by the author under the supervision of Prof. D.E. Ajakaiye and Dr. S.B. Elegba.

To the best of my knowledge, no part thereof has been submitted elsewhere for the award of a degree, or diploma, and the work of others is acknowledged and referenced.

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His experience on Triga reactors which he communicated to me liberally were gainfully utilized.

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The relevance of siting and atmospheric dispersion of radionuclides through diffusion studies became more meaningful after reading the documents.

In proposing the Organizational Chart for the Reactor Safety Board (RSB), the author is indebted to the views and meaningful discussions held with Prof. L.A. Konig of the Radiation Centre Kerforshungszentrum (KFK), Karlsruhe, West Germany. Also the willingness of Siegfried Jacobi and others to conduct the author round the Radiation Centre, the Central Security department of KfK, the controle console of the sodium cooled Fast Reactor of KfK, has been the most inspiring moves that motivated me in proposing the RSB Chart. The jointly edited work of Prof. L.A. Konig 'Jahresbericht 1980 der Hauptabteilung Sicherbeit, KfK 3113, April 1981' is also acknowledged as a source of some of the details used.

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EWA, I.O.B.

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CHAPTER 1

INTRODUCTION

1.1 General Introduction

On March 1981, Dr. S.B. Elegba, Mr. A.C. Bamgbelu and the author jointly inspected two sites, earlier proposed for the siting of a research reactor for the University. One of the sites is situated along the new Kano road, while the other is at Shika along Sokoto road. The author was later informed by the department that these sites were no longer accepted as proposed sites, based on the findings made from previous studies.

The author was then shown another site adjacent to Area A staff quarters and was then asked to examine, and make recommendations on the suitability of the new site for a University nuclear research reactor. This thesis therefore, is a case study of the reactor model, siting and environmental problems associated with the reactor proposed for the University.

A research reactor is desirable in Nigeria for basic training in nuclear technology. Although most developing countries(including Nigeria) are still planning for the acquisition of research reactors, others have operated research reactors for some years. A survey of the need and role of research reactors in some of the developing countries is therefore considered.

1.2 Background survey of research reactors and their role in some developing countries.

The first step in the development of a National Nuclear Programme is the acquisition of a research reactor, which then forms a nucleus around which training and research in the technology could be developed. All over the world, as many as 391 research reactors (SIPRI, 1976) were in operation in 48 countries. Of this number, only 4 are in operation in Africa.

They include:-

(a) WWR-C-CAIRO reactor with a thermal output of 2 Mega watt (2 MW), at Inshas, near Cairo under the Egyptian Atomic Energy Research Establishments

(b) TRIGA REACTOR of One Megawatts(1 MW) at the Trico Nuclear Research Centre, Kinshasa, Zaire

(c) Two reactors at Pelindaba in South Africa; SAFARI-1, rated at 20 Megawatt (20 MW) and PELIDUNA ZERO of negligible thermal output.

According to the International Atomic Energy Agency classification (IAEA, 1980), developing countries are grouped into four classes, namely:

(a) Stage-3 (countries with reactors in operation)

(b) Stage-2 (countries with reactors under construction)

(c) Stage-1 (countries making studies for the acquisition of reactors)

(d) Stage-0 (countries in the pre-planning stages of acquiring reactors)

In Stage - 3, five countries are known to have reactors in operation with India leading as having the greatest number of reactors. In Stage - 2, three countries are involved. Brazil leads this group in the number of reactors under construction. In Stage - 1, twenty-eight countries are undergoing studies for the acquisition of reactors. Stage - 0, includes the bulk of developing countries who are in the pre-planning stages of acquiring reactors. Nigeria is included in Stage - 0.

One practical explanation of such a low response to reactor technology in developing countries is that amidst various social problems, nuclear technology is not given top priority. However some developing countries have given exceptional priority to the development of nuclear technology, through the use of research reactors.

The Pakistan Institute of Nuclear Science and Technology (PINSTECH) operates a 5 MW pool-type research reactor at PINSTECH near Islamabad.

The reactor operation poses no hazard problem to the public including the population of Islamabad located 19 Km to the West of PINSTECH. The Pakistan Research Reactor - 1 (PARR - 1) has afforded Pakistanis a well-planned training programme for the operation of the Karachi Nuclear Power Plant (KANUPP) which has been in operation since 1972 (Nasim and Hasnain, 1974)

Under a bilateral agreement between the Phillipines and the United States of America, the Phillipine Research Reactor (PRR - 1) was acquired and sited at Quezon city. PRR - 1 is thermally rated 1 MW. The reactor reached criticality in 1963 and since then the Phillipine Atomic Research Centre (PARC) has conducted researches such as the Mercury inventory in electrolytic cells, determination of cladding and leaking in reactor vessels as well as plan for the 621 MW (e) PNPP - 1 power plant now under construction and which is to be commissioned in 1984 (IAEA, 1970).

The Egyptian Nuclear Programme apart from its emphasis on the development of nuclear energy is also concerned with nuclear desalination studies. Egypt's 2 MW (th) Tank Pool reactor is also utilized for regional studies under mutual co-operation between the other Arab countries. With a dire need for desalted water for irrigation and development of the coastal area along the Mediterranean, and in West Alexandria, it had been proposed that the 150 MW (e) nuclear power plant

planned for Bung EI Arab coastal area (Mahoud et al , 1969) will include a pilot sea-water desalination unit capable of desalting 20,000 m^3/d of water for irrigation purposes. Studies carried out at Inshas indicated that from 1980 to 2000, Egypt nuclear programme will require dual purpose nuclear plants of 9,000 MW (e) output. The success of the Egyptian nuclear programme studies had been attributed to their research reactor commissioned since 1961 (Mahmoud el al, 1971).

The Zaire TRICO Nuclear Centre operates a 1 MW (th) Triga Mark I reactor which went critical in 1959. The reactor uses enriched Uranium - 235 with Zirconium Hydride as moderator. On the experience gained in using the TRICO reactor, Malu (1971) noted that a research reactor is efficiently utilized when integrated into the activities of a University and when funds for its operation and maintenance are available for its ancillary equipment. The TRICO Reactor is attached to the Kinshasa campus of Universite' Nationale' Zaire. Zaire plans to install a 100 MW (e) Triga reactor for the country's nuclear programme as well as transforming the TRICO Nuclear Centre into a regional centre for nuclear research in Africa (Malu, 1971).

From the examples cited above, it is obvious that the role of research reactors in developing countries is in acquainting nuclear scientists with some of the identical experience expected when power reactors are operated. Even in cases where the development of nuclear power is yet a distant prospect, research reactors have been greatly used in nuclear science technology as in food preservation / production studies, insect control, medicine, water resources development, geologic and industrial applications as well as radiation studies in Health Physics and reactor safety.

The A.B.U. nuclear research reactor will stimulate interest in the development of Nuclear Technology basically in two ways. Firstly, it will expose Nigerian Scientist and technologist in the field of nuclear power planning to fundamental consepts of nuclear power plant operation and maintenance. Nuclear power is very desirable in Nigeria if she has to diversify her energy sources, rather than depend on power supply solely from fossil fuels. Secondly a research reactor promotes thorough study of water movements and related hydrological characterestics through the use of isotopes (as tracers).

A nuclear research reactor is a singular facility that could be used in the training of all categories of scientists, using nuclear techniques for research work. The reactor is therefore desirable in Nigeria for the take-off of nuclear research.

CHAPTER 2

REACTOR MODEL

2.1 Research reactors

Research reactors are classified in several ways, depending on the type and arrangement of fuel, moderator, coolant used and neutron speed, sustaining the fission process.

Some reactors are classified on the basis of the material used in slowing down the neutron energy during the fission process. These materials are known as moderators. The principal moderators are light - water, heavy - water, and graphite.

An arrangement of the moderator and fuel, provides another basis for classification. In reactors where the solid fuel is fixed in a regular lattice within the moderator, the reactor is termed heterogenous, while in reactors where the fuel and moderator are intimately mixed in the form of solutions (aqueous, liquid salts, or metals) the reactor is termed homogenous.

Fission neutrons are also used in classifying reactors. A fast reactor is one in which most of the neutrons are in the energy range of 0.1 to 1.0 MeV, while a thermal reactor has neutrons with energy less than 0.1 eV.

The main classification (IAEA, 1970) of research reactors based on the above features are therefore as follows :-

I Light-water - moderated, pool - type.

II Light - water - moderated, tank - type.

III Aqueous - homogenous.

IV Argonaut.

V Solid - homogenous

VI Heavy - water - moderated.

VII Graphite - moderated.

VIII Fast.

The choice of a reactor from any of the classes listed above depends on several factors including:-

(a) main purpose for which the reactor will be utilized

(b) choice of the fuel cycle

(c) choice of moderator and coolant (e.g. air and water)

(d) economic implications of the model .

(e) technical flexibility (i.e. whether the reactor is upgradable)

(f) thermal power output of the model

and (g) the inherent safety design of the reactor.

Considering these factors therefore, Universites prefer to use less expensive, common and easily operated reactors.

Classes of reactors involving heavy - water moderation are not common research reactors because of the cost of Deuterium (heavy water) plants. Fast, and Graphite moderated reactors are also not popular because of the cost of maintaining such reactors. Out of the eight classes of reactors listed, three of them contain the bulk of the reactors commonly used. These are : the Light - water - moderated reactors, Argonaut reactors, and the Solid - homogenous (Triga reactor) types. These reactors are now considered.

2.2 Light - water - moderated, pool - type:

Light - water - moderated reactors utilize ordinary water as moderator and sometimes also as a coolant and shield. The core design is simple, consisting of a lattice of fuel elements. This is immersed in a large pool of water. The term "pool reactor" is popularly associated with this type of construction.

Highly power - rated models of light - water - moderated, pool - type reactors like the Galileo Galilei rated at 5 MW (th) operated by the University of Pisa at Italy could be used for material testing researches.

A prototype of a light - water - moderated pool - type reactor is the Bulk Shielding Reactor (BSR - 1) at Oak Ridge National Laboratory, U. S. A.

Its thermal output is rated at 2 MW with an average neutron flux of 1.5×10^{13} n/cm^{2}s (IAEA, 1970). The fuel elements of bSR - 1 are hollow bundles of plates, through which water flows by natural convection. The pool water acting as moderator and coolant circulates between the fuel plates. It also serves as reflector and shield. Flexibility of the reactor allows movement of the core in one direction along the reactor pool since the core is supported from a crane. Access to the reactor is practically unrestricted since the use of water as both shield and coolant permits direct visual observation of the reactor core during operation. The gamma radiation dose at water surface directly above the reactor of a power level of 1 Mw is about 140 mR/hr. The high degree of accessibility of the pool type reactors allows a wide choice of diversified experiments including:-

(a) Radiation - damage work carried out on large or small components.

(b) Attenuation of radiation in various materials.

(c) Chemical analysis by means of radioactivity.

(d) Production of ralioactive isotopes with fairly intense specific activities.

(e) Neutron activation analysis

2.3 Argonaut type:

The original Argonaut reactor was designed by Argonne National Laboratory U.S.A. Since then many modifications have been made from the prototype.

One essential difference between Argonaut reactors and the light - water reactors is in the core arrangement. In the light - water reactors, the parallelepiped dimension and shape is prefered with either square of rectangular lattices. While in Argonaut reactors the core is cylindrical annulus with fuel assemblies in a circular lattice positions. This arrangement necessitates two reflector positions and for this reason Argonaut cores have both axial and radial reflectors. The core is not submerged in the coolant like the pool or tank type but rather cooled through loops fed from a nearby feed-water tank. Such an arrangement does not make the reactor fairly accessible as in the pool and tank types. The containment is a brick building with thick walls. One of such reactors is the Argonaut reactor (RIEN - 1) rated at 10 KW (th). The reactor is located at the Institute de Engenharia Nuclear, Cidado Universitaria, Rio de Janeiro, Brazil. Most Argonaut reactors use dimineralized water as coolants. The reactor cores are properly shielded with concrete blocks of varying thickness. The top shield is made in the form of movable parts for the core.

Some of the Argonaut reactors used for research purposes include the JUGERNAUT rated 250 (Kw (th), located at Argonne (USA), the STARK rated 1 Kw(th), at the Federal Rep. of Germany, the UTR - 10 KINKI rated 1 Watt, at Osaka (Japan) and the Argonaut reactor at the University of Manchester (U.K.), jointly used with the University of Liverpool.

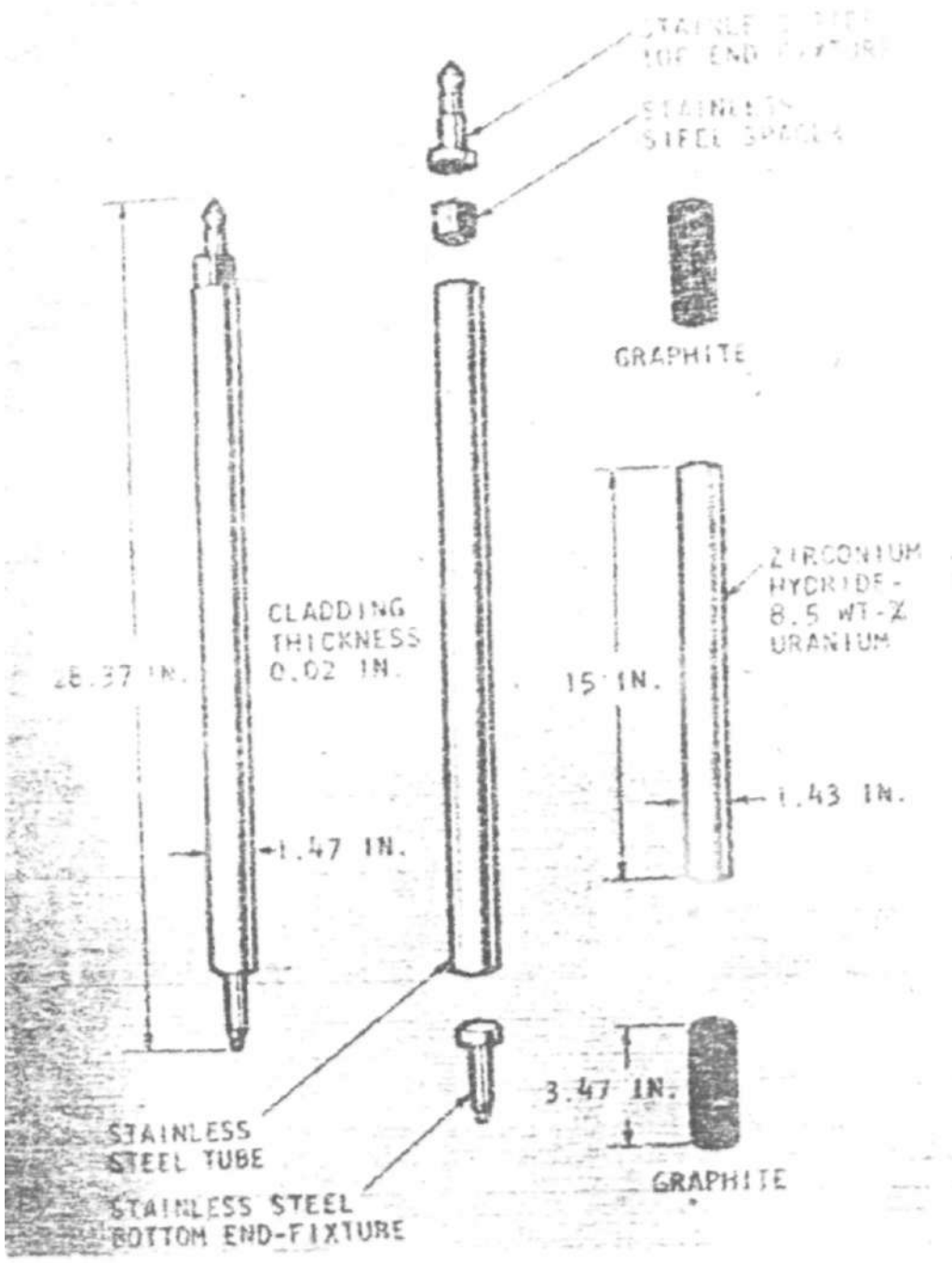
Argonaut reactors have generally low thermal power between zero power and 250 Kw (th). They are bulky as a result of their thick concrete shields and are also difficult to manipulate. They are not upgradable hence may not be suitable for the demands of the increasingly new fields of research in nuclear technology. Such a reactor model is therefore not recommended for the Ahmadu Bello University nuclear research centre.

Some of the areas of research in which Argonaut reactors could be utilized include: studies of neutron flux distribution, determination of velocity distribution of fission fragments, biological and physical effects of thermal neutrons and investigation of radiation damage by hard gamma rays.

2.4 Triga reactors and their characterestics

Triga reactors like most research reactors are the solid-homogenous types, where the fuel and moderator consists of a homogenous mixture of Uranium and Zirconium Hydride.

Fig. 2.1 A TYPICAL TRIGA FUEL ELEMENT



(after GIETZEN, 1980)

All over the world, there are 60 Triga reactors (Gietzen, 1980) operating in various nuclear research institutions. Triga (Training, Research, Isotope production - General Atomic) reactors have a wide range of applications in nuclear technology research. The Mark I prototype designed by General Atomic, San Diego, California has been modified with three other models : the Mark II, III and IV now in common use. These models have various shield designs and experimental facilities. Some of the important features of the Triga reactors which make the models popular in nuclear research are considered below.

2.4.1 Fuel element

Triga fuels consists of 20% enriched U-235 in Zirconium Hydride ($U\text{-}ZrH_x$). This conforms with the International Atomic Energy Agency requirements : that research reactors should use fuel of low enrichments. A standard Triga fuel has an active fuel ($UZrH_{1.65}$) length of 35.6 cm, with graphite pieces at its ends (Fig.2.1). In the Mark I model, the critical number of fuel elements could be 60. However, as a result of pulsing, operational control and poisoning by fission products (e.g. Xe - 135) greater number of fuel elements are required in order to operate at higher power levels. At 250 Kw power, a loading of about 70 fuel elements is required, while up to 80 elements are for 1 MW power and pulsing to 2,000 MW.

