BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY, DHAKA
DEPARTMENT OF PHYSICS
CERTIFICATION OF THESIS WORK
A THESIS ON

AN INVESTIGATION ON THE UPTAKE BEHAVIOUR OF CESIUM-137 IN SOME FRESH WATER FISH SPECIES COMMONLY CONSUMED IN BANGLADESH.

BY

MD. ABDUL MALEK

has been accepted as satisfactory in partial fulfilment for the degree of Master of Philosophy in physics and certify that the student demonstrated a satisfactory knowledge of the field covered by this thesis in an oral examination held on 27 January, 1990.

Board of Examiners :

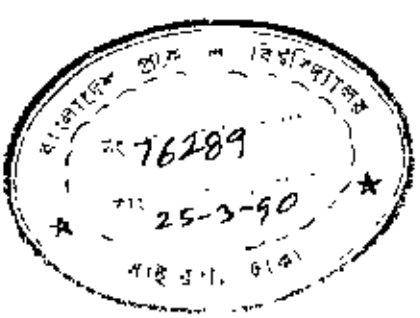
1. Prof. G.U. Ahmad, Head, Physics Dept., BUET. — Chairman, Examination Committee. 27-1-90
2. Mr. Munsur Rahman, Co-supervisor — Member 27/1/90
3. Prof. M. A. Asgar, Dept. of Physics, BUET. — " 27/1/90
4. Prof. T. Hossain, Dept. of Physics, BUET. — " 27.1.90
5. Prof. N. Islam, Dept. of Physics, Chittagong University — Member (External) 27/1/90

AN INVESTIGATION ON THE UPTAKE BEHAVIOUR OF CESIUM-137 IN SOME FRESH WATER FISH SPECIES COMMONLY CONSUMED IN BANGLADESH

by

MD. ABDUL MALEK

Submitted in partial fulfilment
of the requirements for the
Degree of M.Phil



Department of Physics
Bangladesh University of Engineering and Technology

December, 1989.

CERTIFICATE

This is to certify that the author is solely responsible for the work reported in this thesis and that this work has not been submitted to any University for the award of a degree.

(M. A. Malek)
Candidate

(Munsur Rahman)
Co-Supervisor

(Dr. G. U. Ahmad)
Supervisor

ACKNOWLEDGEMENTS

The author expresses his sincere gratitude to his supervisors Prof. Giasuddin Ahmad, Head of the Physics Department, Bangladesh University of Engineering and Technology (BUET), Dhaka, and Mr. Munsur Rahman, Principal Scientific Officer (PSO), and Head, Health Physics and Radiation Protection Division (HPRPD), Institute of Nuclear Science and Technology (INST), Atomic Energy Research Establishment (AERE), Savar, Dhaka for their constant guidance and encouragement throughout the course of this work. The author expresses his gratitude also to Mr. A.S. Mollah, Senior Scientific Officer, HPRPD, INST, AERE for his valuable co-operation and many useful suggestions in the course of this work.

The author expresses his sincere thanks to Dr. S.M.M.R. Chowdhury, Director, INST, and Director General, AERE for his keen interest, constant encouragement and co-operation throughout the progress of this work. He would also like to thank Dr. K.M. Idriss Ali, PSO and Dr. M. Alamgir, PSO, Nuclear Chemistry Division (NCD), INST for their valuable help in the chemical part of this study. The author expresses his sincere gratitude to Dr. M.A. Mannan, Chairman, Bangladesh Atomic Energy Commission (BAEC) for kindly allowing the author to use the laboratory facilities at INST, and for his keen interest in the work.

The author expresses his gratitude to Prof. T. Hossain and Prof. M.A. Asgar of the department of Physics, Bangladesh University of Engineering and Technology for their keen interest in the work and constant encouragement throughout the course of this work. The author gratefully acknowledges the financial support provided by BUET without which this work would not have been possible.

The assistance of the scientific and technical personnel of the HPRPD is thankfully acknowledged. The secretarial assistance of Mr. Liaquat Ali is also thankfully acknowledged. The author would like to thank Mr. Rafiqul Islam Khan, INST for helping the author with the tracing of the figures.

Finally, the author would like to gratefully acknowledge the long and loving care of his wife, Mrs. Rehana Illeun Hena, without whose sustained inspiration, this work would not have been possible.

ABSTRACT

This work describes the investigation carried out into the uptake and retention, biological elimination and the tissue distribution of ^{137}Cs by some fresh water fishes in Bangladesh. Because of its high fission yeild and potential hazard to human being, ^{137}Cs was chosen as the radionuclide of interest. Since Singhi, Magur, Koi and Soiel fishes are eaten by all classes of people of Bangladesh and because of their easy availability in almost every water reserviour of the country, the experiments were carried out on these species of fishes. The fishes were released into the ^{137}Cs spiked water and the accumulated ^{137}Cs activities in the whole body of the fishes were measured regularly by using a HPGe detector coupled with a multichannel analyzer. Radioactivities in Singhi and Magur were measured for upto 21 days and those in Koi and Soiel were measured upto 37 days. In each case, significant accumulation of ^{137}Cs was found. The bioaccumulation factor was calculated from this ^{137}Cs activity in fish tissue and the amount of ^{137}Cs present in the water. These bioaccumulation factors were plotted against the time on a semilog paper. The curves thus obtained for every species of fishes indicate that the accumulation of ^{137}Cs initially increases rapidly with time followed by more gradual accumulation. A steady state concentration could not be reached

at the end of the experiment. The uptake rates were found to depend on the size of the fish species and are also different for different fish species.