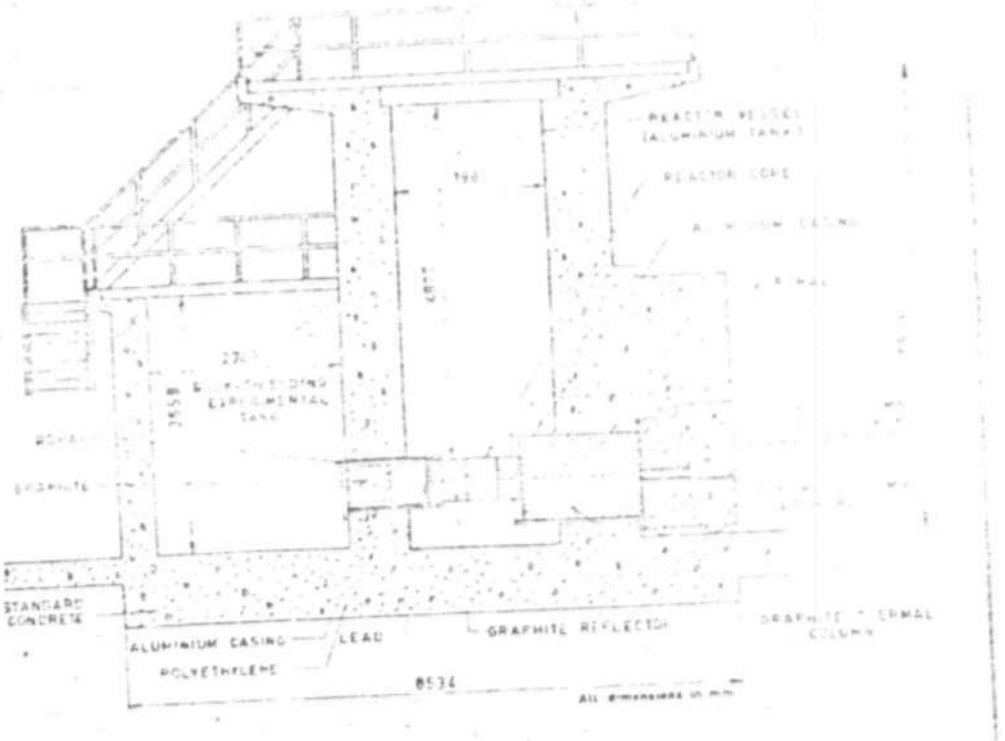
Pulsing a reactor to high power levels are sometimes desirable in material testing. The fuel for the proposed reactor should be a Triga fuel so as to conform with IAEA requirements of low enrichment.

2.4.2. Neutron flux and reactivity:

Neutron flux in Triga reactors vary depending on the thermal ratings of the models. Flux averages of 2×10^{12}n $cm^{-2}s^{-1}$, 4.0×10^{12}n $cm^{-2}s^{-1}$ and 1.7×10^{13}n $cm^{-2}s^{-1}$ have been obtained in the Mark I, II and III models.

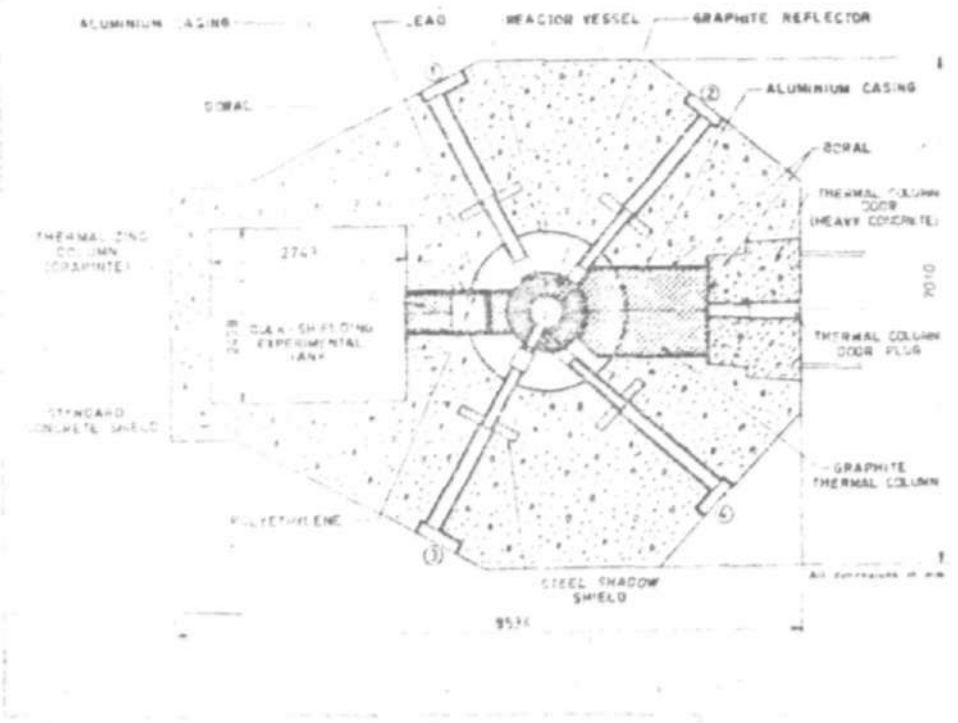
Nuclear research institutes prefer the use of Triga reactors owing to its prompt negative temperature coefficient of reactivity ($-1.0 \times 10^{-4} \frac{\Delta k}{K}$ per ^{o}C) afforded by the homogenous fuel and moderator mixture (Profio, 1976) when the fuel is Uranium - Zirconium Hydride ($UZrH_x$). A power excursion resulting from a step increase in reactivity is self terminated by the temperature rise due to pulsing.

The major contribution to the prompt negative temperature coefficient of reactivity is as a result of the low thermal utilization (fewer thermal neutrons absorbed in U - 235 relative to water) when the Zirconium Hydride becomes heated.



Source: (IAEA, 1970)

Fig. 2.3 HORIZONTAL SECTION OF A TRIGA MARK II REACTOR CORE SHOWING THE 4 BEAMPORTS.



Source: (IAEA, 1970)

This is a unique property of Zirconium Hydride in response to neutrons at higher energies. At higher energies, the transport cross-section is smaller (mean free path longer) since the average chord length of the hydride in the fuel elements is comparable (Profio, 1976) to mean free path, the probability of a neutron escaping into the water increases. In the water, the neutron is rapidly rethermalized (slowed down). Water has a high slowing down power of 1.53 cm^{-1} (Aschner, 1978) and a higher absorption cross section of 0.66 barns than Zirconium (0.18 barns). The net effect is that capture in water is increased while absorption in fuel is decreased. This action decreases the reactivity at high power levels.

2.4.3 Shielding and Control

Triga reactors have adequate designs for shielding and control. For the swimming pool type, the core is submerged in a light - water cylindrical tank at depths of the order of 7 metres. A typical position of a Triga core in relation to other supporting facilities is shown in Fig.2.2 The radial dimension of the tank is about 2 metres with the core supported at a depth of 5 metre by the use of 4 radial beam supports (Fig 2.3).

Shielding of the core is done by the use of cheap and available shielding materials like water and concrete. On the sides of the core, the shielding is light water, and concrete, at the bottom of the core, the shielding is light-water, concrete and earth while the core top is shielded by light water at a height of 5 metres. By this design the light water equally provides for the cooling of the core by natural convection as well as being a transparent shield on top of the core thus affording an easy access for the manipulation of fuel elements and experimental apparatus (Fig.2.2). The core itself could be inspected from the reactor bridge mounted on top of the swimming pool as shown in Fig.2.2. This is a special advantage Triga reactors have in using light water as shield and coolant. The proposed A.B.U. reactor should therefore use light water as shield and coolant owing to its natural abundance cheapness and availability. In the Mark III models the pool water is circulated around the core by a pump through a heat exchanger and is continuously purified in an auxilliary loop by a mixed-bed demineralizer (ion-exchanges) and filter system at 20 g/min (IAEA, 1970). If the proposed A.B.U. reactor is a Mark III model, the loop system used as heat exchanger could be used for basic research in energy conversions (thermal to electrical) as is obtained in large power reactors used in the production of electricity.

Control of the operation of Triga reactors could be accomplished by the use of 1 regulating rod (for fine control) 2 shim rods (for coarse control) and 2 safety scram rods (for rapid shutdown). The control of neutrons (by absorption) in the core is achieved by Borated Graphite poison rods (thermal absorption cross - section of Boron being 750 barns). The rods could be cladded in stainless steel. The control rods are operated by an electromagnet which responds to a servo-mechanism, allowing them to fall under gravity in a scram time of less than 0.35 seconds.

2.5 Triga models and their common features

Apart from other specialized reactors, General Atomic(GA) has designed four Triga reactor models commonly called the Mark I, II, III, and IV models. These models are the most widely used research reactors out of the 60 Triga reactors in 20 countries around the world. All the four models are open pool, light-water-cooled reactors, using Uranium Zirconium Hydride as fuel, at low enrichments. One special advantage of the swimming pool type of Triga reactors is that all radioactivity emanating from the core must first pass through the water (which submerges the core) before it reaches the air at the water surface. The pool water acts as a biological shield, thus reducing the concentration of radioactivity in the reactor building.

The experimental facilities common to all the four models include: (a) a rotatry specimen rack, (b) a central in-core irradiation thimble, (c) a pneumatic transfer system and (d) facility for inserting experimental specimens in various in-core locations. Features that identify each model from others include, thermal power ratings, core locations, irradiation room, access to the reactor core, and exposure room facilities. Each model is considered in detail below.

2.5.1 Mark I

The Triga Mark I was the first in the series of Triga reactors developed by General Atomic. The prototype [illegible] was first put into operation at General Atomic, San Diego, California, in 1958 at a power level of 10 KW. It is the simplest and least expensive model available (General Atomic, 1980).

The reactor core is placed at the bottom of the open cylindrical tank with the top of the tank at grade level. The reactor can be manipulated through an access at the top only. The core is cylindrical with annular graphite reflectors.

The Mark I models have low power levels. The highest power of an operational Mark I is at 1 MW (Gietzen, 1980) A recent listing of facilities to which nuclear reactor instruments made by General Atomic has been approved shows that 16 of this model are in operation all over the world.

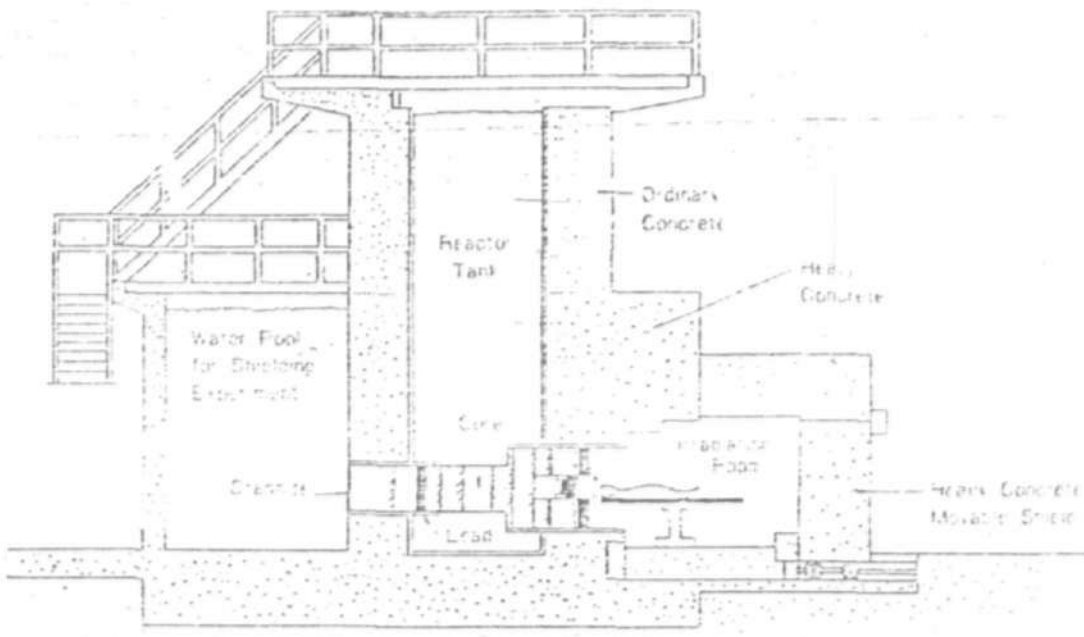
Limitations of this model in research work is as a result of the restrictive access to the core(vertically only), low thermal output (less than 1 MW), abscence of bulky specimen irradiation facility, and difficulty in upgrading to high power levels.

2.5.2 Mark II

The first Mark II reactor was construted in 1960, at the University of Illinois (USA). The Mark II model has a shield structure above the floor level, allowing for horizontal and vertical accesses to the reactor core. The core itself is submerged in a pool of water within a cylindrical tank. Also incorporated into this model are radial and tangential beamports. This model has a reactor platform for core loading and other manipulations. There is a large pool irradiation facility for the irradiation of bulky samples (Fig.2.2).

Some major limitations in the use of the Mark II model is the stationary nature of the core and the abscence of an exposure room for neutron and gamma ray therapy. However, a typical Mark II reactor can be re-modeled to suit this purpose, although the cost and considerable change of structures in the thermal column may not, in some cases, justify the need for the re-modelling.

FIG. 2-4 A VERTICAL SECTION OF A TOKAI PARK II REACTOR RE-MODELED TO INCLUDE AN IMPOUND HOOD



(after AIZAWA, 1980)

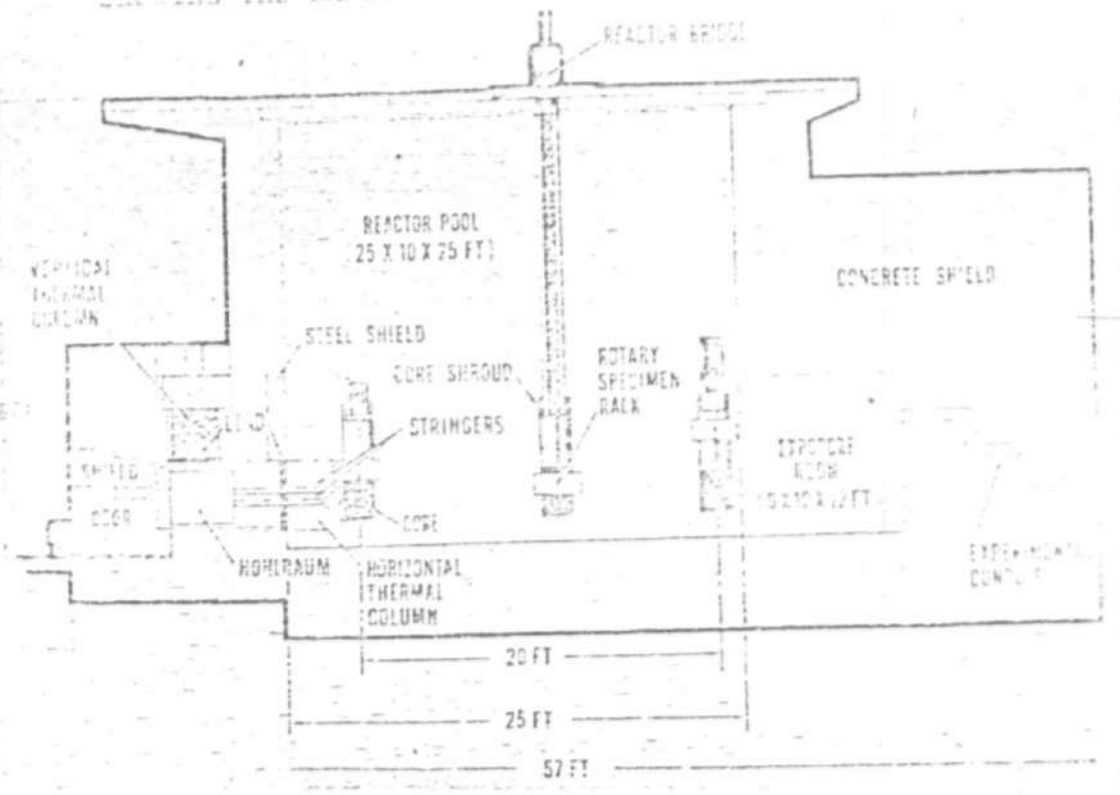
Such a re-modelling has been succesfully achieved at the Musashi Institute of Technology, Japan (Fig 2.4), where a Triga Mark II reactor rated 100 Kw was re-modeled to include an irradiation room (Aizawa et al, 1980). The Mark II model is the most widely used Triga. with 20 currently in operation (Gietzen, 1980).

2.5.3 Mark III

Basically the design of this model is identical to the other two models. The core is a movable type, supported on a bridge.

The reactor core, cooled by natural convection of pool water, could be made to move along the bridge to three core positions (Fig.2.5). This makes the model more flexible in reactor experiments than those with stationary cores. The core can be manipulated to move along the bridge to the exposure room position, allowing for the utilization of thermal neutrons for neutron therapy at the exposure room. The presence of a large exposure room in this model makes it more desirable for biomedical research.

The rotatry specimen rack in this model can be constructed to contain as many as 81 specimen vials, which can be rotated about the core, allowing an equal neutron exposure to specimens inspite of an azimuthal variations of neutron flux density.



(after GIETZEN, 1980)

There are 6 of this model currently in operation all over the world (Gietzen, 1980).

2.5.4 Mark IV

This model is not commonly used by research institutions and Universities. They are high powered Triga reactors with high neutron fluxes. The pool and shield structures are larger than those of the other models, and the power levels are in the range of 5 to 15 MW. They are mostly used for power reactor fuel testing, and investigation of special effects of radiation bursts. This model has the basic configuration of the other models but with additional three radial beam-ports. (Fig.2.6)

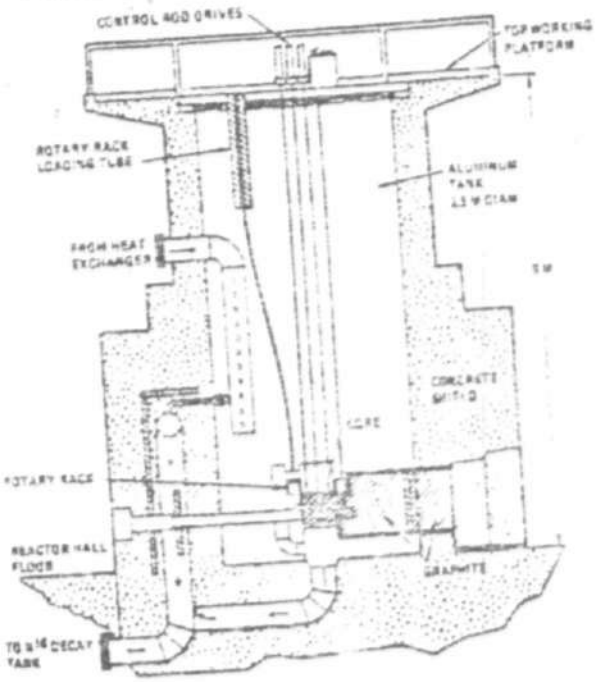
2.6 Proposals

From the discussions on reactor models, it is hereby suggested that a reactor proposed for the Ahmadu Bello University Nuclear Research Centre should have the following features:-

(a) Low U-235 fuel enrichment, so as to conform with the International Atomic Energy Agency requirements.

(b) The reactor should use cheap available light water as coolant for economic reasons. It is not possible to operate a heavy water moderated reactor without installing first a heavy water plant. Heavy water plants are expensive.

Fig. 2.6 A TRIGA MARK IV MODEL CONFIGURATION



(after GIETZEN, 1980)

(c) The Zaria reactor should have a high neutron flux of the order of 8.0 x 10^{13} n cm^{-2} s^{-1} since in some medical treatment, like neutron capture therapy a flux rate above 2.5 x 10^{12} n cm^{-2} may be required for a considerable length of time (Aizawa et al, 1980)

(d) Since installing a reactor is an expensive investment, and since reactors are not installed too frequently, Ahmadu Bello University should go in for a reactor in the range of 1 MW, rather than those in the kilowatt range. These low power reactors have limitations in neutron fluxes.

(e) The Zaria reactor should be one that enjoys popular demand, as well as common to most developing countries, and Universities. Out of the 30 research reactors in developing countries (see Appendix E) 80% of them are rated below 5 MW. Of this number, 50% of them are rated 1 MW, and most of them are utilized by Universities for educational and research purposes. Such a reactor(1 MW) therefore will allow for a wide range of joint research programmes as well as quick identification of reactor faults and problems, which may be similar with other users.

(f) The proposed reactor should be such that could be quickly and easily constructed and installed so as to minimize the ever increasing cost of construction materials due to inflation. This will keep the overall cost of the reactor as low as possible.

(g) As beginners in the quest for nuclear technology in Nigeria, the ABU reactor should be easily operated and maintained so as to give the University community constant assurance of its safety. A moderate power reactor of 1MW rating is desirable in this context.

2.7 Recommendations

Using as guidelines the proposals and the salient discussions in this chapter, it is recommended that the principal design parameters of the proposed Ahmadu Bello University research reactors be as follows:-

Reactor model	TRIGA Mark II
Maximum steady - state power level	1 MW(th)
Type	Swimming pool reactor
Neutron flux	8.0×10^{13} n $cm^{-2} s^{-1}$
Coolant	Light water (H_2O)
Cooling system	Natural convection
Fuel element design	
Fuel-moderator material	Triga fuel ($UZrH_x$)
Enrichment	20% U-235
Shape	Cylindrical
Cladding	Stainless Steel
No. of fuel elements	Up to 70

Reflector	Graphite rods
No. of control rods	
Safety	2 scram rods(rapid shut-down)
Regulating	1 (fine control)
	2 (coarse control)
Transients	1
Experimental facilities	
No. of beam tubes	4
Reflector irradiation positions	As may be required
Specimen racks	100
Rabbit systems	As may be required
Utilization	Multipurpose, Radioisotope production, Education and Research.
Schedules	
Period of construction studies	1982 - 1983
Construction period	1984 - 1987
Staff training (Algerians)	1982 - 1987
Commissioning	1987
Reactor life span	30 years

CHAPTER 3

SITING

3.1 Siting criteria and safety aspects

The siting of a nuclear facility is always considered more carefully and restrictive than other industrial facilities as a result of the associated environmental problems anticipated from either normal operations or the worst possible accident. Siting criteria therefore varies, with more demanding conditions laid down in Safety Analysis Reports (SAR) for power reactors and fuel reprocessing plants, than is expected for research reactors. Also it varies from country to country depending on licensing legislations, Rosen and Schmidt (1980) outlined some typical siting practices maintained by some countries(table 3.1). Such siting practices are used for siting power reactors. The proposed reactor being a research reactor should have its siting criteria scaled down considerably.

In siting a nuclear facility, the criteria used for site assesment includes: reactor zones, site topography, land-use, meteorology, demography, ecological problem, accessibilty, and proximity to coolant source. These details are hereby considered in assessing the proposed site.

3.2 Reactor zones

It is common practice to acquire two zones around a reactor for constant monitoring of radiations. The zones are the 'exclusion' and the 'restrictive zones'.

TABLE 3.1

Typical current reactor siting practices

Country	Exclusion Zone	Restrictive Zone	Remarks
Canada	1 km	-	Individuals and collective dose limits used.
India	1.6 km	5 km	No population centre of 16,000 within 16 km in the main wind axis.
Italy	0.8 - 1 km	-	Typical value adopted.
USA	0.65 km	5 km	Accepted value for plants licensed in 1960's.
USSR	3 km	-	Typical value.

(after Rosen and Schmidt, 1980)

For the proposed research reactor location, both zones should extend extensively in the north-east/south-west directions, since they are the prevalent wind directions.

The exclusion zone as the name implies is a zone completely under the control of the institution or agency running the reactor. In most research reactors this zone is well marked around the reactor by the use of a well secured fence on which the internationally accepted radiation emblemsare displayed at some convenient intervals. In the vicinity of the fence there should be a continuous margin of accessible road enclosing the reactor and its allied laboratories. This road is necessary for the continuous and fast surveilance of boundary dosimeters in times of emergency and also for a quick movement of the patrol team(Security Unit) along the reactor fence.

The restrictive zone may not be within the control of the University)operating the reactor). However, the University may be required to influence the development and growth of facilities around this zone as well as restricting the concentration of population within this zone. Land use in this zone may also be restrictive. This zone does not require any fence on its borders. Extensive use of this zone for agricultural purposes like planting of vegetables and livestock grazing should be discouraged for fear of contamination by precipitation of airborne radionuclides during reactor operation, especially in the downwind direction.

Since the waste water pathway will be within this zone, soil contamination could be another limiting factor for effective land use of the area around the waste water pathway.

As long as the proposed 1 MW research reactor is a nuclear facility using nuclear fuel, any abnormal condition could arise which may cause unnecessary anxiety and fears amongst those living near the reactor. Population concentrations centres like staff quarters, students population, and Jam'are village, will give the reactor management serious environmental problems to contend with should there be any reactor accident. To elimate these fears, the reactor should be located at a convenient distance of say 2 km from human populations. If this is done, the Health Physics unit will have enough area to monitor effectively as well as establish a high degree of confidence on those living around. This aspect of reactor management is important for a smooth take-off of nuclear technology in Nigeria. If the Health Physics unit fails to inform the public accurately about the safety of the first reactor, it will be difficult for legislators in the National Assembly to effect the necessary bills for the smooth licensing of reactors in the country. In this regard therefore, the analysis of the safety of the first reactor in Nigeria will be very crucial to the acceptance of nuclear technology in the country.

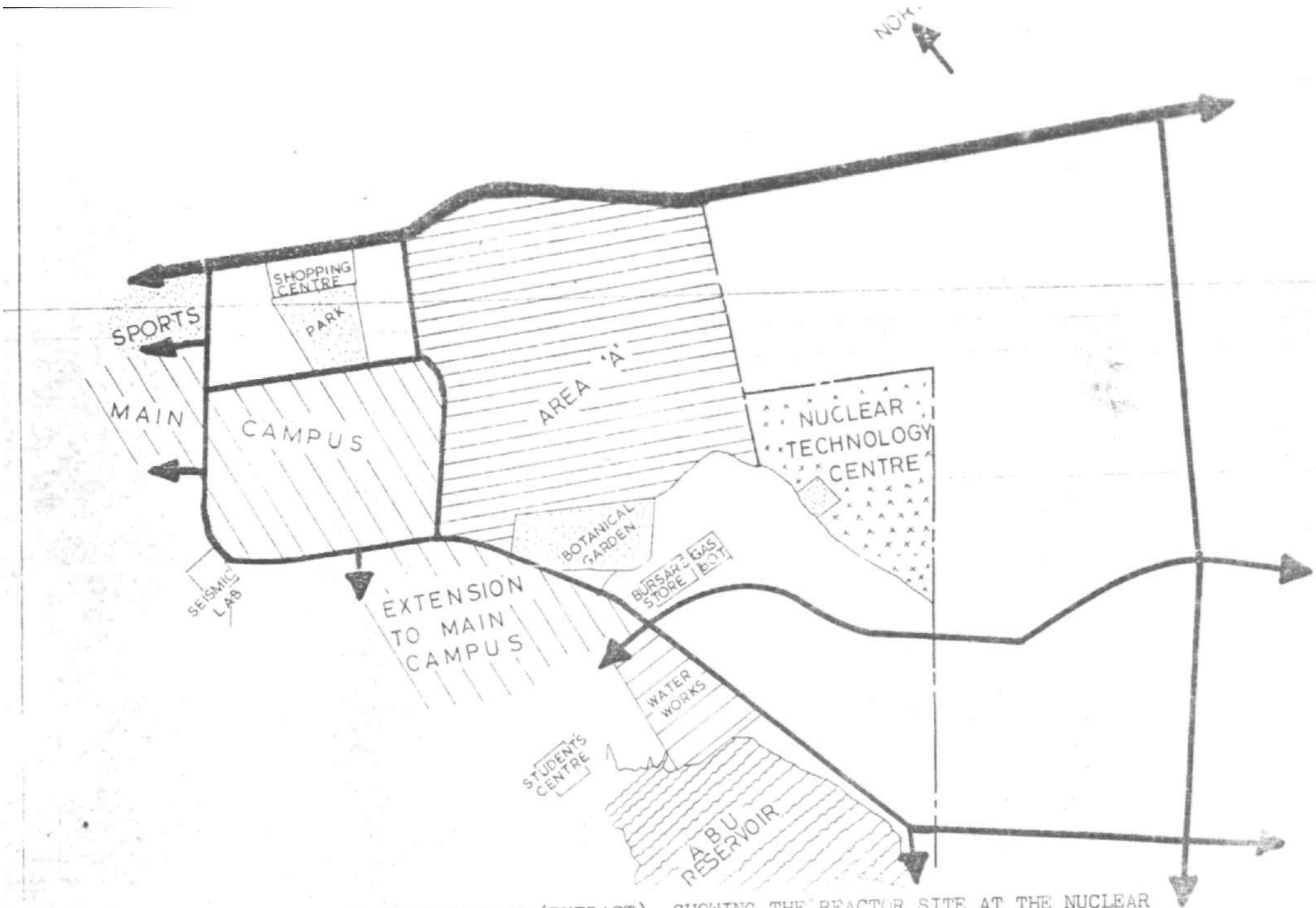


Fig. 3.1 A.B.U. MASTER PLAN (EXTRACT), SHOWING THE REACTOR SITE AT THE NUCLEAR TECHNOLOGY CENTRE.

Some research reactors sited at distances remote from human populations are the 5 MW rated Galileo Galilei at Pisa (Italy), the 2 MW Triga reactor at Inshas(Cairo), and the Oregon State University Triga reactor of 1 MW power located at the Radiation Centre.

3.3 Accessibility to users

The parcel of land constituting the reactor site is bordered by area A staff quarters, the Zaria abbattoir, Jam'ar village, the water works and the university dam(fig. 2.1). The major road nearest the site is the Zaria - Sokoto road, which is about 2 km from the site. This road serves as the main link between the reactor site to other off campus institutions, that may likely use the reactor. They include the A.B.U. Teaching Hospital and the Institute of Agricultural Research (IAR). These two institutions will make heavy demands on the use of radio-isotopes for medical research and seed irradiation studies. The site is also well located and accessible to other users requiring the services of the reactor like the department of Geology. Nuclear techniques (isotopes used as tracers) are among the most modern means for studying direction and velocity of groundwater flows, dynamics of lakes, leakages from lakes and reservoirs in geological research.

The departments of Geology and Physics (Geophysics) could plan for joint research programmes, studying the hydrologic cycle of the arid zones in the country. The reactor will therefore be useful if it is located close to these departments. Other faculties that have access to the reactor are the faculties of Engineering, Environmental Studies, Faculty of Science, Pharmaceutical Sciences and Vertinary Medicine,

3.4 Topography:

The most conspicious environmental problem of a nuclear facility on the aesthetics of a landscape is the abrubt change in the visual quality of the site as at the pre-construction stage. The exact topographical nature of the site could be infered from topographical maps: Zaria SW and SE sheets 102 on a scale 1:50,000. The site is located on a relatively flat plain with the terrain gently sloping towards a dry valley. Scanty solitary shrubs and tree groupings of Baobab and Mango are found scattered all over the terrain. The viewscape, which extends over 10 km is broken by the only topographical relief-the Kufena Hill, outcropping at the background while in the south-easterly direction, the horizon meets the skyline boundary at a strongly defined interface. The area surrounding the site is completely cultivated except towards the University dam where there are no farm lands due to the rocky nature of the soil.

T A B L E 3.2

NOBLE GAS AND HALOGENS IN THE REACTOR[a]

Radionuclide	Quantity (Ci)
Br - 83	1,.2)
Kr - 83 m	1,080
Br - 84	2,000
Br - 85	2,150
Kr - 85 m	2,150
Kr - 85	113
Kr - 87	5,400
Kr - 88	7,700
Kr - 89	9,750
Kr - 90	10,850
Kr - 91	7,350
I -131	5,950
Xe -131m	5,950
I -132	8,850
I -133	14,350
Xe -133m	250
Xe -133	14,350
I -134	16,100
I -135	13,400
Xe -135m	4,050
Xe -135	13,850
I -136	12,550
Xe -137	12,550
Xe -138	11,700
Xe -139	11,800
Xe -140	8,100

a - 250 KW Triga Mark - II Reactor of the Technical University of Istanbul, Turkey.

Where the slope is steep, deep gorges exists and the soil layers are highly weathered and eroded. All the eroded materials appear to be drained towards the dry valley around the low plains of the dam.

3.5 Ecological considerations.

The land use around the site is primarily for agricultural purposes with millet, pepper, maize and sugar cane predominantly cultivated along the valleys. Grazing routes (livestock) terminate at the flood plains of the dam where drinking water exists for the grazing animals. The conspicuous presence of several grazing paths around the site could be attributed to the proximity of the Zaria abbattoir at 2 km east of the site. If the site is accepted for the operation of the reactor, the reactor management will have to establish the level of radiation released, although it is known that such releases are well below harmful levels. Table 3.2 is a list of accumulated amount of airborne fission products (Aybers and Yavuz, 1978) during a continuous four year operation of a 250 kw Triga research reactor. Aybers listed the atmospheric burden of the planned releases as follows:-

1. 100% of the noble gases are discharged through the chimney.
2. 10% of the Halogens are in the form of organic compounds which are totally discharged at the chimney.

3. Of the remaining 90% in organic halogens, 1% are discharged through the chimney.

4. Amount of gases that escape from the fuel element are estimated as follows: 49.54 μCi for the noble gases and 29.9[illegible] μCi for the Iodines.

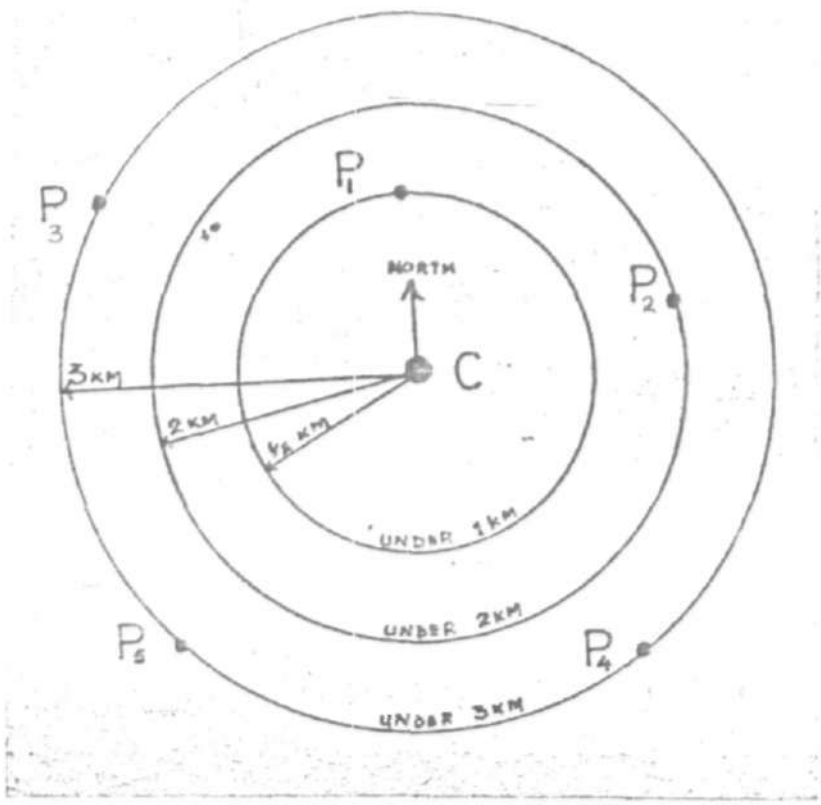
Iodine will create serious ecological problems around the reactor site if a reactor accident occurs, because of:

(a) Its role in all food chains terminating in milk.

(b) Its high adsorption on plant foliages. Gaseous I_2-131 will adsorb on plant leaves(e.g. Millet foliages) with 35% to 40% penetrating the leave epidermis and about 2% moving to other parts of the plants (Selders and Hungate, 1956).

Other critical nuclides include Argon -41, Cesium - 137, and Strontium - 90. These nuclides are going to be of radiological interest to the radiation monitoring unit, while monitoring the waste water pathway. Cesium and strontium tends to accumulate as surface contaminants on vegetation along the waste water pathway. Soil contamination is predominantly as a result of these nuclides, leaching into the subsurface layers. Apart from foliage depositions, Sr-90 may be deposited on the soil and held long enough for some absorbtion by plants roots to [illegible] (Slade, 1968).

AND DIRECTION FROM REACTOR CORE).



LEGEND:

C Centre of reactor site(possible core position)

P_1 Area A staff quarters (under 1,000)

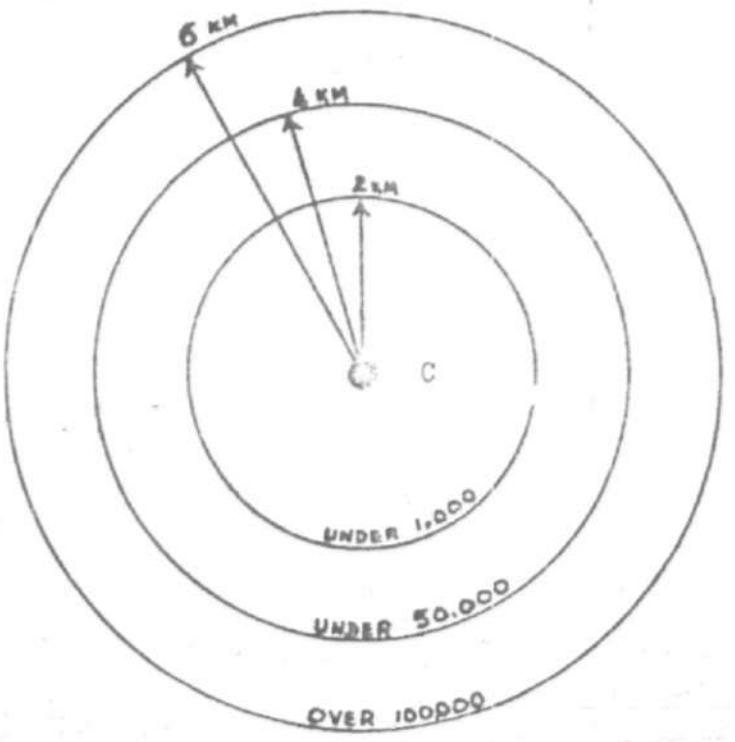
P_2 Jama'ar village (under 3,000)

P_3 A.B.U Main Campus (over 12,000)

P_4 & P_5 Distant village settlements (under 1,000)

NOTE: Populations are projected estimates of 1963 Census data

Fig. 3.3 ESTIMATES OF HUMAN POPULATIONS WITHIN RADIAL DISTANCES FROM REACTOR CORE.