Experiments on biological elimination of ^{137}Cs from various species of fishes were also conducted. Some fishes from all the species were released into ^{137}Cs spiked water for a certain period to accumulate the ^{137}Cs. Fishes were then removed from the radioactive water and released into non-radioactive water. The radioactivities remaining in the fish body were measured regularly and from the data thus obtained the effective half-lives of ^{137}Cs in Singhi, Magur and Koi were found to be 33.60, 151.27 and 217.04 days respectively. Tissue distribution of ^{137}Cs for all fish species was also determined. The total body of a fish was divided into edible and non-edible parts. The ^{137}Cs accumulated in edible parts was found to be 87.20, 85.03, 76.65 and 88.31 percent of total parts for Magur, Singhi, Koi and Soiel fishes respectively.

CONTENTS

			Page
CHAPTER	1	INTRODUCTION	1
CHAPTER	2	BIOLOGICAL EFFECTS OF RADIATION ...	7
CHAPTER	3	REVIEW OF THE EARLIER WORKS	14
CHAPTER	4	THE DETECTION SYSTEM	17
CHAPTER	5	THEORY FOR ERRORS IN THE EXPERIMENTS..	34
CHAPTER	6	MEASUREMENTS	38
CHAPTER	7	RESULTS AND DISCUSSION	51

List of tables

		Page
Table 1.	Identification of the fish species.	58
Table 2.	Grouping and size measurements of the fish species based on their lengths and weights. ...	58
Table 3.	Parameters for uptake of ^{137}Cs by fish species. ...	59
Table 4.	Data for uptake of ^{137}Cs by 'Magur' fish at different exposure times.	59
Table 5.	Data for uptake of ^{137}Cs by 'Singhi' fish at different exposure times.	60
Table 6a.	Data for uptake of ^{137}Cs by 'Koi' fish of large size at different exposure times. ...	61
Table 6b.	Data for uptake of ^{137}Cs by 'Koi' fish of intermediate size at different exposure times...	62
Table 6c.	Data for uptake of ^{137}Cs by 'Koi' fish of small size at different exposure times. ...	63
Table 7.	Data for uptake of ^{137}Cs by 'Soiel' fish of intermediate size at different exposure times...	64
Table 8.	Biological elimination of ^{137}Cs from 'Singhi' fish.	65
Table 9.	Biological elimination of ^{137}Cs from 'Koi' fish.	66
Table 10.	Biological elimination of ^{137}Cs from 'Soiel' fish.	67
Table 11.	Calculation of effective half-lives of fish species.	68
Table 12.	Data for tissue distribution of the fish species.	70

List of figures

Page

Chapter 4

Fig.1 The basic configuration of an intrinsic germanium detector. 30

Fig.2 Plastic pot used to measure the radioactivity in the live fish. 31

Fig.3 Top view of the geometry taken by the live fish when placed into the pot.... 31

Fig.4 Block diagram of HPGe counting system. 32

Chapter 6

Fig.1 The schematic diagram of aquarium. 46

Fig.2 The schematic diagram of filter bed, specially designed to filter the turbid water in aquarium. 47

Fig.3 Photograph of the experimental set up. 48

Chapter 7

Fig.1 Uptake of ^{137}Cs by Magur fish 71

Fig.2 Uptake of ^{137}Cs by Singhi fish 72

Fig.3 Uptake of ^{137}Cs by Koi fish 73

Fig.4 Uptake of ^{137}Cs by Soiel fish 74

Fig.5 Elimination of ^{137}Cs from Singhi fish 75

Fig.6 Elimination of ^{137}Cs from Koi fish 76

Fig.7 Elimination of ^{137}Cs from Soiel fish 77

CHAPTER I

INTRODUCTION

CHAPTER 1

INTRODUCTION

The artificial radionuclides due to fallout from testings of nuclear weapons, release of radioactive effluents from nuclear reactors, production of radioisotopes, fuel fabrication and reprocessing, nuclear accidents and other allied nuclear activities may constitute short-term as well as long term risks to population at large, particularly, in the vicinity of the place of occurrence and other parts of the world through the atmospheric transport and also through the consumption of contaminated food stuff(s) and inhalation of gaseous discharges (1-8).

There may be a variety of short-lived and long-lived radionuclides including fission products like ^{137}Cs, ^{134}Cs, ^{131}I, $^{90}(Sr-Y)$, etc. and activated products like ^{51}Cr, ^{60}Co, ^{65}Zn, ^{95}Nb, etc. which may normally get entry into the human body through food chain and via other pathways in the critical organ(s) causing internal radiation hazards. The fission products normally receiving a considerable attention are ^{137}Cs and $^{90}(Sr-Y)$ because of their high fission yields and long half-lives. The testings of nuclear weapons in the atmosphere have caused ^{137}Cs to be widely distributed over the world along with other fission products (9-11). ^{137}Cs is a fission product rather than a manufactured isotope. Some inorganic ceasium salts are highly soluble and some are sparingly soluble in water (12). Moreover, this element may be compared with potassium because among the common elements in animal body, potassium is most closely related to ceasium in its metabolic behaviour (13). Both ceasium and potassium are

alkali metals. Absorption of both from the diet is large, approximately 100% (14) and takes place through digestive tract (15-16) and circulates freely through the body although ceasium has no known biological function. Ceasium and potassium enter body cell where ceasium is more tenaciously retained (17-18) so that the radiation doses received by most organs will be comparable. Both elements are deposited in the soft tissues (muscle) of the body from which they are readily turned over via urinary tract and in varing degrees, depending on species and diet, via excreta (14). Increasing of potassium intake has only slight effect in decreasing of ceasium body content (19-20). Thus ceasium metabolism is both similar to, but rather independent of, potassium metabolism (13). Having relatively high radiotoxicity, ^{137}Cs is, therefore, a potential cause of genetic as well as somatic injury.

It has been demonstrated that consumption of aquatic organisms in the fresh water environment may represent a direct route to human population for ^{137}Cs (21). Since fishes are the primary fresh water organisms commonly consumed by men, it is prudent to estimate the bioaccumulation factors (BFs) for the different species of fishes in order to account the radionuclide transfer to men through food chain and to evaluate the safety consequences, vis-a-vis, the potential hazards to population at large.

The BF is defined as the ratio of radionuclide concentration in the organism or tissue in question to that in the water(22):

$$BF(R)_i = [R]_1 / [R]_w$$

where, $BF(R)_i$ = bioaccumulation factor of radionuclide R in organism or tissue i,

$[R]_i$ = radionuclide concentration in Bq/gm fresh weight in organism or tissue i and

$[R]_w$ = radionuclide concentration in water, Bq/ml.

BFs are used to predict radionuclide concentrations in whole organisms or their tissues from the knowledge of radionuclide concentration in water. BFs are also used to predict the transient dynamics of radionuclide concentration in organisms. Therefore, an understanding of variables that affect BF is used to calculate steady state and transient dynamics of radionuclide concentration in aquatic organisms (23). In order to determine the BFs, the knowledge of uptake behaviour of radionuclide in fresh water fishes is, therefore, essential.

Fish accumulates radionuclide from water and from organisms of the food chain. Upon leaving a contaminated area, however, this fish eventually loose much of its radioactivity. The amount lost will actually depend upon the physical half-lives of specific radionuclides and the capacity of fish to retain these nuclides under various ecological as well as environmental conditions (24). Retention studies are needed to provide data for assessment of contamination and for prediction of time required for fish to be adequately decontaminated.

The organs of accumulation of radionuclide in fish must also be considered in evaluating the potential risk of radioactively contaminated fish to man (24). Some radionuclides may accumulate in soft tissue and some in bone. People like to eat soft tissue

of some fish species and some times they like to eat both muscle and bone as in case of small fishes.

Many investigations have been carried out throughout the world pertaining to accumulation and loss of radionuclides from different species of both marine and fresh water fish. But in Bangladesh no such investigations have probably been performed although peaceful applications of nuclear energy are increasing day by day in the country. In this connection, a study was undertaken to document the BFs, biological half-lives and tissue distributions of ^{137}Cs in the four species of fresh water fishes, namely, 'Magur' *(Clarius batrachus)*; 'Singhi' *(Heteropneustes fossilis)*; 'Koi' *(Anabus testudineus)* and 'Soiel' *(Channa striatus)*. These four species of fish can survive in all kinds of water and are widely distributed all over Bangladesh. These fishes are popularly consumed by the Bangladeshees to a greater extent compared to other fish species because, they are easily available in plenty in ponds, paddy fields, irrigation canals, swamps, drains, small rivers and other natural and/or artificial water reserviours. They are rich in protein contents. These fish species have accessory respiratory organs to breath atmospheric air. They can live for a long time out of water or in water of very low oxygen content and can also live in brackish water. They feed on worms, insects, shrimps and fish meal, etc. which are easily available and can be fed easily. Thus these species of fishes were well suited for the uptake and retention studies of radionuclide in the context of existing facilities and equipment in the laboratory.

References

1. WEERS,A.W.van; "Uptake of Cobalt-60 From Sea Water and from Labelled Food by the Common Shrimph (Crangon Crangon (L))", In:Impacts of Nuclear Releases into the Aquatic Environments. Proceedings of a symposium, Otamiemi,30 June - 4 July, 1985, IAEA-SM 198/44, PP 359-361.

2. Pinder III, J.E., McLeod, K.W., Alberts,J.J., and Andriano,P.C.;"Uptake of ^{244}Cm, ^{238}Pu and other Radionuclides by Trees Inhabiting a Contaminated Flood Plain", Health Physics, 47 PP. 375-384, (1984).

3. Blaylock, B.G., Frank,M.L. and DeAngelis,D.L.; "Bioaccumulation of ^{95m}Tc in Fish and Snails", Health Physics, 43, PP.257-266, (1982).

4. Weiss,H.V. and Shipman,W.H.;"Biological Concentration by Killer Clams of Cobalt-60 from Radioactive Fallout", Science 125, PP. 695, (1957).

5. Robertson,D.E., Silker,W.B., Langford,J.C., Peterson,M.R. and Perkins,R.W.; "Transport and Deplation of Radionuclides in the Columbia River", In: Radionuclide Contamination of Marine Environment, Proceedings of a Symposium Seattle, 10 - 14 July, 1972, PP 141-158, Vienna, IAEA, SM-158/28.

6. Harrison, F.L.; "Accumulation and Loss of Cobalt and Ceasium by the Marine Clam, Mya Arenaria, Under Laboratory and Field conditions. In: Radioactive Contamination of Marine Environment; Procedings of a Symposium, Seattle, 10-14 July, 1972, IAEA-SM-158/28, PP. 453-478.