LEGEND C Centre of site (Core position)

Populations are projected estimates of 1963 Population Data

The deposition of neutral salts from the drift in the wa water pathway will be another ecological problem. A sma increment of sulpnates, carbonates and chlorides may acid or 'bind' Selenium to the soil and may effect the chemis of Selenium in the soil(Edp&. 1981).

It is known that these releases are well below the Maximum Permissible Values (MPV) allowed by the Internat. Committee on Radiological Protection (ICRP), but there e tence will afford the Health Physics unit a lot of monit experiences.

3.6 Demography

Assesing the site in terms of population density is difficult owing to the absence of accurate and reliable National demographic records. The population centres ar the reactor site is shown in fig. 3.2. Most population d are mere estimates. Although the present population den does not affect the siting of a low power research react (1 MW) like that proposed for the University, it is worth while considering some of the demographic conditions use assesing the criteria for the siting of the proposed rea if there are future intentions of upgrading it to 5 MW.

Such population densities are normally considered i sectors of 30^{o} are (12 - point compass rose) and by conc zones with emphasis placed on the downwind trend. Such population estimate is shown in fig.3.3.

In the estimate of population within 6 km radius, the area extends to the Leather Research Institute(LERIN), Samaru village and the Institute of Agricultural Research Samaru (IAR). Along the prevailing wind direction(NE-SW) the population settlement that should be restricted from further expansion is the Jam'ar village.

The growth of Samaru village and the Main Campus in terms of human population under 20 years is comparatively high. As at 1963(Census figures), Samaru was 4,147 while the Main Campus then called Nigeria College stood at 1,226. Presently the figures estimated for 1981 are Main Campus (over 10,000) and Samaru (14,000). This shows a high population growth. If the reactor life span is estimated at 40 years, then by 2020, the reactor will be surrounded by dense population centres. This will affect an effective management in terms of environmental radiation monitoring and could cause unnecessary tension and anxiety in case of reactor accidents. It is expected that the Nuclear Research Centre will grow in terms of additional laboratories hence it will be a waste of funds to duplicate the centre due to expansion limitations. Thus the research reactor could be located in an area where extensive expansion programmes of the centre up to 2020 will be unhinderd. Due to the nearness of population units such as the Jam'ar village, staff quarters and the Main Campus, the present parcel of land proposed for the reactor will not be adequate for expansion purposes by the year 2020.

The 250 kw(th) Triga Mark II reactor of the Indonesian National Atomic Energy Agency is sited at Bandung. Open fields exist on the north west and south sides, with the campus located on the east. A low population density of 100 peoples/km^2 exists at a radius of 1 km. It could therefore be concluded that even research reactors could be sited at remote distances(where there is available space) to allow for future expansion. This is necessary because once the core is installed, it can not be moved but rather human settlements around it may be forced to move. If human settlements are forced to evacuate in order to create room for further expansion of reactor facilities, it will set a bad precedence for the nuclear 'industry' in Nigeria.

3.7 Soil characterestics

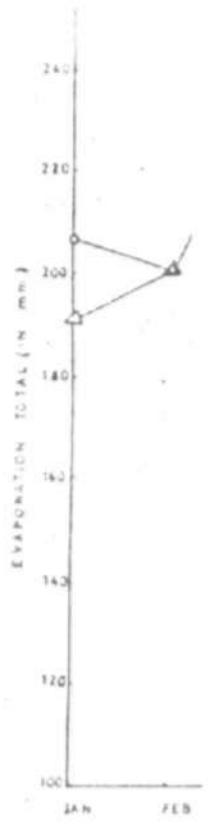
In colloboration with the department of Soil Science (ABU), studies on the nature of the soil at the proposed site was performed in April 1981. The main objective of the study was to obtain information about the engineering properties of the soil.

Three soil pits were dug, one at the lower slope close to the stream(along the valley), and two at the higher slope. The depths of the pits were 1.80,2.11, and 1.95 meters respectively. Soil samples obtained from the pits were tested for particle size, soil reaction($_pH$), bulk density(Db), and particle density (D_p). The soil samples were analysed and the soil data interpreted (Ojanuga, 1981).

Except for a narrow strip of land close to the stream, the soils are well drained. Water table and its effects are not observed within the 2 m depth soil. The soils in the narrow strip close to the stream are imperfectly drained, to poorly drained; implying that the water table is at or near the surface at some period of the year, particularly during the rainy season. Soil reaction (or pH) is strongly acid to slightly acid. The soils have a hard consitency when hard and are firm when moist. They can be considered plastic. Texturally, they are loam soils having an appreciable amount of fines (about 50% or more). Therefore to be used as subgrade, they have to be compacted properly. The soils are deep (deeper than 2 meters) and wel strutured, Depth to bedrock is not reached at 3 meters. Root and ant activities are significant in the upper 2 m of the soils; their effect becoming minimal below this depth. In judging the soils as foundation for structures, a more detailed study of stress measurements, soil reaction to load pressure, and the depth of the water level should be known. The soil characteristic at depth beyond 10 meters could be investigated for this purpose.

3.8. Meteorology:

The meteorological conditions around the nuclear research site proposed for ABU, Zaria will follow the trend as recorded at the two nearest stations namely:- the Zaria Airport Meteorological Office and the Institute of Agricultural Research (IAR).


EVAPORATION TOTAL (IN mm)
240
220
200
180
160
140
120
100
JAN
FEB

SOURCE : SAM

A brief analysis of the meteorological observations which will affect the operation of the reactor as has been recorded for the past twenty years is hereby reviewed.

3.8.1 Solar radiation

The intensity of solar radiation reaching the ground varies seasonally. In 1979, Zaria received a maximum of 8.9 daily mean hours of sunshine within the months of January and February, after which it fell to 5.7 for the months of August. Records noted for the past 25 years (1954-1979) show almost the same trend with a mean of 8.0 daily hours of sunshine (Appendix A) Such a long duration in sunshine will eventually raise the surface temperatutres considerably leading to high evaporation at Zaria. Long overcast also affect soil temperatures. Solar radiation could be reflected or transmitted, depending on the properties of the soil. High soil temperatures enhances evaporation which in turn reduces percolation. Reactors built for tropical countries especially in a place such as Zaria, should be designed to be able to withstand such additional temperature stresses.

3.8.2 Evaporation

Evaporation rates measured at the Samaru Observatory showed an annual mean of 171,8 mm for 1979 and a corresponding total mean of 174.8 mm for over 25 years (fig.3.4).

Waste heat from cooling towers are more favourably disposed of during conditions of high evaporation and low humidity. In the discharge of thermally contaminated liquid wastes, the slow rate of percolation of the waste in disposal wells around the site could delay the seeping of radionuclides down the soil strata to shallow water tables.

3.8.3 Humidity

The humidity chart at Samaru shows a normal distribution all through the year, with a maximum during the months of intense rains, July-August(Fig.3.5). As a result of low precipitation around Zaria, the relative humidity measured in the mornings and evenings are almost identical (Fig.3.5). Mean values of 49.9 and 40.7(1979) as well as 49.2 and 37.4 (1954-1979 for the mornings and afternoons respectively have been obtained at Samaru. The effect of such a low humidity on the reactor management will be on the fast cooling rate of water from the cooling ponds. This will consequently reduce the cost of maintaining a large quantity of water for cooling.

3.8.4 Soil temperatures

Soil temperatures depend on several weather conditions like insolation, humidity, wind and evaporation rates. Measurements of soil profiles at Samaru shows a decrease of soil temperatures with soil depth(Table 3.3). The qualities of the soil that permit the transmission of heat energy depend on the physical properties of the soil material.

TABLE 3.3

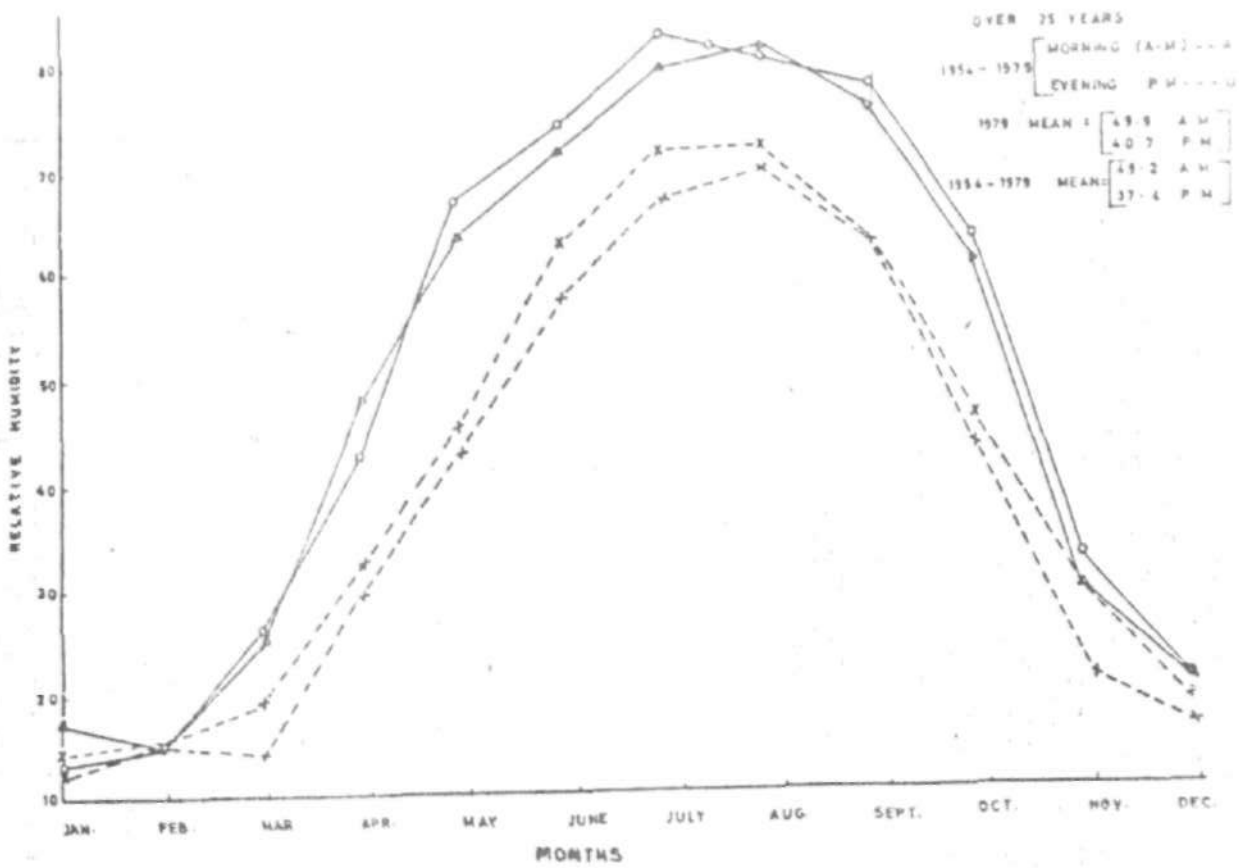
Soil temperatures at various depths for 1954 to 1979

Depths	Mean temperatures (^{o}C) for 25 years	
	Morning	Afternoon
5 cm	32.1	33.1
30.5 cm	36.4	27.0
122 cm	26.6	27.2

Measurements made at 0900 and 1500 Hours GMT.

Source: Field Report, Samaru Meteorological Station.

Fig. [illegible] RELATIVE HUMIDITY AT SAMARU



SOURCE: SAMARU METEOROLOGICAL STATION

The two physical properties of importance are thermal conductivity and specific heat. When the thermal condutivity is high, heat is transmitted through the soil to great depths during the day. At night this stored energy flows upwards through the soil, and warms the atmosphere at the surface. In the absence of night precipitation (rainfall, dew etc.) the soil temperatures at mornings and afternoons are likely to be identical or differing by a little factor(Table 3.3). This is the soil temperature condition that prevails at Samaru. If the open cooling pond system is utilized for a reactor at Zaria(for thermal treatment of waste water), such a high soil temperature will militate against fast evaporation by inducing localized convection currents due to thermal mixing in the ponds. It should be noted that a reactor at Zaria may not operate on a once-through cooling system due to conspicuous absence of a large body of water. Also since there is no large body of water, nearby, the draining of the waste water of thermally polutted water will be another problem.

3.8.5 Cloud cover/Air temperatures

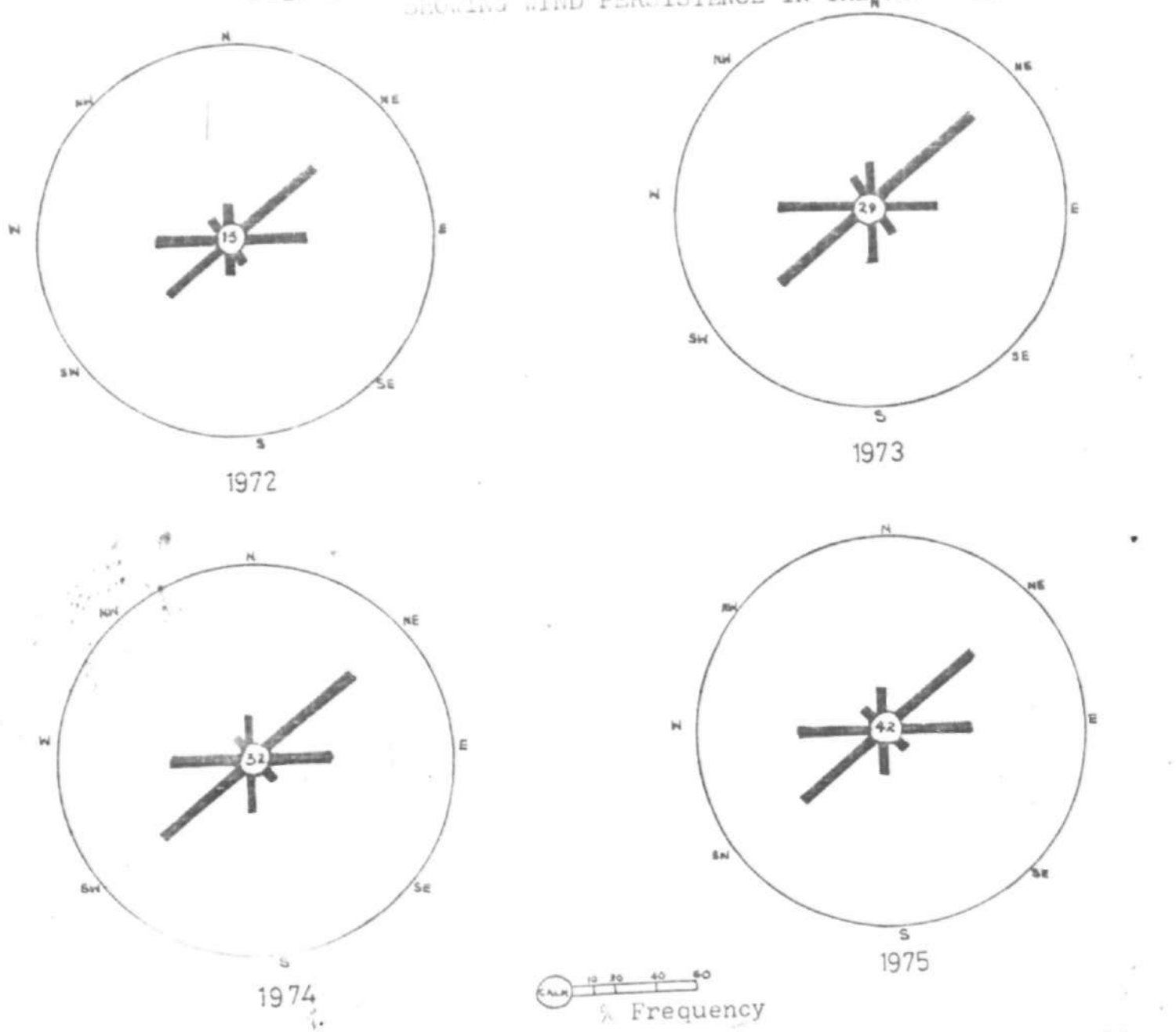
All through the year, the cloud cover at Zaria varies with thick clouds only appearing within the months of heavy rainfall (June to September). The remaining months are almost cloudless-thin overcast. When clouds are present, incoming solar radiation is depleted.

In the absence of clouds insolation is greatest thus leading to high surface temperatures. The average air temperature at a given location is as a result of the energy balance of the atmosphere at that location and could lead to several climatic results. This will invariably affect the functioning of the reactor if it is designed without taking into consideration the temperatures of the local environment. Temperature patterns could be quite complicated, varying at different elevations. Since the reactor will be installed at ground level, it is worth noting the temperature variation at this level. The Samaru Observatory records air tepertures, taken a few feet from the ground. For a thorough understanding of air temperatures, other elevations above an effective reactor stack height of say 60 metres should be considered since air borne effluents will be released at such heights. For Zaria, Mean (Maximum) air temperature of 31.4°C (1938-1979) was recorded for screen height. Since this average has been maintained for the past 24 years, the designers of the reactor should consider 31.4°C as the local air temperature and should incorporate this in the design of the research reactor.

3.8.6 Wind:

The atmosphere is a continium in space and time. Like any turbulent fluid it has a wide variety of perturbations on all possible time and space scales. Such turbulence is characterized in random motions of air parcels isotropically.

Fig. 3.6 WIND DISTRIBUTION BY DIRECTION AT ZARIA(1972-1975), SHOWING WIND PERSISTENCE IN THE NE - SW DIRECTION



SOURCE: Wind roses drawn, using data obtained from Meteorological Office at Zaria Airport.

When the air parcels are streamlined and "sensible", they form a wind pattern for a given area. The wind pattern at Samaru including Zaria and its environs is mostly in the NE and SW directions with slight seasonal changes (fig.3.6). Mixing and turbid air flows are well known in the upper layers. Such mixings result in wind inversions which on a large scale induce atmospheric instability. A pollutant released from a stack at Zaria will under pasquill-A weather conditions spread rapidly in both the lateral (downwind NE or SW) and vertical directions. The vertical spread is limited by the viscous drag of the particulate in air aided by gravity. Other factors that may make the prediction of the direction of the release difficult is air mixing, turbulent atmosphere due to strong winds, in dispersing radioactive plumes released into the atmosphere. The wind pattern at Zaria fluctuates with most periods of calms observed in the mornings between 6 a.m. to 10 a.m. The afternoons are always turbulent. The difussion problems of reactor effuents are lessened in the afternoon, when wind masses are considered larger than stack effluents. The former tends to tear apart the latter down the gradient leading to a quick dilution of airborne aerosols. The prediction of atmospheric stability depends on the adiabatic lapse rate for a temperature profile.

With the prevailing wind pattern at Zaria, the plume spread will be in the SW direction for winds blowing NE and NE winds in the SW direction. The proposed site will have an advantage of natural mixing and dilution actions of the atmosphere.