7. Carvalho,F.P.;"Comparative Uptake From Sea Water And Tissue Distribution of ^{60}Co in Marine Mollusks", Health Physics, Vol. 53, PP.73-81, (1987).

8. Klement, Jr. A.W.; "Radioactive Fallout Phenomena and Mechanisms", Health Physics 11, PP.1265-1274, (1965).

9. Folsom,T.R., Mohanroa, G.J., Pillai, K.C. and Screekomaran, C.; "Distribution of Cs-137 in the Pacific", Health and Safety Laboratory Report, HASL-197, (Washington D.C., U.S. Atomic Energy Commission), 1968.

10. Folsom, T.R. and Grismore,R.; "Survey of Oceanic Fallout Traces Using Ceasium Absorbers", IEEE Trans Nuclear Sci. NS-17, 202, (1970).

11. Young, D.R., Folsom, T.R. and Hodge, V.F.; "^{137}Cs and ^{40}K in the flesh of Pacific Albacore, 1964-1974", Health Physics, 29, PP. 689, (1975).

12. Scott,D.P.;"Radioactive Ceasium as a Fish and Lamprey Mark", J.Fish. Res. Bd. Canada 19(1), PP. 149-157, (1962).

13. Pedleton,R.C., Mays,C.W., Lloyd,R.D.I. and Church,B.W.; "A Trophic Level Effects on ^{137}Cs Concentration", Health Physics 11, PP. 1503-1510, (1965).

14. Gustabson, P.F. and Miller,J.E.; "The Significance of ^{137}Cs in Man and His Diet", Health Physics, 16, PP 167-183, (1970).

15. Davis,J.J., Radioecology (Edited by V.Schultz and A.W. Klement). P.539, Rainhold, New York (1963).

16. Rundo,J., Br.J. of Radiology 37, 434, 108 (1964).

17. Relman, A.S., Lambie,A.J., Burrows, B.A. and Roy, A.M. J.Clin. Inves. 36, 1249, (1957).

18. Wasserman, R.H. and Comar,C.L., Radiat. Res. 15, 1, 70,(1961).

19. McNeill,K.G., Green,R.M. and Rapoport, A.; Can. Med. Assoc. J. 85, 1377, (1961).

20. Lloyd, R.D., May,C.W., Fisher,W. and Hintze,R.; Health Physics 8, PP. 777, (1962).

21. Poston, T.M. and Klopfer,D.C.; "Concentration Factors Used in the Assessment of Radiation Dose to Consumer of Fish: A Review of 27 Radionuclides", Health Physics 55, PP. 751 - 766, (1988).

22. Yamagata,N., Iwashima,K., Ilnuma,T.A., Wateri,K. and Nagi, T.; "Uptake and Retention Experiments of Radiorutheum in Man-I", Health Physics 16, PP. 159-166, (1970).

23. Vanderploeg, H.A., Parzyck,D.C., Wilclox, W.H., Kercher, J.R. and Kayee, S.V.; "Bioaccumulation Factors For Radionuclides in Fresh Water Biota", Oak Ridge National Laboratory, TN: Energy Distribution Center, ORNL-5002, (1975).

24. Baptist, J.P.; Hoss, D.E. and Lewis, C.W., "Retention of ^{51}Cr, ^{59}Fe, ^{60}Co, ^{65}Zn, ^{85}Sr, ^{95}Nb, ^{141m}In and ^{131}I by the Atlantic Croaker (Micropogon Undulatus)", Health Physics 18, PP 141-148, (1970).

CHAPTER 2

BIOLOGICAL EFFECTS OF RADIATION

CHAPTER 2

BIOLOGICAL EFFECTS OF RADIATION

The interaction of ionizing radiation with the human body, arising from external sources or from internal contamination, leads to biological effects which may later appear as clinical symptoms. The nature and severity of these symptoms and the time at which they appear depend on the amount of radiation absorbed and the rate at which it is received. Radiation injuries can be divided into two classes, somatic effects in which the damage appears in the irradiated person himself, and hereditary effects which arise only in the offspring of the irradiated person as a result of radiation damage to germ cells in the reproductive organs.

The somatic effects of radiation

Early radiation effects:

The early radiation effects are those which occur in the period from a few hours upto a few weeks after an acute exposure, that is a large dose received over a few hours or less. The effects are due to major depletion of cell population in a number of body organs to cell-killing and the prevention or delay of cell division.

The main effects are attributable to bone marrow, gastrointestinal or neuromuscular damage depending on the dose received. Acute absorbed dose of about 1 gray (1Gy = 100 rad) gives rise to nausea and vomiting. This is known as radiation sickness, and it occurs a few hours after exposure as a result of

damage to cells lining the intestine. Absorbed dose above about two Gy can lead to death, probably 10 to 15 days after exposure.

There is no well defined threshold dose below which there is no risk of death due to acute doses, though below about 1.5 Gy the risk of early death would be very low. Similarly, there is no well defined point above which death is certain, but the chances of surviving an acute dose of about 8 Gy would be very low. A reasonable estimate can be made of the dose which would be lethal for 50% of the exposed subjects within 30 days of exposure. This is called the LD_{50}^{30} and is thought to have a value of about 3 Gy for man. For doses upto 10 Gy, death is usually due to secondary infections because of depletions of the white blood cells which normally provide protection against infection. The range of doses from 3 to 10 Gy is often called the region of infection death. In this range the chance of survival can be increased by special medical treatments which include isolating the subject in a sterile (i.e., infection free) environment and giving bone marrow transfusion to simulate white blood cell (WBC) production.

For dose above 10 Gy, survival time drops abruptly to between 3-5 days. It remains at about this figure until much higher doses are reached. In this region the radiation dose causes depletion of the cells lining of the intestine. Gross damage occurs in the lining of the intestine, followed by severe bacterial invasion. This is called the region of gastrointestinal death.

At much higher doses, survival times become progressively shorter. There are very little human data in this region but, from animal experiments, the symptoms indicate some damage to the central nurvous system; hence the region is called the region of central nurvious system (CNS) death. However, it is found that death is not instantaneous even in amimal irradiated with doses in excess of 500 Gy.

Late effects:

It became apparent in the early part ,of the twentieth century that groups of people such as radiologists and their patients, who were exposed to relatively high levels of radiation, showed a higher incidence of certain types of cancer than groups not exposed to radiation. More recently, detailed studies of the population exposed to radiation from atomic bombs, of patients exposed to radiation therapy, and of occupationally exposed persons, particularly, uranium miners have confirmed the ability of radiation to induce cancer.

Cancer is an over-proliferation of cell in a body organ. It is thought that cancer may result from damage to the control system of a single cell causing it to divide more rapidly than a normal cell. The defect is transmitted to the daughter cells so the population of abnormal cells build up to the detriment of the normal cells in the organ. The estimation of the increased risk of cancer is complicated by the long and variable latent period from about five to thirty years or more, between exposure and the appearance of the cancer and by the fact that radiation induced cancers are not normally distinguishable from the non-radiation

induced cancers.

Another possible late effect of radiation is cataract formation in the lens of the eye. It appears that there is a threshold dose below which cataract can not be induced. This is of the order of 15 millisievert (1 mSv = 100 mrem).

There is some evidence from animal experiments that exposure of radiation may slightly reduce the life expectation of individuals who do not exhibit any specific radiation-induced symptoms. Observation of human populations exposed at relatively high levels indicate that, if life shortening occurs at all, it is very slight, almost certainly less than 1 year per sievert.

The hereditary effects of radiation:

The hereditary effects of raidation result from damage to the reproductive cells. This damage takes the form of alterations, known as genetic mutations,in the hereditary material of the cell.

The reproduction occurs when the ovum is fertilized by a sperm. As a result, offspring receives a complete set of genetic material from each parent. Thus the child receives two complementary sets of genes, one from each of its parents. In general, it is found that one gene is 'dominant' and the other is 'recessive'. The dominant gene determines the particular characteristic with which it is associated.

Recessive genes are only recognized when by chance two of the recessive-type genes come together. A considerable number of

diseases are associated with recessive gene and will, therefore, only menifest themselves when both parents have the same recessive genes. Spontaneous mutation accounts for the fact that an appreciable fraction of the world's population suffer from one of the 500 or more defects or diseases attributable to hereditary effects.

Radiation induced gene mutations are indistinguishable from naturally occurring mutations. It should be noted in passing that heat and chemicals can also cause mutations. Mutated genes are generally recessive and so it is generally assumed that all mutations are harmful, which, of course is not always true.

Since ionizing radiation can cause an increase in the mutation rate, its use may increase the number of genetically abnormal people in the future generations. Clearly the consequences of excessive genetic damage would be very serious indeed and strict control must be exercised over the exposure of the general population to radiation

The risks of hereditary effects due to exposure of the gonads are very uncertain. International Commission on Radiological Protection (ICRP) estimated the risk of serious hereditary ill health within the first two generations following the irradiation of either parent to be about 10 per million per mSv. Over all generations, the risk would be about twice this value. Normally, the exposure which occurs up to the time of conception can affect the genetic characteristics of the offspring, and since the mean age of childbearing is about 30

years, only a proportion of the dose received by a typical population will be genetically harmful. The total genetic risk in all generations averaged over both sexes and over all ages, is therefore, about 8 serious effects per million per mSv.

Recently, ICRP introduced another term to distinguish between effects for which the probability of occurrence does not depend on the dose received and those for which the severity is related to dose. The former are stochastic and the latter are non-stochastic. The term stochastic can best be understood by considering it to refer to effects which either occur or do not occur, there being no intermediate state. Thus cancer induction is a stochastic effect, the probability of a radiation induced cancer of a particular type not depending on the severity of the dose received. Hereditary effects are also regarded as being stochastic. The early effects of radiation are non-stochastic since there severity depends on the dose. Similarly, the severity of some late effects, such as cataract formation, depends on the dose received and so these effects are also non-stochastic.

Thus, the stochastic effects are those for which the probability of the effect occurring, rather the severity of the effect if it occurs, varies with the size of the dose. For such effect as in the induction of genetic defects or cancer no threshold dose can be assumed below which some effects may not occur. The results of high radiation exposure which are likely to occur whenever a threshold dose has been exceeded are

commonly, if awkwardly, referred to as non-stochastic effect. This intends to contrast with the hereditary or carcinogenic effects of radiation, of which the dose determines a probability rather than a certainty of the effect occurring, and which are termed stochastic.

CHAPTER 3

REVIEW OF THE EARLIER WORK

CHAPTER 3

REVIEW OF THE EARLIER WORKS

Research works have been performed in various ways to investigate the uptake behaviour and loss of various radionuclides in fresh and marine water fishes. To put things into prospective a critical review of the earlier works is envisaged.