3.9 Dispersion and deposition of airborne effluents:

Once the reactor begins operation "minute" quantities of air borne radionuclides, will be released continuously at the reactor stack either by way of natural or forced convection. Airborne particles once dispersed remain in the atmosphere as long as the residence times permit otherwise they are subjected to deposition forces like precipitation, surface impaction, electrostatic attraction, adsorption as well as their appropriate gravitational velocities. They therefore settle down on various surfaces depending on their deposition velocities and nature of surface of contact (Slade, 1968). Primarily the surface of contact include water, soil, grass and sticky surfaces. Zaria has a wide grasland, therefore presumably attention will be focussed on radionuclides, that have heavy depositions on grasslands. Convair (1959,1960) computed some deposition velocities for various radionuclides identified with fission product releases from reactor stacks. The airborne effluents include:- Caesium, Ruthenium, Zirconium, Cerium, Niobium and Tellurim.

TABLE 3.4

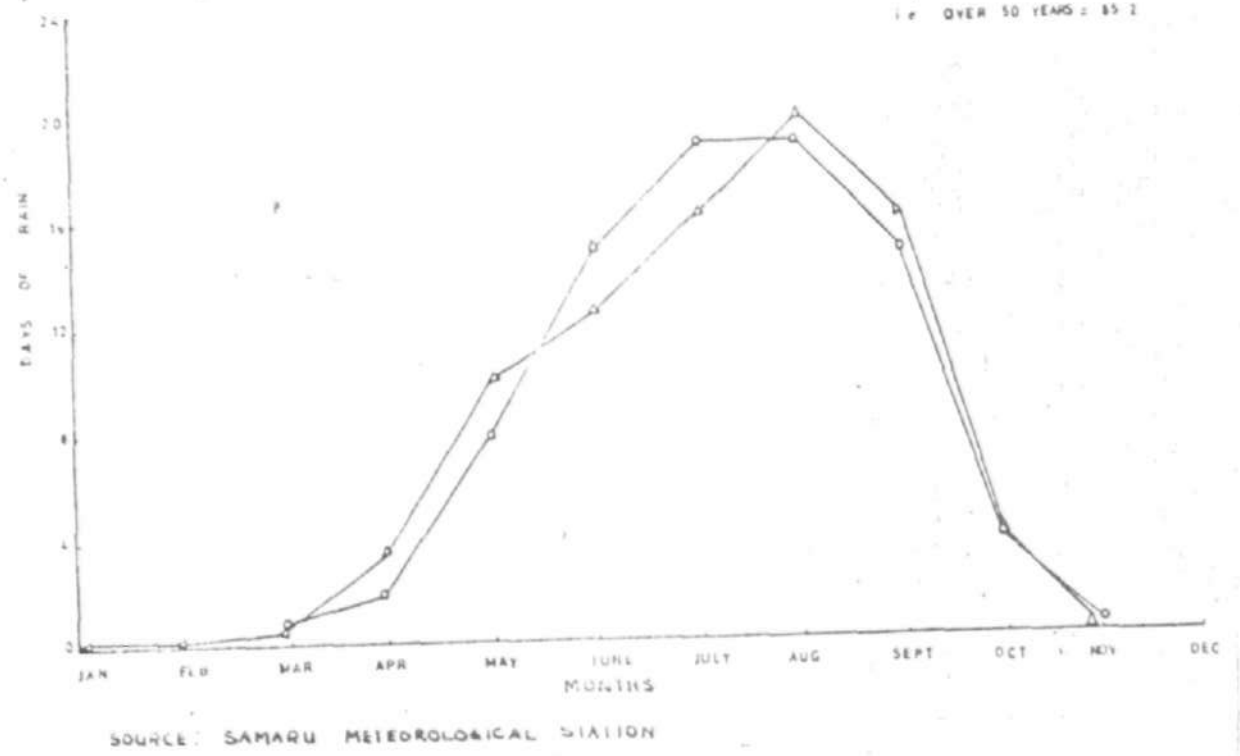
Convair summary of radionuclide deposition velocities on surfaces

Radionuclides	Deposition velocities cm/s			
	Water	Soil	Grass	Sticky Paper
Cs - 137	0.9	0.04	0.2	0.2
Ru - 193	2.3	0.4	0.6	0.4
Zr - 95, Nb - 95	5.7	2.9	-	1.4
Cr - 141	-	-	-	0.7
Te - 127, Te - 129	-	-	-	0.7

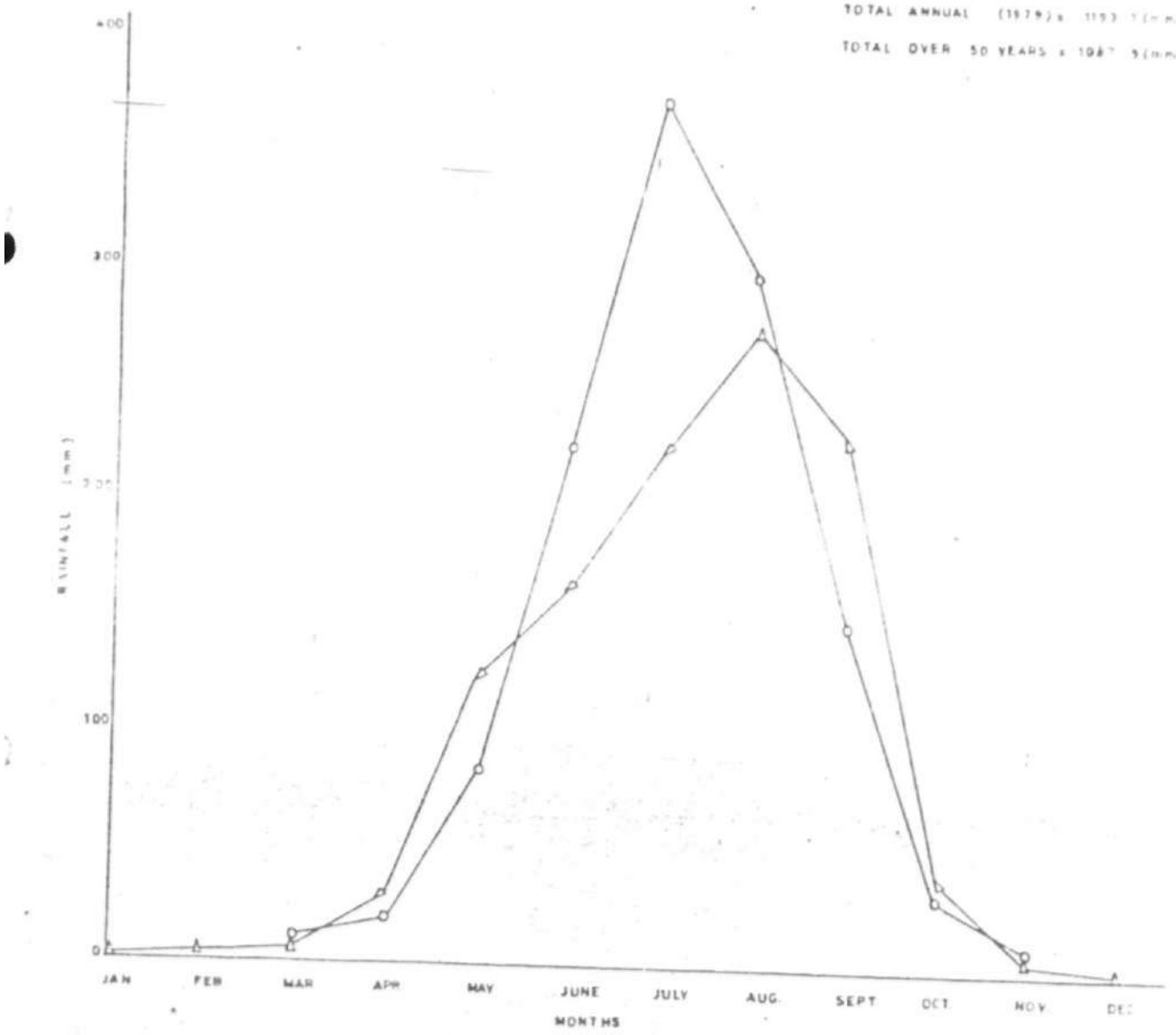
Measurements made involving the release and downwind measurements of radioactive isotope from irradiated reactor fuel elements.

Fig. 2.0

FREQUENCY OF RAINFALL AT SAMARU



SOURCE: SAMARU METEOROLOGICAL STATION



SOURCE: FIELD DATA, SAMARU METEOROLOGICAL STATION

The large deposition velocities on water followed by that on sticky paper is expected as a result of the nature of the surfaces for the contact. Deposition on vegetation (grass) and soil could be obstructed by movements of grass blades as well as any localized object at the time of deposition.

Iodine - 131 is one of the critical nuclides released at reactor stacks as fission products. Chamberlain(1960), made important measurements of the deposition of radioactive vapours and aerosols including Iodine - 131. Although Iodine - 131 is released as a vapour, it is known that I-131 could be adsorbed on condensation nuclei which are too small to have an appreciable gravitational settling velocity hence it could be transported as airborne aerosols at downwind distances. Apart from poor performance of exhaust filters, the release of radioiodine will not cause serious radiological problem at the proposed site except for the occurence of the worst accident.

3.9.1 Wet deposition

Zaria enjoys a very short period of rainfall - an average of only 84 days of rainfall annually. The rainfall pattern for a period of over 51 years of observation is similar (fig. 3.8). A total average of 85.2 days of rainfall annually has been recorded for 1928 to 197.(Appendix A). With such a low frequency of rainfall, wet deposition may not be considered predominant in Zaria.

During atmospheric releases under precipitation conditions, rain will wash out some of the radionuclides released in the plume based on the chemical reactivity of the isotopes in air, their particle or droplet size, and the precipitation rate. Predicted wash-out values for Iodine gas are between 3×10^{6} to $2 \times 10^{-7} s^{-1}$ and in rainfall of 0.5 to 3.0mm/hour, 30 to 40 micron droplets are expected to range from $2 \times 10^{-4} s^{-1}$ (Slade, 1968).

Low precipitation for Zaria implies low wash-out frequency hence it is expected that most vegetation spread and soil strata with deposited radionuclides, will retain much of their deposits. This will increase the probability of contact of such deposits by farmers and grazing cattles since an average of 85 days of rainfall annually, implies over 200 days for cattle grazing.

Summarilly, because of the location of the site with respect to grazing routes, planned releases should be very low and environmental surveilance should be given serious attention at the take-off stage of the reactor.

3.10 Siting and Cooling water facility

The siting of the reactor at the proposed site will have an advantage of obtaining cooling water from the University Dam. A typical Triga reactor of 2 MW rating has a coolant flow rate of 1,000 gallons per minute (Gen. Atomic, 1975).

One can infer from this, the flow rate for 1 MW Triga reactor. Such a large volume of water will require re-cycling after dimineralization otherwise the volume of water at the Dam will be reduced. One main problem of siting a reactor at Zaria is the abscence of naturally flowing rivers. The nearest large body of water is the River Kaduna and it is not possible to direct the waste water from the reactor to this river because of the inexistence of a link from Zaria. Waste water from the reactor will be stored in cooling ponds after which it may be drained away after the necessary treatment has been perfomed.

3.11 Siting and transport

The main transport systems that are likely to be used for hauling reactor components in Nigeria are mainly the road and railway transport systems. The use of the ports via its waterways is limited since the inland waterways transport connections from the ports to the reactor site (Zaria) are not in existence and the nearest linking route via River Kaduna is not fully developed to accomodate large vessels. Reactor components arriving in Nigeria may be discharged in one of the four port complexes namely:- Lagos, Port-Harcourt, Calabar and Delta ports. The choice of any of the ports as landing berths for the reactor components will be determined by the economic cost of transportation of these components from the port of call to the reactor site at Zaria.

The main traffic routes and transport systems that will be involved in haulage are considered.

3.11.1 Roads and road transport

Road systems in Nigeria consists mainly of Trunk A and B roads forming a network with varying mesh widths. The routes relevant to the siting and utilization of the reactor are those that link the ports to the reactor site as well as those that link the reactor site to institutions requiring the services of the reactor. The distances of the roads from two of the ports to the site are: Lagos to Zaria, about 912.8 km and Port-Harcourt to Zaria, about 1156.8km.

Most of the road shoulders thin down to less than 3.6 m wide, consequently the older bridges linking these roads are only 3 to 3.6 m wide. These dimensions are not large enough for containner trailers that will be used in transporting reactor components. Other defects of the road system include numerous bends which are not desirable for container haulage especially in the use of 121.9 m long trailers. For these reasons therefore, it will not be convenient to transport reactor components from the ports through roads for fear of accident hazards.

3.11.2 Waterways

Zaria has no water link to other inland waterway stations. The nearest inland waterway connection to Zaria is the Kaduna terminal station at the Kaduna River.

A possible route therfore could be the Escravos light-house station to River Kaduna via the River Niger confluence. The distance is approximately 946 km.

Although it is cheaper to transport components by river transport, this route is not navigable. The main reasons include the shallow depths of the river channels. The Least Available Depth (LAD), varies seasonally and at some points the depths are not sufficient for inland waterway vessels to sail through (Netherlands Engineering Consultants - NEDECO, 1971). LAD is based upon depth-discharge relations established during the Niger - Benue survey of NEDECO (1955 - 1958). Waterway transport is therefore not feasible for the transport of reactor components from any port of call to the reactor site at Zaria.

3.11.3 Railways

The Nigerian Railway Corporation (NRC), operates a 1.06 m gauge railway system with two main lines running in a north easterly/westerly direction, starting from the two largest ports of Nigeria (Lagos and Port-Harcourt). Zaria serves as a junction for the Kaura Namoda and Nguru terminals. The Zaria to Kaura Namoda line runs almost parallel to the Zaria-Sokoto road and passes through Samaru, close to the reactor site at a distance of approximately 4 km.

The rail-route distance from Zaria to the two main

ports are as follows : Zaria to Lagos(984 km) and Zaria to Port-Harcourt (993 km). Comparing these distances with the road distances, it is obvious that transporting by rail involves a shorter distance, although it involves a longer duration. The advantages of using the rail system includes :-

(1) Assurance of the safety of containers conveying reactor components from road accidents.

(2) Cheap cost of transportation from any of the two major ports to the reactor site.

(3) Little or no limitations to weights of reactor components required for haulage.

(4) Isolation of delicate and dangerous reactor materials (fuel elements including spent fuel rods) from the public.

For these reasons therefore, it is suggested that the rail route be used in transporting reactor components from any of the berthing ports to the reactor site.

3.12 Summary

From the above considerations, the following conclusions on the siting of the ABU research reactor are outlined:

(1) The reactor requires two zones: the exclusion and restrictive zone, as limiting areas for radiation monitoring.

(2) If the reactor is sited at the proposed site, it will be accessible to users.

(3) The proposed site is just enough for a reactor operated as a university research facility.

(4) The meteorological factors at Zaria, favour the siting of a reactor at the proposed site and at any other site around Zaria.

(5) A reactor sited at Zaria, should not have a dense human population in the NE - SW wind direction. Since the reactor is a low power reactor (1 MW), depositions along the wind axis may be considered insignificant, and of no radiological danger as long as the planned releases are low and there is no reactor trip.

(6) The siting of a reactor, requires cooling water facility. The university dam which is close to the site will serve this purpose.

(7) In transporting reactor components, the rail system is economically cheaper and it involves less hazards.

It is hereby concluded that a 1 Mw reactor can be sited at the proposed site to be operated as a University research facility. However, if the reactor is to be upgraded, there will be limitations to the new power, in view of the proximity of human settlements. In this regard therfore, the Centre may be restricted from installing highly powered radiation sources.

CHAPTER 4

ENVIRONMENTAL PROBLEMS

Research reactors are considered as nuclear facilities since they operate on nuclear fuels. The siting therefore of the proposed reactor will raise anxieties in people living within the vicinity of the reactor. The University community and other population units living around the reactor site will want assurance on the safety of the reactor from all forms of accidents. This assurance is guaranteed as it has been noted that during 1,800 reactor years of reactor operation, no one has been killed or injured outside a nuclear plant in an accident (IAEA - 1980 Stockholm conf. reports). However, once the reactor is installed, the success of the safety programmes of the reactor will depend largely on the safeguard measures, waste management programme and the environmental monitoring programme planned for the Centre. Considerations on reactor accidents, safeguards, waste management and other environmental problems that may be associated with the reactor are considered.

4.1 Reactor accidents (Instrumental failures)

The safety of the operation of the proposed reactor could be considered under three main categories of reactor accidents such as :-

(a) Reactivity accidents.

(b) Cooling-failure accidents commonly called loss-of-coolant (LOCA) accidents.

(c) Fuel element failure.

4.1.1 Reactivity accidents with Triga reactors

Most Triga reactors use low graded Uranium enrichment in the form of Uranium - Zirconium Hydride ($UZrH_x$). The unique property of $UZrH_x$ as having a negative temperature coefficient of reactivity for an increase in core temperature has been discussed. Reactivity accidents in Triga reactors could be studied, assuming that absolute failure of all the control rods is possible.

The reactor is loaded to maximum excess reactivity, all the control rods (except the transient rod) are slowly withdrawn completely out of the reactor so that the reactor operates at the highest steady-state power(Aybers and Yavuz,1978). For a Triga Mark III reactor(Texas, 1967) r ted 1 Mw, a power level of 1.4 Mw was reached when all the control rods were up. Under this condition, the prompt insertion of 2.1 $\% \frac{\Delta k}{k}$ reactivity results in an average temperature rise of 233^{o}C in the core and a peak temperature of 399^{o}C. Studies with Triga cores (Texas, 1967), show that power excursions of 1,200 Mw at a maximum core temperature of 539^{o}C could be reached without any harm to the reactor core. Triga Mark cores are

Table 4.1 Summary of the results of meltdown events due to LOCA

Accident initiating event	Probability of occurence of the initiating event per reactor per year. (P_1)	Failure of safety functions. (P_2)	Probability of occurence of core melt per reactor per year. ($P_3 = P_1 \times P_2$)
Large LOCA	2.7×10^{-4}	1.7×10^{-3}	4.5×10^{-7}
Medium LOCA	8.0×10^{-4}	2.3×10^{-3}	1.8×10^{-6}
Small LOCA	2.7×10^{-3}	2.1×10^{-2}	5.7×10^{-5}
Loss of off-site power	1.0×10^{-1}	1.3×10^{-4}	1.3×10^{-5}
Loss of main feed-water supply	8.0×10^{-1}	4.0×10^{-6}	3.2×10^{-6}
Emergency power case with small leak at pressurizer	2.7×10^{-4}	2.6×10^{-3}	7.0×10^{-7}
Other transients with small leak at pressurizer	1.0×10^{-3}	2.0×10^{-3}	2.0×10^{-6}
Anticipated transient without scram	3.0×10^{-5}	3.0×10^{-2}	9.0×10^{-7}

(after Birkhofer, 1980)

therefore safe in terms of reactivity accidents.

4.1.2 Loss-of-coolant accidents (LOCA)

A loss-of-coolant accident can occur in a Triga core as a result of leaks in the piping system or blocking by obstacles. Such leaks are in the form of slowly growing cracks, or other imperfections caused by fatigue, corrosion or creep. Birkhofer(1980), summarized likely events that may lead to a loss-of-coolant accident as shown in table 4.1.

A loss-of-coolant at shutdown raises the fuel temperature of a typical Triga reactor of thermal rating 250 Kw up to 275°C (Aybers and Yavuz, 1978). At such a high temperature, a mechanical stress is imposed on the fuel cladding at a pressure of 1,200 psi. Triga cores are built to withstand cladding stresses of 3,500 psi (General Atomic, 1975), hence such a coolant accident will be far below the yield stress of the claddings.

Aybers and Yavuz(1978), studied the response and intergrity of Triga vessels at zero cooling (complete draining of the reactor tank). It was noted that a broken 6 inch. radial beam port without plugs will drain the reactor tank in 215 seconds. Ayber considered a coincident accident, when a rapid insertion of control rods lead to excess reactivity with a coolant loss 2 secods after transient. Heated elements

rose to an average and maximum fuel temperatures of 697°C and 939°C respectively. If this occurs, it is assumed that the cladding rupture of (the highest power density) fuel element may occur which may eventually initiate a core meltdown. The possibility of both events occuring in practice seems very remote. Triga reactors have emergency core cooling systems to prevent coolant accidents. If the proposed reactor is a Triga reactor, a LOCA accident may not occur and if it occurs, the emergency cooling system will minimize the extent of the accident.

4.1.3 Fuel element failure

A failure of fuel element involves the breaching of the cladding. Bobe (1976), defined fuel failure as a perforation or defect of the fuel cladding, or any structural change which may cause abnormal maintenance or early replacement of a fuel assembly or its component. Garzarolli et al (1979), identified seven different failure mechanisms prevalent with water-cooled reactors. They are: primary hydriding, stress corrosion cracking of the clad, accelerated corrosion, rod collapsing or flattening, structural changes, rod bowing and wear corrosion on fuel rods. The investigation of cladding rupture due to fuel element failure in research reactors has been studied extensively (General Atomic, 1975).

It has been observed that fuel elements located within the innermost ring are more likely to fail due to the high power density. General Atomic(1975), estimates a release of 1.5×10^{-5}Ci of fission products due to a breach of the Uranium - Zirconium Hydride fuel cladding of a typical Triga core for a 250 Kw reactor. However, fuel element failure is not common in research reactors because of the low percentage duty cycle and low fuel burnup.

4.2 Natural or site-induced accidents

Most site-induced accidents with a high potential of occurence depend on the location of the reactor. Some of these disasters that should be examined in relation to the proposed ABU research reactor include crashes of aircrafts, floods, forest fires and failure of the University dam.

4.2.1 Aircraft crashes

Samaru is quite close to a small airport which also serves as an aviation training centre. Most of the planes used, fly at low altitudes. Heavy planes like the jet passenger planes do not land on the airport. The reactor, if sited at the proposed site, should consider the hazards that may occur if there is an aircraft crash.

Nuclear facilities especially the reactor core(containment) are normally designed to absorb aircraft impacts by the use of

several layers of concrete that can contain the greatest impact. In special cases (mainly for power reactors), the design takes into consideration such impacts. If the probability of an aircraft strike were determined to be greater than 10^{-7} per year (Grimes, 1974), the first step would be , to ask the constructing firm to examine the inherent capability of the nuclear facility structures withstanding a strike of the type of the aircraft that ply the airspace , where the reactor is sited. In some cases, additional protection of the reactor may require several layers of concrete as well as protection against fire outbreak due to combustible fuels when aircrashes occur. Grimes (1974), notes that on the basis of aircrash disasters, the design of the Three-Mile-Island (TMI) reactor, was provided with six feet of reinforced concrete on flat wall strucures, to protect against the impact of 200,000 lb aircraft striking at a velocity of 200 knots.

Aircrafts used at the Zaria airport are light aircrafts used mainly for training. One can infer therefore that aircrashes could be highly probable in this case. The designers of the proposed reactor should therefore take note of all possible damages a light aircraft can cause on a research reactor and the safety measures to be implemented if this happens. This should be well laid out in the Safety Analysis

Report for the reactor.

Since the University has no direct control over off-site private activities, it is necessary for safety reasons to make arrangements with the Aviation Centre, so that they can plot their low-level flying routes some convenient distance away from the reactor. This safety measure by itself could reduce the possibility of an aircraft hazard.

4.2.2 Floods

The proposed site is located in a gently rolling terrain which is relatively flat. The site is also bordered on the south-west by an extensive flood plain and towards the western margin by a gently descending slope with a run-off gradient towards a dry river valley(over 80 metres wide). Presently under low rainfall, it is most likely that the area might not be flooded, but with prolonged rainfall, flood problems might be encountered. Since the flooding of river basins occur without warning during months of heavy rainfall, it is recommended that the reactor be built as far as possible beyond the edge of the valley. The constructing firm should also undertake a detailed study of the flooding possibilities so as to integrate this into the design of the foundation structures for the reactor.

4.2.3 Forest fires

Forest fires are well known to be a disastrous hazard in Zaria. In most cases, it is always difficult to trace the causes of such fire out-breaks. Forest fires may not cause serious problems if the design of the centre takes into consideration, this hazard.

Forest fires require continuity of fuel source, like an extensive continuous mass of dry vegetation. Once this continuity is therefore broken, the fire is abated. This could be achieved at the Centre by the construction of a continuous stretch of road around the fence enclosing the Centre. However, the placement of combustible fuels in storage facilities at the fence perimeter, could activate the spread of forest fires into nuclear facilities at the Centre, hence, this should be avoided.

A fire fighting unit is also desirable for the Centre. This is necessary, since other forms of fires (apart from forest fires) need experience hands in fire extinguishing. Such fires include on-site fires from electrical cables, oil storage facilities and nearby transport fire outbreak.

4.2.4 Dam failure

The proposed site is quite close to the University dam. It is necessary to examine the consequences of the failure of the University dam situated at about 2 km from the reactor

site. Although by the design of the dam, failure may appear impossible, it is however, probable.

The volume and depth of water in the dam varies seasonally, with shallow depths during the dry seasons to a high depth, large and extensive volume during months of heavy rainfall. If the dam fails, that is the embankment breached, water held back by the embankment will be forced to flow towards the flood plains. If this happens during the period of heavy rains, the river valley at the slope of the site will be flooded. This may likely affect reactor facilities built near the slope. For this reason, reactor facilities should be built at convenient distances farther up the slope of the valley. Dam failure should be examined also in the safety analysis report.

4.3 Objections

Objections are always lodged whenever nuclear facilities are to be sited. This is always as a result of a few misinformed public. The anticipated fears and risks of nuclear accidents has always hampered the smooth take-off of nuclear technology. Since the reactor will be sited near the University, various anti-nuclear pressure groups within the University community may lodge 'strong' objections in the course of the site construction and licensing of the reactor.

Objections are always stated without sufficient proof of the claims. Objections if not well handled, could prolong the passage of a licensing bill (for the reactor) at the National Assembly. Public hearings and regular lectures on the safety aspects of the reactor, are measures which should be used in dispelling rumours and countering all forms of objections put forward by anti-nuclear pressure groups.

4.4 Nuclear thefts and safeguards

African states involved in the acquisition of nuclear technology intend to use it for peaceful purposes especially in the development of nuclear techniques in science, medicine and agriculture. Research reactors are ultimately acquired for this purpose. Already, 33 African states having interest in the development of nuclear technology are parties to the Non-Proliferation Treaty (NPT). These states are also members of the International Atomic Energy Agency (IAEA), whose aims include the provision of technical assistance (on the acquisition of nuclear technology), to all her members (Cisse, 1980).

The IAEA maintains strict safeguards policies on the issue of siting nuclear facilities as well as the use of nuclear materials. Such safeguards make it imperative on recipients of nuclear technology to guard against all

TABLE 4.2

Threshold amounts and quantities of safeguard significance

A. THRESHOLD AMOUNTS

Material	Threshold Amount (TA)	TA applied to
Pu (Pu-239, 95%)	8 kg	Total element
U-233	8 kg	Total isotope
U (U-235, 90-95%)	25 kg	U-235

B. QUANTITIES OF SAFEGUARDS SIGNIFICANCE

Material	Quantity of Safeguards Significance (SQ)	SQ applied to
(a) Direct use material		
Pu	8 kg	Total element
U-233	8 kg	Total isotope
U (U-235 $\geq$ 20%)	25 kg	U-235
	Plus rules for mixtures where appropriate	
(b) Indirect use material		
U (U-235 $<$ 20%)+	75 kg	U-235
Th	20 kg	Total element
	Plus rules for mixtures where applicable	

+ Including natural and depleted Uranium
Source : IAEA Bulletin, Vol. 22 No. 3/4 August, 1980.

forms of nuclear thefts, perpetrated for the diversion of nuclear materials (especially spent fuel) for the fabrication of nuclear weapons. The operation and maintenance of the ABU research reactor, will therefore require some safeguard measure since it operates with nuclear fuel.

The objectives and criteria for safeguards are well laid down in IAEA documents coded INFCIRC/66/Rev.2 and INFCIRC/153 (IAEA, 1980). The IAEA identifies threshold amounts of nuclear materials that have safeguard significance. The 'threshold amount ' is defined as the approximate quantity of special fissionable material needed for a nuclear explosive. Such materials include plutonium.

Table 4.2 shows the threshold amount for various nuclear materials having safeguards significance.

Although spent fuel from the proposed reactor will fall below threshold amounts, by IAEA standards, they should be stored under close supervision. Special precaution should be applied to guard against the theft of nuclear materials used for research in hot laboratories, and irradiated fuel rods from glove boxes. The proposed reactor should therefore have an irradiated room facility as close as possible for the wet storage of spent fuel, before they are packed away for dry storage at the waste storage facility.

4.4.1 Terrorism and security measures

One of the most disturbing aspects of nuclear safeguards involves the action of terrorists. Terrorism could stem from any anti-social group. Terrorist blackmail has become an increasingly popular vehicle for wide spread political, and economic satisfaction. One of such anti-social attitude that could affect the operation of the reactor, may stem out from the incessant students demonstrations within the University. In a violent student demonstration, a well financed and imaginative extremist group could hide under the guise of the students and conceivably force its way into positions of threatening the nuclear Centre with disaster if some compelling demands are not met. If the terrorists succesfully destroy the reactor; the risk, mechanical damage, economic waste and radiological problems that will be suffered by the University will be unparalled to any other hazard, involving the reactor.

Kupperman et al (1978) notes that inspite of the fact that the constraints of retaliation and jail terms are punitive enough, a terrorist group may have little to lose and much to gain in setting ablaze or disrupting a nuclear instalation; for such radicals often lack a sufficient stake in the established social order. They generally perceive themselves to be outside the system; they lack the fears of

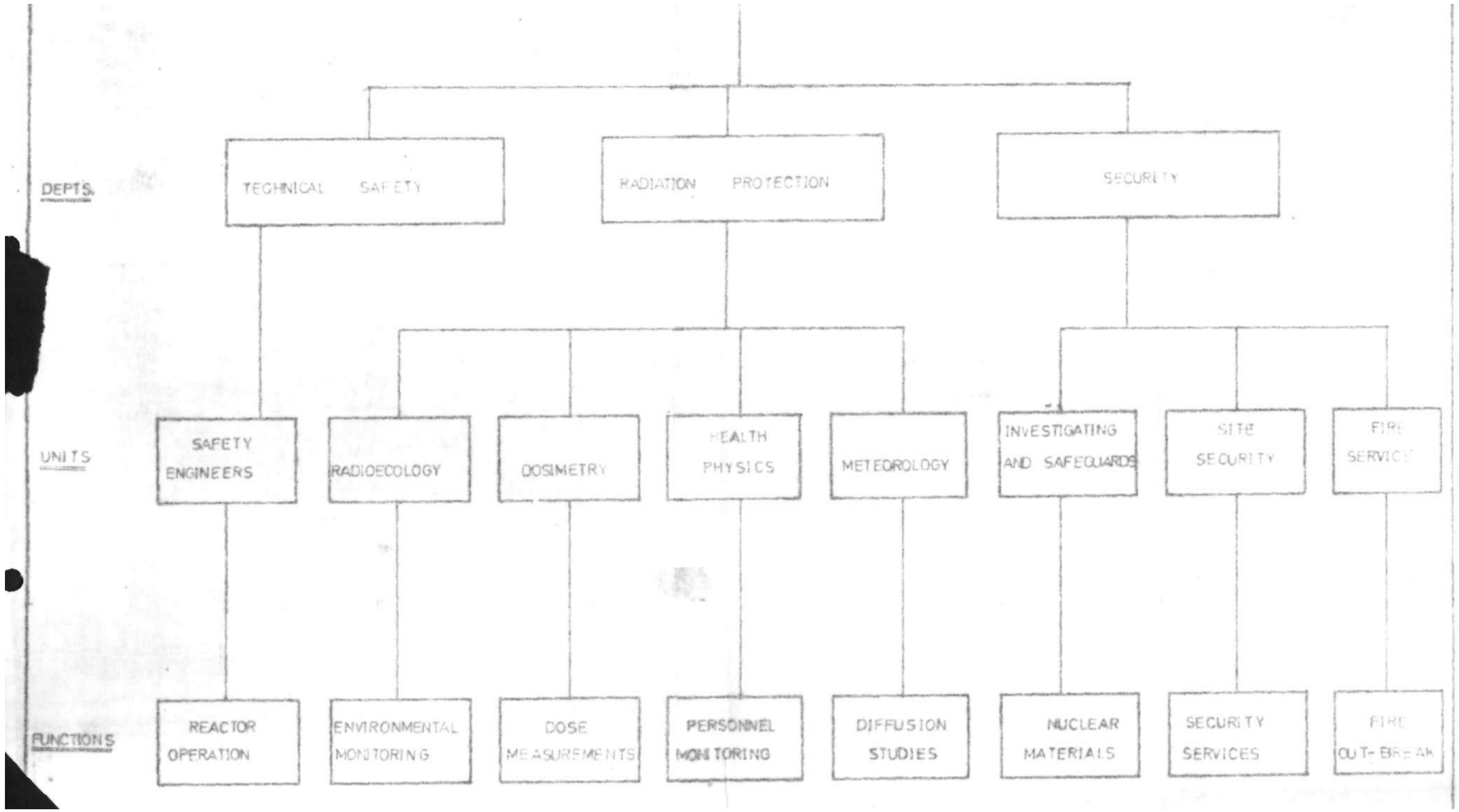


FIG. 4.1 ORGANIZATIONAL CHART OF THE REACTOR SAFETY BOARD PROPOSED FOR THE AHMADU BELLO UNIVERSITY NUCLEAR RESEARCH CENTRE

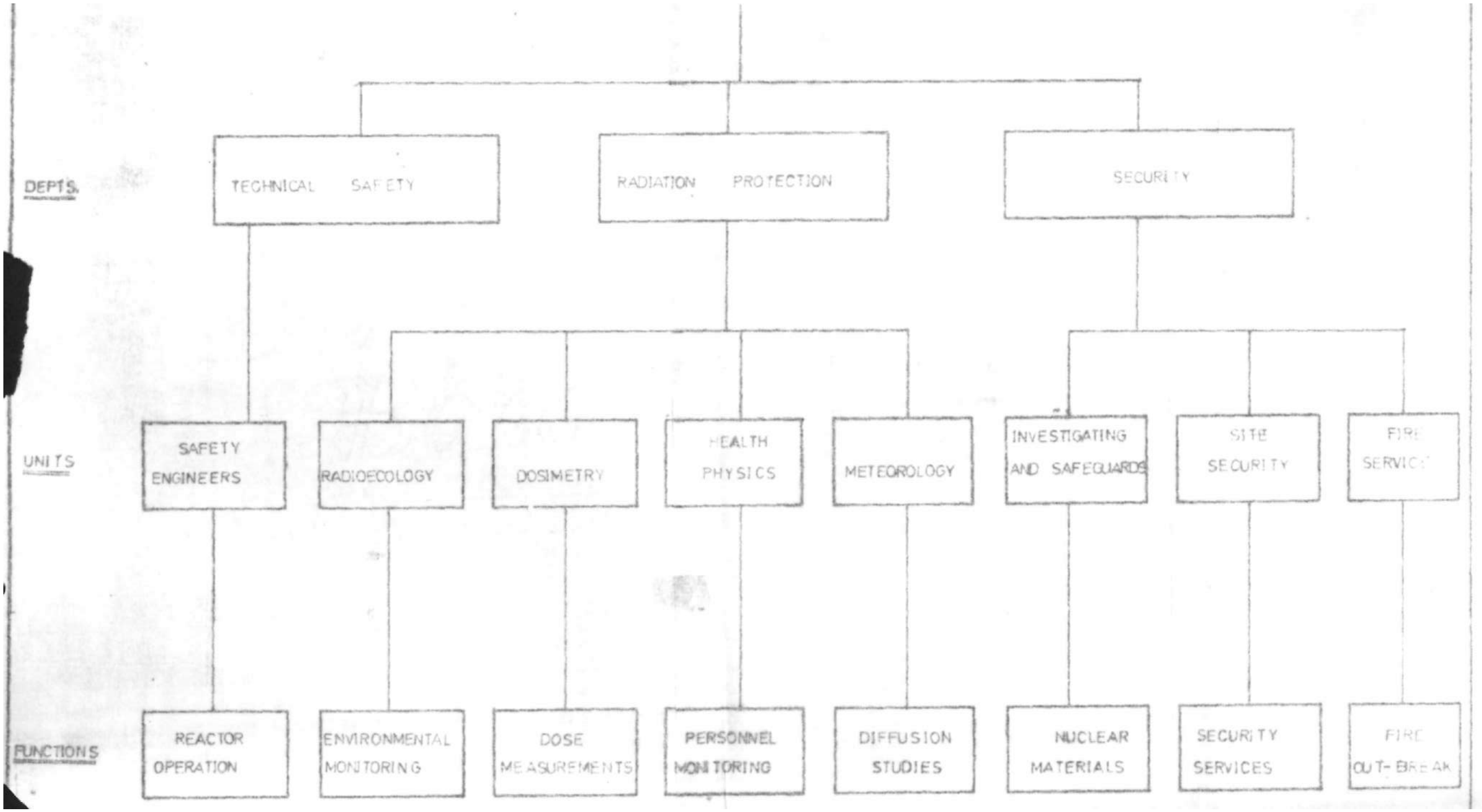


FIG. 4.1 ORGANIZATIONAL CHART OF THE REACTOR SAFETY BOARD PROPOSED FOR THE AHMADU BELLO UNIVERSITY NUCLEAR RESEARCH CENTRE.

losing assets; indeed they may have no assets to lose.

The University must therefore improve its ability to limit or avert such crises by considering strict measures that will ensure the safety of nuclear materials and the reactor Centre. The following recommendations are therefore suggested for consideration.