An excellent review of the bioaccumulation factors of fresh water fishes for different radionuclides have been made by Vanderploeg et al (1). Poston, T.M. et al (2) has made an indepth review of concentration ratios of selected radionuclides in fresh and marine water fishes.

Florence L. Harrison (3) conducted an experiment on marine clam (*Mya Arenaria*) under laboratory and field conditions by using radioactive nuclides of cobalt and cesium. The accumulation of ^{137}Cs from the water and food was followed in the laboratory for 179 days. The concentration of ^{137}Cs in the clam increased rapidly at first and then more slowly. The steady state concentration factor was about 4.6 in whole body. For ^{60}Co the accumulation pattern for whole body remains the same. The biological half-lives for ^{137}Cs and ^{60}Co were found to be 63.6 days and 120 days respectively.

R.S. Harvey et al. (4) conducted an experiment for uptake and loss of ^{137}Cs by fresh water clam (*Lampsilis Radiata* (Gmel)) under field conditions. They found that the concentration of ^{137}Cs increased rapidly upto 35 days and then an apparent

equilibrium was observed, 56 days was, however, required for maximum concentration in whole body. Experiment was conducted for 91 days. The biological half-life was found to be 41 days.

Ross A. Jeffree et al. (5), performed an experiment for the uptake of ^{226}Ra by the tropical fresh water mussel (*Velesunio Angasi*). They found that the rate of accumulation of ^{226}Ra by the tissue of the mussel is linear with respect to the period of exposure under laboratory conditions. They also found that ^{226}Ra has very long biological half-life in the mussel.

A.W. van WEERS (6) also conducted an experiment to investigate the uptake behaviour and loss of ^{60}Co from sea water by the common shrimph (*Crangon Crangon (L)*). He found that the mean concentration factor increased slowly upto a value of about 13 at 31 days. A steady state concentration was not reached at that time. The biological half-life was found to be approximately 21 days.

J.F. Baptist et al.(7) conducted an experiment to determine the biological half-lives of ^{51}Cr, ^{59}Fe, ^{60}Co, ^{65}Zn, ^{85}Sr, ^{95}Nb, ^{141m}In and ^{131}I in Atlantic Croker (*Micropogan Undulatus*) under laboratory conditions. They found the following biolgical half-lives: ^{51}Cr - 70 days, ^{59}Fe - 215 days, ^{60}Co - 31 days, ^{65}Zn - 138 days, ^{85}Sr - 138 days, ^{95}Nb - 465 days, ^{141m}In - 224 days and ^{131}I - 24 days.

REFERENCES

1. H.A. Vanderploeg, D.C. Parzyck, W.H. Wilcox, J.R. Kercher and S.V. Kaye; "Bioaccumulation Factors for Radionuclides in Fresh Water Biota", ORNL-5002, Oak Ridge National Laboratory, Oak Ridge Tenessee 37830, 1975, USA.

2. Foston, T.M. and Klofer, D.C.; "Literature Review of the Concentration Ratios of Selected Radionuclides in Fresh Water and Marine Fish", PNL-5484, Pacific Northwest Laboratory, Richland, Washington, 1986, USA.

3. Florence L. HARRISON, "Accumulation and Loss of Cobalt and Ceasium by Marine Clam, *Mya Arenaria*, under Laboratory and Field Conditions", Radioactive contamination of marine environment, Proceedings of a symposium, Seattle, 10-14 July, IAEA-SM-158/28, P.153, 1972.

4. R.S. Harvey, "Uptake and Loss of Radionuclides by the Fresh Water Clam *Lampsilis Radiata* (Gmel)", Health Physics, Vol.17, P.149, 1969.

5. Ross A. Jeffree and R.D. Simpson; "An Experimental Study of the Uptake and Loss of Ra-226 by the Tissue of the Tropical Fresh Water Mussel *Valesunia Angasi* (Sowerby) under varing Ca and Mg Water Concentrations", Hydrobiologia, Vol.139, P.59, 1986.

6. A.W. van WEERS, "Uptake of Cobalt-60 from Sea Water and from Labelled Food by the Common Shrimp *Crangon Crangon*(L)", Impacts of nuclear releases into the aquatic environments, Proceedings of a symposium, Otamiemi, 30 June - 4 July, IAEA-SM-198/44, 1975.

7. J.P. Baptist, D.E. Hoss and C.W. Lewis; "Retention of ^{51}Cr, ^{59}Fe, ^{60}Co, ^{65}Zn, ^{85}Sr, ^{95}Nb, ^{141m}In and ^{131}I by the Atlantic Crocker (*Micropogon Undulatus*)", Health Physics, Vol.18, P.141, 1970.

CHAPTER 4

THE DETECTION SYSTEM

CHAPTER 4

THE DETECTION SYSTEM

High-purity germanium detector (HPGe) is a semiconductor device which was used to detect and measure the radioactivity from ^{137}Cs in whole body live fish and passive samples in this study. This detector can be stored at room temperature. The main system is a germanium crystal in an unusual high state of purity. The depletion depth of a noraml p-n junction at a given voltage increases in proportion to the square root of the resistivity of the material. If the impurity concentration in germanium can be reduced to about 10^{10} atoms/cm^3 the corresponding resistivity is sufficiently high so that a depletion depth of 10 mm can be reached using reverse bias of less than 1000 volts. It is, therefore, possible to obtain large active volumes that are nearly comparable with those available in Ge(Li) detectors, without the lithium compensation step.