The reactor security department, should be divided into three namely:

(1) the site security unit

(2) the investigating/safeguards unit

and (3) the fire service unit.

The organizational chart of the Reactor Safety Board (RSB), is shown in fig. 4.1, and a brief note on the functions of each department is given in Appendix F.

For an efficient safeguard of the reactor and its allied facilities, the following recommendations are also suggested.

(a) All users of nuclear facilities in the Centre must be duly authorized by way of access permits, before they are allowed within the exclusion zone of the reactor. All other workers must always display their identification cards whenever they are on duty , within the reactor premises. Permits and identification cards should be issued by the investigating/safeguards unit.

(b) Within the exclusion zone, there should be limiting areas for reactor users, and only competent operators should be allowed around the the storage room of fuel assemblies, and other nuclear materials.

(c) Film cameras, and microprocessor closed circuit television (CCTV) systems, coupled to special alarming devices could be used for the effective monitoring of the movements of authorized and unauthorized persons around the reactor hall.

(d) Basically, three security post should be built within the nuclear installation. One at the entrance of the exclusion zone, the second to admit persons into the nuclear science laboratories, and the third strictly for persons working with the reactor. These posts should screen effectively workers, staff, students and guest scientists entering and leaving the research centre.

Safeguards if given due consideration, will reduce the risk of nuclear theft, terrorist hold-ups and violent attacks on the proposed nuclear installation. If safeguard programmes are well implemented, there will be a succesful nuclear programme, rather than become victim to an unprecedented damage that could have been averted, with effective safeguard measure.

4.5 Waste Management

The continuous operation of a nuclear facility generates different categories of substances whose radioactive content could cause some serious environmental problems, if not well monitored. Nuclear wastes covers a wide range, including solids, liquids and gases of which, some are known to contain radioactive contaminants (potential wastes), while others have unknown radioactive contents (suspect wastes). These wastes are the main problems, generating growing public awareness of the need to protect the environment and the population surrounding a nuclear facility.

The classification of radioactive waste into three main classes of high, low and medium or intermediate level waste is merely arbitrarily, varying from place to place, depending on the handling and ultimate disposal techniques developed in the management scheme. Classification could be based in terms of activity (Lenneman, 1967), as required for burial packages at the Oak Ridge National Laboratory (ORNL).

Low - having a radioactive content of less than 353 Curies per cubic meter.

Intermediate - having a radioactivity content between 353 to 353,000 Curies per cubic meters.

High - having a radioactivity content of over 353,000 Curies per cubic meters.

Roberts (1979) also maintains three categories of

classification with emphasis on sources of the various wastes from the reactor:

High-level wastes: associated with the fuel elements themselves,

Medium-level wastes: associated with fuel element claddings, certain process streams in the reactor, laboratory equipment and plutonium contaminated waste,

Low-level wastes: includes a large category of plant and laboratory trash effluent, including solid particles released from stacks, liquid effluents drained into sewage ponds.

Nuclear research laboratories are likely to generate large quantities of low-level waste in view of all the materials that are likely to be handled during irradiation and laboratory investigations. Most of them will be suspect wastes.

The physical nature of wastes arising from the low-activity category is highly heterogenous (Howels, 1967), including materials such as:

Paper: Towels, cleaning tissues, contaminated floor covering materials, cardboard boxes, drums and bags.

Plastics: Sheeting materials, bags and sacks, bottle tubings, protective clothing, footwear,

gloves, respirators and cables.

Metals: Scrap metals, conduits and electrical cables, scrap instruments, engineering tools, buckets, metal drums and containers.

Miscallaneous: Laboratory rubbles, brooms, mops glasswares etc.

These materials require monitoring to ascertain their radio-active level before packing for burial.

4.5.1 Waste storage facility and disposal of high-level waste, at the proposed centre.

A waste storage facility is essential, to act as an ultimate barrier in protecting the environment from being contaminated with high-level waste. The building will therefore serve as a shelter for the drums from weathering, mechanical and corrosive damage or any interference by un-authorized persons.

A storage building could either be on-site or off-site. In designing and constructing a waste storage building for the ABU research reactor, certain structural features (Graf and Rottenberg, 1977), should be taken into consideration as follows:

(1) The floor of the storage hall must be smooth and impermeable. Its mechanical strength must be

chosen such that it could withstand the heaviest anticipated load.

(2) The whole building including the roof structures should consist of incombustible (fire resistant) material to withstand any fire out-break or fire raid due to sabotage.

(3) The entrance to the building should be secured by steel doors with safety locks. The entrance could be monitored with the use of television cameras.

The requirements of the International Committee on Radiological Protection (ICRP) is that the overall activity of a filled drum stored in the building should have a radiation level of 10 mR/h at a distance of one metre, and 200 mR/h at the surface, for each drum (IAEA, 1965).

In siting the waste storage building, the following features proposed by Graf (1967) could be used as siting criteria.

(1) Remote location, with respect to inhabited buildings.

(2) It should be as far as possible from any important ground water source.

(3) The soil and sub-soil of the site should have homogenous permeability and good water control combined with a high ion exchange and absorption capacity.

(4) The site should have year round easy accessibility from reactor and laboratory site.

In view of the requirements for a storage building as proposed by Graf(1967), Graf and Rottenberg (1977), the site may not be suitable for a storage building. Howevr, for a low power reactor (1 Mw), as the one proposed for the Centre, it could be assumed that the radiation level of the waste may be much lower, hence a detailed study of the suitability of the site for a storage building may be necessary.

4.5.2 Low - level waste disposal at the site

The composition of low-level waste expected from the research Centre has been discussed. Most of the wastes will be regarded as suspect wastes, and if they give a radiation of 80 mR/h at a distance of 30 cm from a detector, they could be disposed of in shallow pits (IAEA, 1966) as recommended by ICRP. The problem therefore is, whether the proposed site is suitable for such shallow disposals. The suitability of the proposed site for shallow pit disposal could be considered if it satisfies certain basic criteria as defined, below.

(1) Burial sites should be land of low industrial potential, little agricultural value and remote from human settlements.

(2) Disposal trenches should have deep ground water with a low soil permeability, so as to reduce the

penetration of surface water, reaching the radioactive containers.

(3) Disposal sites so chosen, need not be re-excavated for any purpose for a period of over 20 years.

(4) Burial sites should be well protected to keep unauthorised persons from tampering with the disposal trenches.

Based on the above criteria, the proposed site is therefore examined in order to ascertain its suitability for an on-site burial of low-level waste.

From the topography of the proposed site, it seems that all the surface run-off will eventually out-crop at a flood plain near the University dam. Unless it is proved otherwise, the existence of a continuous saturated region of water at the flood plains could be attributed to a continuous directional flow of subsurface water to that region. From all indications, the plains of the dam is a water catchment area for both surface and subsurface water.

From the forgone discussions, any burial site around the proposed site will be too close to the water catchment zone, hence undesirable for shallow burial of radioactive contaminants. It is therefore suggested that the disposal trenches for the nuclear research centre be off-site.

4.6 Environmental monitoring of radiations at the Nuclear Research Centre.

The radiation protection department is mainly responsible for all forms monitoring ionizing radiations in nuclear establishments. In the organization plan proposed for ABU (fig. 4.1), the department is made up of four units, comprising the Radioecology, Dosimetry, Meteorology and Health Physics units. The main objective of radiation monitoring by all the four units could be summed up as follows:

(1) To protect the health and safety of all the the staff of the centre, others performing various research programmes as well as the immediate public located within the reactor monitoring zone.

(2) To ensure that the planned releases does not exceed the laid down limit.

(3) To constantly monitor the dose commit ment of the environment, through pathways including air, water, and ground contamination.

Radiation monitoring is being given serious attention where even low power research reactors are operated. At Yugoslavia where a 250 Kw pool-type Triga reactor is operated, an intensive monitoring of all categories of workers is performed constantly in order to ascertain the absorbed dose. The Health Physics unit monitor about 40 staff, consisting of reactor operators

and experimental staff (Kristan et al, 1978). All of them wear dosimeter badges with monitoring films for gammas and fast neutrons. The lowest monthly evaluated dose for both films is 50 mrem while the highest dose is 300 mrem with non exceeding 500 mrem (Kristan et al, 1978). These radiation levels are very low as compared to the maximum permissible dose (MPD). The MPD for radiation workers as recommended by ICRP (1959), is as follows:

Critical organ	MPD(annual) rem
Gonads, red bone marrow and whole body	5
Skin, thyroid and bone	30
Hands, forearms, feet and ankles	75
All other organs	15

All operators of nuclear facilities are expected by International standards to protect individuals, working in nuclear establishments, by ensuring that the occupational exposures fall below the levels stated above. The radiation protection department proposed for the ABU research centre will be saddled with this responsibility. In addition to the

MPD values, Piesch.(1977) notes that in personnel monitoring the following quantities should be monitored in reactor centres:

(1) Skin dose or the surface absorbed dose; to assess the dose equivalent to the basal layer of the epidermis at a depth of 5 - 10 mg/cm^2 (for X-rays and beta rays with energy less than 15 KeV).

(2) The body dose or depth absorbed dose at a depth of 400 - 1,000 mg/cm^2 below the surface of the body to assess the mean value of the dose equivalent in the critical organs for penetrating radiation (X-rays, gamma rays and neutrons).

(3) Surface water dose commitment in the reactor hall for 6 MeV gamma rays due to the reaction $^{16}O(n,g)^{17}N$ in the water used for neutron moderation and core cooling.

Radiation monitoring is therefore essential in nuclear establishments hence the following proposals are considered necessary for the protection of individuals from undue exposure to ionizing radiations at the centre.

4.6.1 Aerosol content of the air

This requires continuous monitoring for long lived alpha and beta activity. It is achieved by ensuring that the site boundaries are lined with fence detectors at low warning

thresholds of 1 mR/h and alarm thresholds at 100 mR/h for beta and gamma dose rates. These detectors should be fixed to aluminium poles of 3 metres height above ground level. Solid state dosimeters could also be zoned in two concentric circles of radii 100 meters and 200 meters from reactor chimney. They should be more concentrated in the main wind direction. Filter systems could be installed and monitored in measuring huts weekly for air samples.

4.6.2 Precipitation

Zaria has fairly, low precipitation, with rainfall, dew mist and fog being the commonest ones. Some specific nuclides associated with precipitation within the neighbourhood of a reactor include Tritium, Strontium-90 and Caesium-137. These nuclides should be monitored constantly for alpha and beta gross activity monthly. Rainfall samples obtained from wet collecting funnel tanks and dew/fog precipitates collected from special collecting surfaces by swabbing, could be analyzed for the prescence of these nuclides.

4.6.3 Water

Surface water contamination should be measured from shallow streams, wells and the dam in the neighbourhood of the reactor. The nuclides monitored are those with long lived alpha and beta activity with special emphasis on Potassium (K-40) and Tritium. This could be performed weekly

so as to ensure that drinking and ground water are not contaminated.

4.6.4 Biological materials

Zaria is an agricultural area, where food crops such as guinea corn, millet, maize, vegetables, tomatoes, onions, okro and sugar cane are widely grown. These foodcrops will also require weekly and monthly monitoring for short and long lived alpha, beta and gamma radiations. The critical nuclides monitored should include K-40, I-131 and other emitters.

It is hoped that the reactor centre management will ensure that these measurements are made (and some of the results published), to assure the public constantly of the safety of the reactor environment.

On grounds of environmental safety, a 1 Mw reactor could operate at the proposed site without any serious environmental problems, but the acceptance of this view by the public may be a matter of serious debate within the university community.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

A case study of the proposed Ahmadu Bello University nuclear research reactor has been made, with respect to the reactor model, siting and environmental problems. The need to operate a research reactor in Nigeria has been stressed. On the question of the reactor model to be chosen, the following conclusions are made ;

5.1 Reactor model

(a) Two types of research reactors are commonly used namely : Argonauts and Triga reactors.

(b) In terms of popular demand, versatility, low enrichment of fuel, and assurance of safety, a Triga reactor is recommended for the University.

(c) Of the four models (Mark I, II, III, and IV), the Mark II model is recommended. This model is common, easily operated, and has a moderate neutron flux of the order of 10^{13}n $cm^{-2}s^{-1}$, high enough for biomedical research.

(d) The reactor power rating recommended is 1 Mw (th). As beginners in nuclear technology, the ABU reactor should be such that could be easily operated, cheap, easily constructed and maintained, as well as common in most of

the developing countries currently operating research reactors.

5.2 Siting

Two zones have been proposed at the site as limiting areas for radiation monitoring, namely, the exclusion and restrictive zones.

There are merits and demerits on the siting of the reactor at the proposed site. The merits include :-

(a) accessibility to users

(b) good road networks linking the site with users

(c) fairly good site-topography

(d) proximity to a cooling water source

(e) suitable meteorological conditions

and the demerits include :-

(a) safeguard problems anticipated as a result of violent students demonstration

(b) proximity to population units like the University and Jam'ar village

(c) fear of'strong' objections that may be raised by the academic communities of the University thereby bringing to a halt progress of the work at site

These demerits could be considered not restrictive enough if:

(a) The laboratories and other allied nuclear

facilities proposed for the Centre in 20 years time are all low radiation sources.

(b) The reactor planning committee considers objections as common, wherever nuclear facilities are to be sited.

In view of this therefore, the planning committee could plan ahead, the organisation of public hearings, in order to inform and educate the University community on the safety of the proposed reactor.

Based on the merits outlined, it is therefore concluded that a 1 Mw reactor operated as a University research facility could operate safely at the proposed site.

5.3 Environmental Problems

It has been examined that Triga reactors are safe in terms of reactivity accidents and loss-of-coolant (LOCA) accidents.

Aircraft crashes and forest fire outbreaks are considered as having a high potential of occuring. In order to prevent aircraft crashes, it is suggested that the University request the Aviation Centre to plot their low level flying routes at a convenient distance off the reactor site. For combating fire hazards, it is recommended that a well trained fire fighting unit should be attached to the Centre.

The possibility of terrorist acts and nuclear thefts

were considered, and the safeguards recommended include the use of close circuit television cameras (CCTV), for monitoring personnel in the restrictive zone.

For an effective management of the reactor, a Reactor Safety Board (RSB), has been proposed (fig.4.1), and the organizational chart, duties and responsibilities of each department and unit outlined.

Waste management has been considered as another major environmental problem. It has been suggested that the present site is not suitable for on-site waste burial of low radioactive waste that will be generated from the reactor and its ancilliary laboratories. An off-site burial is therefore suggested.

5.4 General Conclusion

There are several research reactors in operation all over the world. Some of them include the Canadian SLOW-POKE, the French reactors like the ARIANE reactors, the ORPHEE, EL 3 and OSIRIS reactors. Others are the Russian WWR-C reactors and the American General Atomic TRIGA reactors (Appendix G).

Some of these reactors are not suitable for A.B.U. nuclear research centre because of the following reasons.

Reactors such as the OSIRIS (70 MW) and the EL 3 (18 MW) are advanced material testing research reactors which may be difficult to be operated by beginners in the field of nuclear technology. Others like the SLOWPOKE, and ORPHEE types have very highly enriched fuels (93% of U-325), which may involve difficult safeguard measures. The low power reactors like the ARIANE and the SLOWPOKE, have low neutron fluxes (less than 10^3n $cm^{-2}s^{-1}$) that limits their use in some aspects of neutron therapy in biomedical research. Since the proposed reactor is intended to be used for Isotope production as well as research in neutron therapy, the proposed reactor should therefore have a moderate neutron flux (10^{13}n $cm^{-2}s^{-1}$).

A reactor of 1 MW rating and probably a TRIGA Mark II model is therefore recommended for the university. This reactor has a moderate neutron flux (10^{13}n $cm^{-2}s^{-1}$), and uses fuel of low enrichment. It is easily maintained and operated as well as technically flexible for upgrading. The reactor could be sited and operated safely at the proposed site with little or no environmental problems.

METEOROLOGICAL OBSERVATIONS SAMARU 1979 (Sheet One)

Month	RAINFALL(mm) 1979	RAINFALL(mm) 1928 to 1979	DAYS OF RAIN 1979	DAYS OF RAIN 1928 to 1979	RELATIVE HUMIDITY 1979 AM	RELATIVE HUMIDITY 1979 PM	RELATIVE HUMIDITY 1954-1979 AM	RELATIVE HUMIDITY 1954-1979 PM	AIR TEMPERATURE °C 1979 MIN	AIR TEMPERATURE °C 1979 MAX	AIR TEMPERATURE °C 1979 MEAN	AIR TEMPERATURE °C 1938-1979 MIN	AIR TEMPERATURE °C 1938-1979 MAX	AIR TEMPERATURE °C 1938-1979 MEAN	SUNSHINE Daily Mean Hours 1979	SUNSHINE Daily Mean Hours 54 - 79
JANUARY	0.0	0.1	0	0.1	13.0	14.2	17.7	13.8	13.9	30.2	22.5	13.9	30.3	22.1	8.9	8.7
FEBRUARY	0.0	1.0	0	0.2	14.4	14.9	15.3	10.6	15.8	33.6	24.7	16.0	32.7	24.4	8.9	9.4
MARCH	10.4	6.6	1	0.9	26.3	19.0	25.7	14.3	19,8	35.2	27.5	19.5	35.3	27.4	7.4	8.4
APRIL	19.8	37.1	2	3·9	45·1	32·7	48;3	29·2	21·3	35.8	28.6	21.7	35.7	28.7	8.7	8.0
MAY	86.3	122.2	8	10.0	67.6	45.3	63.4	43.1	21.1	32.8	27.0	21.2	32.9	27.4	8.2	8.2
JUNE	220.2	161.2	15	12.9	74.7	62.8	72.5	57.1	20.5	30.1	25.3	19.9	30.7	25.4	7.6	7.8
JULY	373.8	221.5	19	16.4	82.3	71.7	79.4	66.1	19.4	28.9	24.2	19.5	28.4	23.9	6.9	6.1
AUGUST	299.8	278.2	19	20.2	81.6	71.8	81.2	69.6	19.7	28.8	24.3	19.3	27.7	23.5	5.7	5.2
SEPTEMBER	142.8	232.2	15	16.4	77.8	62.6	75.9	62.9	18.9	29.6	24.3	19.1	29.3	24.2	6.8	6.9
OCTOBER	30.8	36.1	4	4.0	63.2	45.6	60.1	43.1	18.1	32.1	25.1	17.7	31.4	24.8	8.7	8.8
NOVEMBER	9.8	0.6	1	0.2	32.6	29.3	29.3	21.4	15.1	32.3	23.7	15.5	31.5	23.5	8.7	9.5
DECEMBER	0.0	0.1	0	0.0	20.4	18.5	21.1	16.5	12.2	28.3	20,2	13.8	30.3	22.2	8.3	9.1
Total	1193.7	1087.9	84	85.2	-	-	-	-	-	-	-	-	-	-	94.8	96.1
Mean	-	-	-	-	49.9	40.7	49.2	37.4	18.0	31.5	24.8	18.1	31.4	24.2	7.9	8.0

SOURCE:
Institute of Agric. Research, (I.A.R) Samaru.

APPENDIX B

METEOROLOGICAL OBSERVATIONS SAMARU 1979(Sheet Two)

MONTH	GRASS MINIMUM TEMPERATURE °C		SOIL TEMPERATURES										Open Pan Evaporation		Piche Evaporimetre	
			At 5 Cm				At 30.5 Cm				At 122 Cm		Total in (mm)		Total in (mm)	
	1979	1954 to 1979	1979		1954-1979		1979		1954-1979		1979	1954 to 1979				
			AM	PM	AM	PM	AM	PM	AM	PM	AM	PM	1979	54-79	1979	54-79
JANUARY	5.9	8.3	22.0	30.4	21.8	30.8	22.8	23.5	23.4	23.9	24.3	25.2	207.3	191.7	393.7	331.7
FEBRUARY	9.4	10.6	24.8	34.4	24.7	34.6	25.3	26.2	25.5	25.9	25.0	2..	200.2	203.1	356.7	351.9
MARCH	15.6	14.3	28.3	37.4	28.7	38.3	28.4	29.2	28.6	29.2	26.9	27.6	243.5	246.2	402.8	374.9
APRIL	17.7	18.0	30.6	39.8	30.6	40.0	30.4	31.4	30.1	30.9	28.4	29.3	158.9	210.5	351.8	252.2
MAY	19.9	18.9	28.0	35.0	29.5	37.4	28.7	29.6	29.3	30.0	28.6	28.6	-	195.8	183.5	177.8
JUNE	18.9	18.6	27.0	27.2	30.9	33.1	27.3	27.8	27.6	28.0	28.0	28.6	205.9	162.7	92.6	177.1
JULY	19.2	18.3	25.6	30.1	25.5	30.3	26.6	26.9	26.3	26.3	26.7	27.2	-	137.3	70.4	72.9
AUGUST	19.2	18.1	25.7	29.3	25.0	28.9	26.3	26.6	25.5	25.8	26.8	26.7	127.2	123.4	62.1	59.4
SEPTEMBER	18.4	18.1	25.3	29.6	26.0	30.7	26.2	26.4	26.7	26.4	26.8	26.8	125.4	134.7	90.2	66.9
OCTOBER	15.9	15.8	26.2	30.8	26.6	31.5	26.5	26.9	26.5	26.4	26.7	27.2	138.1	144.5	119.7	132.7
NOVEMBER	11.9	10.2	24.9	24.2	29.3	30.7	25.2	25.8	24.8	26.9	26.2	26.6	147.2	166.4	197.2	252.0
DECEMBER	6.2	7.7	21.2	27.6	22.2	30.2	22.4	22.7	23.4	24.0	24.6	25.6	164.6	175.0	303.7	302.1
TOTAL	-	-	-	-	-	-	-	-	-	-	-	-	1718.3	2090.8	2624.4	2492.6
MEAN	14.9	14.8	25.8	26.0	32.1	33.1	26.3	26.9	26.4	27.0	26.6	27.2	171.8	174.2	100.9	95.9

NOTE (1) Evaporation at 0900 and 1500GMT

(2) Evaporation records from open tank 1.83 x 1.83 meters at ground level.

(3) Piche Evaporation records taken in screen.

SOURCE:
Institute of Agric. Research (I.A.R.). Samaru.

APPENDIX C

1963 Population of human settlements around Zaria

Settlements	Population
Basawa	1,708
Bomo	3,197
Gwanda	1,005
Hanwa	2,718
Jam'ar Kubani	795
Pan Ladan	1,194
Sabon Gari Bindare	6,835
Dogon Bauchi	3,229
Jushin Waje	3,969
Muchiya Dan Auta	9,020
Sabon Gari	15,842
Tsugugi	1,061
Sakadadi	2,184
Samaru	4,147
Shika	973
Zabi	1,513
Nigeria College	1,226
Research Samaru	1,760

SOURCE:

Population of Northen Nigeria (1963)
Federal Office of Statistics, Lagos, 1965.

APPENDIX D

WIND DIRECTION, DISTRIBUTION AT ZARIA (ANNUAL AVERAGES 1972-1975)

YEAR	CALM	NE	E	SE	S	SW	W	NW	N
1972	15	46	30	5	11	34	29	7	10
1973	29	60	28	5	18	49	37	4	17
1974	32	55	33	6	14	46	36	5	14
1975	42	49	38	6	16	44	36	6	12

NOTE:
Direction measured by a wind vain, hourly at a height of 33 feet above ground level.

SOURCE:
Field Data, Zaria Meteorology Office (Zaria Airport).

APPENDIX E

RESEARCH REACTORS IN DEVELOPING COUNTRIES

Country	Location	Designation	Research Output	Type, Enrichment, Moderator, Coolant	Maximum Thermal flux($n\ cm^{-2}s^{-1}$)
Argentina	Buenos Aires	Ra - 0; Ra - 1, Ra - 2			
	Ezeiza	Ra - 3	5 Mw (th)	Tank, 90% U, H_2O	4×10^{13}
Brazil	Sao Paolo	IEAR - 1	5 Mw	Pool, 20% U, H_2O	7.1×10^{13}
	Belo Horizonte	Triga - Brazil	100 Kw	Solid. homog. 20% U, ZrH - H_2O	4×10^{12}
	Rio de Janeiro	RIEN - 1	10 Kw	Argonaut, 19.9% U, graph, H_2O	1.2×10^{11}
Bulgaria	Sofia	IRT - Sofia	1 Mw	Pool, 10% U, H_2O	1.6×10^{13}
China	Hsin Chu	TOPR	1 Mw	Pool, 20% U, H_2O	9.9×10^{12}
Colombia	Bogota	IAN - RI	20 Kw	Pool, 90% U, H_2O	5.6×10^{11}
Congo(Dem. Rep.)	Kinshasha	TRICO	1 Mw	Solid homog. 20% U, H_2O	2×10^{12}
Greece	Athens	GRR - Democritus	5 Mw	Pool, 20% U, H_2O	1.5×10^{13}
Hungary	Csillaberg	WWR - C - Budapest	2 Mw	Tank, 10% U, H_2O	2×10^{13}
India	Trombay	Aspara, CIR, Zerlina	1 Mw	Pool, 46 % U, H_2O	2×10^{13}
Indonesia	Bandung	Triga - II	1 Mw	Solid. homog, 20% U, ZrH + H_2O	7.2×10^{13}
Iran	Amirabad	UTRR	5 Mw	Pool, 20% U, H_2O	7×10^{13}
Iraq	Twartha	WWR - C - Baghdad	-	Tank, 10% U, H_2O	-
Israel	Nahal Soreq	IRR - 1	5 Mw	Pool, 90% U, H_2O	7×10^{13}
	Dimona	IRR - 2	-	-	-
Korea, Rep. of	Seoul	Triga - II - Seoul	250 Kw	Solid. homog. 20% U, ZrH + H_2O	1×10^{13}
Mexico	Salazar	Triga Mark III	-	-	-
Pakistan	Islamabad	PARR	5 Mw	Pool, 90% U, H_2O	5×10^{13}
Philipines	Quezon City	PRR - I	1 Mw	Pool, 20% U, H_2O	3.5×10^{13}
Poland	Swierk	WWR - C - Warsaw - Eva	10 Mw	Tank, 10% U, H_2O	10^{14}
Romania	Bucharest	WWR - C - Bucharest	3 Mw	Tank, 10% U, H_2O	4×10^{13}
Thailand	Bangkok	TRR - 1	1 Mw	Pool, 90% U, H_2O	6×10^{12}

Research reactors in developing countries contd.

Country	Location	Designation	Reactor Output	Type, Enrichment, Moderator, Coolant	Thermal flux
Turkey	Cekmece	TR - 1	1 Mw	Pool, 90% U, H_2O	5.3×10^{13}
UAR(Egypt)	Inshas, Cairo	WWR -C- Cairo	2 Mw	Tank, 10% U, H_2O	2×10^{13}
Uruguay	Montevideo	Univ. of Montevideo	-	-	-
Venezuela	Altos de pipe	RV - 1	3 Mw	Pool, 20% U, H_2O	3.5×10^{13}
Vietnam	Dalat	Triga - II - Dalat	250 Kw	Solid, homog. 20%U, $ZrH+H_2O$	1×10^{13}

SOURCE: (1) Peaceful Use of Atomic Energy in Africa: ' Role of research reactors in developing countries ' by B. I. Spinard, V. Tchernilin (IAEA, Vienna, 1974)

(2) Directory of Nuclear Reactors Vol. VIII (IAEA, Vienna, 1970)

(3) Directory of Nuclear Reactors Vol. X (IAEA, Vienna, 1970)

APPENDIX F

Functions of the various departments, and units of the Reactor Safety Board (RSB) proposed for the Ahmadu Bello University Nuclear Research Centre.

The Reactor Safety Board (RSB).

The RSB is an advisory board made up of heads of departments from the Technical Safety, Radiation protection and Security departments. Their main function is to draw up , study and ensure that safety guidelines for the safe operation of the reactor are maintained. The composition could be increased to include the participation of other experts in the field of reactor safety, radiation protection and reactor safeguards. The RSB is the highest policy board in charge of the safety of the reactor (fig. 4.1).

1 Technical Safety Department

This department is made up of safety engineers whose main duties include the safe operation of the reactor, protection, and maintenance of the reactor. The department compiles reports on the state of the reactor from time to time ensuring that the maximum duty cycle of the reactor is not exceeded. The department also accepts and considers the feasibility of all research programmes planned for the reactor and issues acceptance permits for all researches that can be carried out with the reactor. The composition of this department will be made up of all categories of engineers in Nuclear Science as well as all the operators who are expected to be trained on reactor operation.

2 The Radiation Protection Department.

This is a large department comprising the Radioecology unit, the

Dosimetry, Meteorology and Health Physics units.

2.1 Radioecology Unit

The radioecology unit will monitor radiations (alpha, beta and gamma) from all liquid effluents from the reactor and all water sources around the reactor monitoring zone. Also vegetation and soil monitoring for critical nuclides emitted will be conducted by this unit. The unit could run and maintain counting tubes and measuring stations around the monitoring zone. For the proposed reactor site, measuring stations could extend as far as LERIN and Jam'ar villages.

2.2 Dosimetry Unit

The Dosimetry unit is mainly responsible for the distribution, inspection and interpretation of all forms of dosimetres used in personnel and environmental monitoring. Neutron dosimetry involving measurements of scattered neutron fields is also the responsibility of this unit.

2.3 Meteorology Unit

The meteorology unit will undertake diffussion studies for airborne radionuclides. The extent of atmospheric pollution by radiations emitted at reactor stack and exhaust pathways will be determined by this unit. For a proper study airborne nuclides it is recommended that a measuring tower with platforms at different heights be erected at the Centre. These platforms will be used for atmospheric diffusion studies using tracer techniques for detectable aerosols.

2.4 Health Physics Unit

The Health Physics Unit is responsible for the monitoring of personnel working at the reactor centre. This unit will undertake decontamination whenever there are surface contaminations.

The personnel monitoring include body, hand and foot contaminations. They will also monitor objects for surface contamination ensuring that all objects monitored have radiation levels conforming with either National or International standards.

3 The Security Department

The Security department is made up of three units namely: the Investigating /Safeguards, Site Security and Fire Services.

3.1 Investigating and Safeguards Unit

The Investigating unit is solely responsible for all forms of investigations relating to the safety of the reactor. They are responsible for the storage of confidential documents (classified and unclassified) of the Centre. This unit is also responsible for the issue and withdrawal of identity cards issued to all the staff and visitors of the centre. The safeguards aspect involves the safety of all nuclear materials used in the Centre. This unit should regularly inspect nuclear fuels under close circuit television cameras (CCTV). They should also monitor the movement of all staff, guest scientists, researchers within the reactor building by the use of CCTV. They are expected to inform the site security unit of any hazard posed by any personnel within the reactor hall.

3.2 Site Security Unit

The Site Security unit is responsible for the overall security of the Centre. This is achieved by constant patroling, guarding accesses at the gates as well as periodic surveillance of all areas which are security risks within the centre, using short range transmitters.

This unit also controls the movement of traffic in and out of the centre. They also confirm how genuine access permits issued to visitors are.

CONCLUSIONS

All the departments and units are not expected to function in isolation . Most of their duties and responsibilities may overlap. It is the extent of flexibility and purposefulness allowed by the over-lapping that will ensure the smooth running of the A.B.U nuclear research centre. The ommission of staff strenght and qualifications is deliberate. It is hoped that this may vary depending on available skilled man-power and experts in their respective fields.

The reactor safety board proposed for the centre could be taken as an ideal model. This may not be obtained in reality owing to acute shortage of experts, funds and facilities. A more attainable board composition may comprise of at least two specialist in radiation protection, threee safety engineers and a few well trained security officers. The security department could be linked with the fire fighting unit of the university for immediate fire services. However, no matter the strenght of the staff, it is very neccessary that the board should be able to assure the public of the safe operation of the reactor , through various study reports as outlined in the functions column of the chart (Fig. 4.1).

APPENDIX G

COMMON TYPES OF RESEARCH REACTORS

TYPES	MODEL	POWER (RANGE)	FUEL, ENRICHMENT	MODERATOR COOLANT	NEUTRON FLUX ($n\ cm^{-2}s^{-1}$)	USES
SLOWPOKE	1 & II	Zero	U-235,93%	H_2O	Under 10^{13}	R,I.P
ARIANE	-	Under 500KW	UO_2	H_2O	Under 10^{13}	R,I.P.
ORPHEE	-	14MW	U-235,93%	H_2O	3×10^{14}	R, NP
EL 3	-	18 MW	U-235,93%	D_2O	2.2×10^{14}	R,NP,MTR
OSIRIS	Pool	70 MW	Caramel (UO_2,8%)	H_2O	2×10^{14}	R,IP,MTR
OSIRIS	ISIS	Under 800KW	Caramel (UO_2,8%)	H_2O	3.7×10^{12}	NP
WWR - C	Tank	Under 10 MW	U-235,10%	H_2O	Under 10^{14}	R,NP,MTR
TRIGA	I,II,III,IV	10KW-15MW	Triga (U-235,20%)	$UZrH_x+H_2O$	Under 10^{14}	R,IP.MTR

USES: R - Research, IP - Isotope Production, [illegible] MTR - Material Testing Reactor
NP - Neutron Production.

SOURCES:

(1) OSIRIS Bulletin 1982
(2) ORPHEE Reactor Bulletin 1981
(3) Directory of Nuclear Reactors Vol. VIII and X (IAEA, Vienna, 1970)

LIST OF REFERENCES

Aizawa, O. et al., 1980. 'Remodelling and dosimetry of the Triga Mark II Musashi reactor', Nuclear Technology, Vol. 48 p. 151.

Aybers, N. and Yavuz, H., 1978. 'Atout the safety analysis of Instanbul Triga Mark II reactor, Proc. of the 5th European conf. of Triga users, Yugoslavia.

Birkhofer, A., 1980. The German risk study of nuclear power plants. IAEA Bulletin Vol. 22 No. 5/6.

Bobe, P.E., 1976. Rep. NUREG - 0032.

Chamberlain, 1959., Deposition of Iodine - 131 in Northern England in Oct. 1957. Quart. J. Ray. Meteor. Soc. 85 (366), 350 -361.

Cisse, A.M., 1980. Developing countries and N.P.T. IAEA Bulletin Vol.22 No. 3/4.

Convair, 1959. Fission products release Test I, Report NARF 59 - 32T (FZK-9-140), US Air Force Nuclear Aircraft Research.

_____, 1960. Fission products release Test II. Report NARF 60-10T (FZK-9-149).

Edge, 1981. TMI accident. Journal of BNES , April, p.102.

Garzarolli et al., 1979. Fuel element failure, Atomic Energy Review Vol. 17. No. 1.

General Atomic, 1975. Safety analysis for the Triga reactor , Technical University of Instanbul, E - 117 - 478.

_____, 1980. Proc. of conf. of Triga users. Mainz (unpub.)

Gietzen, 1980. Triga fuels. Proc. of conf. of Triga users. Mainz (unpub.)

Graf, P. and Rottenberg,W., 1977. Plans for long-term storage of low and medium level waste. IAEA -SM - 92/23, Vienna, Austria, p.329-341.

Grimes, B.K., 1974. External hazards as they affect nuclear power plant siting. IAEA -SM- 188/58 Vienna, Austria, p. 140.

Howels, H., 1967. Trench disposal of solid radioactive waste from the Windscale and Calder Works of the UKAEA, IAEA -SM- 93/2 Vienna, Austria, p.5.

International Atomic Energy Agency (IAEA), 1965. Regulations for the safe transport of radioactive material. Safety Series No. 6 Vienna, Austria.

_____, IAEA 1966. Solid radioactive wastes: Operational tech. Safety and waste disposal, Vienna, Austria.

_____, IAEA, 1970. Power and research reactors in member states, Vienna, Austria.

_____, IAEA, 1978. Radioactive wastes. IAEA, Vienna, Austria.

_____, IAEA, 1980. International Safeguards. IAEA Bulletin Vol 22 No. 3/4 p. 2.

Kristan, J., Udovo, H., et al., 1978. Radiation protection measurements around the Triga reactor, Ljubljana, Yugoslavia.

Kupperman, R.H. and Trent, D.M., 1978. New perspective on arms control and crisis management, Mariel Dokkev Inc. , New York.

Lenneman, W.L., 1967. United States Atomic Energy Commission IAEA SM - 93/20, Vienna, Austria, p. 264.

Mahmoud, K.A., et al., 1969. UARSCEAR No. 10.

_____, _____, 1971. A/Conf. 49/p/142, p. 250.

Malu, M. and Hasnain, S.A., 1974. Siting considerations for nuclear facilities in Pakistan, IAEA SM - 188/36, Vienna, Austria.p. 153

NEDECO, 1971. Netherlands Engineering Consultants Report. 1971.

Ojanuga,A.G., 1981. Soil tests at the ABU Nuclear Research Centre site(unpub.)

Piesch, E.A, 1977. Conf. paper on the use of TLD dosimeters

Profio, E.A., 1976. Experimental reactor Physics, Wiley, New York. p. 210.

_____, 1979. Radiation shielding dosimetry, Wiley, New York. p.418.

Rosen, A and Schmidt, B., 1980. Conf. paper on reactor siting Vienna, Austria.

Selders, K. and Hungate, P., 1956. Radioiodine depositions. Meteorology and Atomic Energy. TID - 24190.

SIPRI, 1976. Stockholm International Peace Research Institute. World Armaments and Disarmaments. SIPRI Yearbook 1976. Cambridge, Mass. MIT Press p. 43.

Slade, D.H. (ed.)., 1968. Meteorology and Atomic Energy. US Atomic Energy Commission , TID- 24190.

Stockholm, 1980. Stockholm Conf. reports IAEA. Bulletin, Vol. 23, No. 1 Vienna , Austria

Texas A&M University, 1977. Nuclear Science Centre Safety Analysis report. p.23. (unpub.).