In any germanium detector, excessive leakage current prevents its use at room temparature, but the absence of lithium compensation allows HPGe to be stored at room temperature between uses. Successful operation of such detectors over many cycles of warming and cooling has been reported. However, it is recommended that the detector should be kept continuously at liquid nitrogen temperature to avoid potential contamination of the detector surface from any residual vapours within the detector vacuum housing. For this reason, it is conventional to operate HPGe detector at liquid nitrogen temperature; in some applications it may be more convenient to allow the detector temperature to rise

above this 77K value. Satisfactory performance can be obtained at temperatures as high as 150-180K. The principal limitation is the rise in noise level which corresponds to increase in trapping effect and band-to-band bulk-generated leakage current.

General characteristics:

The basic configuration of an HPGe detector is shown in Fig.(1). Because the bulk of the high purity material is generally p-type, this configuration is referred to as n^+-p-p^+ diode structure (the designation ' + ' refers to highly doped material). The n^+ contact is usually formed by lithium evaporation into a lapped surface of the germanium followed by a short period of diffusion at elevated temperature. The detector depletion depth is formed by reverse biasing this n^+-p junction. The contact at the opposite face must be a noninjecting contact for a majority carrier and often consists of a metal-to-semiconductor surface barrier junction which acts as a p^+ contact. The dead layer associated with the n^+ lithium contact is always considerably greater than that associated with the surface barrier so that when the detector is totally depleted (discussed below) the p^+ face is normally used as the entrance window.

Reverse biasing requires that a positive voltage be applied to the n^+ contact with respect to p^+ surface. The depletion region effectively begins at the n^+ edge of the central region and extends further into the p region as the voltage is raised. If the voltage is made sufficiently high, the detector becomes fully depleted and the active volume extends all the way from one

contact to the other. Under these conditions, the electric field is at a maximum at the n^+ side of the p-region, and decreases to zero at the p^+ side. An additional increment of bias voltage (also known as over voltage) is normally applied which has the effect of raising the electric field by a constant amount throughout the entire detector (Fig.1). It is preferable to apply sufficient overvoltage so that the minimum electric field is still sufficiently high to impart saturation velocity to the charge carriers, and to minimize the collection time and the detrimental effects due to recombination and trapping. In germanium at liquid nitrogen temperature, saturated electron velocities are reached at a minimum field of about 10^5 v/m, but field strengths three to five times larger are required to fully saturate the whole velocity. Practical problems related to breakdown and surface leakage often limit the maximum voltage to values at which electrons but not holes will reach saturated drift velocity.

Electric field and capacitance:

The active volume in the "i-region" is not free of any net space charge. Let us assume that the n^+-p junction is abrupt, the applied reverse bias is much larger than the contact potential between the n^+ and p-regions, and the doping level is much greater in the n^+ region than the residual impurity level in the high purity p volume. Solving the Poisson's equation $\nabla^2 \phi = -\rho/\epsilon$, the electric potential ϕ in the presence of the charge distribution ρ can be obtained (ϵ is the dielectric constant). In

this case $\rho = -eN_A$ where N_A= impurity density and e is the electronic charge.

Planner geometry:

The detector depletion depth is

$$d = (2\epsilon V/\rho)^{1/2}$$

Full depletion requires a minimum applied voltage V_d

$V_d = \rho T^2/2$ where, T = slab thickness.

In one-dimensional slab geometry, Poisson's equation becomes

$$\frac{d^2\phi}{dx^2} = -\frac{\rho}{\epsilon}$$

For an applied voltage less than that required for full depletion, the electric field $\mathcal{E} = -\text{grad}\phi = -d\phi/dx$ is obtained by solution of equation $d^2\phi/dx^2 = -\rho/\epsilon$ with the boundary condition $\phi(d) - \phi(o) = V$. The result is

$$-\mathcal{E}(x) = (V/d) + (\rho/\epsilon)(d/2-x)$$

or, $$|\mathcal{E}(x)| = (V/d) + (eN_A/\epsilon)(x-d/2)$$

where x is the distance from the p^+ contact. For $V<V_d$, the portion of this solution corresponding to the undepleted region of the detector is not applicable, and the field is zero.

Equation $|\mathcal{E}(x)| = (V/d) + (eN_A/\epsilon)(x-d/2)$ also holds for $V>V_d$ because the effect of the over voltage $(V-V_d)$ is to increase the field by a constant amount $(V-V_d)/T$ everywhere within the detector. The capacitance varies with the applied bias voltage up to the value at which the detector is fully depleted. In planar geometry, the detector capacitance per unit area prior to the point of full depletion is given by

$$C = (\epsilon\rho/2V)^{1/2}$$

For $V>V_d$, the detector capacitance is a constant obtained by setting $V=V_d$ in equation $C = \epsilon\rho/2V$. The independence of detector capacitance on applied bias is often taken as an indication of full depletion within the detector.

Coaxial geometry:

It is preferable to fabricate HPGe detector in cylindrical form in order to achieve large active volumes. The outer surface of a cylindrical crystal (assumed to be p-type) is commonly provided with a lithium-diffused thin n^+ layer to serve as one electrical contact. Because the equivalent of undrifted central core of a coaxial Ge(Li) detector does not exist in this case, a second contact must be provided by removing the core and applying a p^+ contact over the inner surface. If r_1 and r_2 are the inner and outer radii respectively, the depletion voltage is

$$V_d = \rho/2\epsilon \; [r_1^2 \ln(r_2/r_1) - 1/2(r_2^2 - r_1^2)]$$

Poisson's equation takes the form $d^2\phi/dr^2 + 1/r(d\phi/dr) = -\rho/\epsilon$. Applying the boundary condition $\phi(r_2) - \phi(r_1) = V$ and solving for $\mathcal{E}(r) = -d\phi/dr$, the resulting electric field configuration is

$$-\mathcal{E}(r) = -(\rho/2\epsilon)r + \frac{V + (\rho/4\epsilon)(r_2^2 - r_1^2)}{r \ln(r_2/r_1)}$$

or, $$|\mathcal{E}(r)| = \frac{eN_A}{2\epsilon} r + \frac{V - (eN_A/4\epsilon)(r_2^2 - r_1^2)}{r \ln(r_2/r_1)}$$

provided N_A (the acceptor concentration) is a constant over the detector volume.

Energy resolution:

The dominant characteristic of an HPGe detector is its excellent energy resolution when applied to gamma ray spectroscopy. The excellent energy resolution by HPGe system allows the spectrum of many closely spaced gamma ray energies to be clearly resolved, which otherwise remain unresolved in NaI(Tl) spectrum. Consequently, virtually all gamma ray spectroscopies that involve complex energy spectra are now carried out with HPGe detectors.

The overall energy resolution achieved in an HPGe is normally determined by a combination of three factors: the inherent statistical spread in the number of charge carriers, variation in the charge collection efficiency and contributions of electronic noise. Which of these factors dominate depends on the energy of the radiation and the size and the inherent quality of the detector in use. The full width at half-maximum (FWHM) W_t of a typical peak in the spectrum due to the detection of a monoenergetic gamma can be synthesized as follows:

$$W^2_t = W^2_D + W^2_X + W^2_e$$

where, W values on the right-hand side are the peak widths that would be observed due only to the effect of carrier statistics, charge carrier collection and electronic noise. W^2_D represents the inherent statistical fluctuation in the number and is given by

$$W^2_D = (2.35)^2 F \epsilon E$$

where F is the Fano factor, ϵ is the energy necessary to create one electron-hole pair and E is the gamma ray energy.

The contribution of the second term W^2_x is due to incomplete charge collection and is most significant in detectors of large volume and low average electric field. Its magnitude can be experimentally estimated by carrying out a series of FWHM measurements as the applied voltage is varied. If the electric field could be made infinitely large, the effect of incomplete charge collection could be reduced to an insignificant level. Therefore, a plot of the observed FWHM versus the reciprocal of the average electric field within the detector allows an extrapolation to infinite field conditions. The residual value of FWHM given by the extra-polation is then assumed to arise only from the remaining two factors in equation

$$W^2_t = W^2_D + W^2_X + W^2_e$$

The third factor W^2_e represents the broadening effects due to the electronic components following the detector. Its magnitude can be measured by supplying the output of a precision pulser with a highly stable amplitude to the preamplifier and recording the corresponding peak in the pulse height spectrum. These measurements should be made with the detector normally connected to the preamplifier so that capacitive loading of the preamplifier input is typical of conditions under actual use.

Pulse shape and timing:

The timing and pulse shaping properties of any detector are

dominated by the shape of the electric field within the active volume and the distance over which the charges must be collected.

The charge collection process: In standard pulse height spectroscopy, it is necessary for the shaping times of the pulse processing electronics to be substantially larger than the longest rise time likely to be encountered from the detector if resolution loss due to ballistic defecit is to be avoided. In applications where timing information must be obtained from the pulse both the rise time and the detailed shape of the leading edge of the pulse become important when considering various time pick-off methods. The ultimate time resolution obtainable from an HPGe detector is critically dependent both on the overall average rise time as well as significant variation on the pulse shape from event to event.

Assuming that equivalent circuit of the measuring electronics presents a large time constant compared with the largest rise time produced by the detector the leading edge of the signal pulse is almost entirely determined by the details of the charge collection process within the detector. Because it is always advantageous to have the smallest possible rise time, conditions are normally sought in which charge collection occurs within the minimum possible time. For low electric field the velocity increases linearly with the field which implies a constant value for the electron or hole mobility. At sufficient high electric fields, however, the velocity ceases to increase and approaches a constant saturation value for electron in germanium at 77K; this saturation drift velocity is approximately

10^5 m/s and is achieved at a field value of about 10^5 v/m. The saturated velocities for holes is similar but requires a minimum field of approximately $3x10^5$ v/m. Pulses of minimum rise time are, therefore, obtained by operating the detector with sufficient applied voltage so that an electric field of at least this magnitude is present every where within the active volume. An HPGe coaxial crystal having 53 cc active volume (Princton Gamma Tech, West Germany, Model IGC 8) is used in this experiment.

The output pulses from the detector are relatively of small amplitude. The detector has a high output impedence, i.e., a high internal resistance to the flow of the electric current. In handling electronic signals, it is important that the impedence levels of successive components match one another.

The purposes of a pre-amplifier are three folds: (1) to amplify, if necessary, the relatively small signals produced by the radiation detector, (2) to match impedence levels between the detector and the subsequent components in the electronic circuitry and (3) to shape the signal pulse for optimal signal processing by the subsequent components. In the present counting system the HPGe detector is mounted on the top of the pre-amplifier (built-in with the detector) and the crystal dewer (liquid nitrogen dewer). Before the supply of electronic signal to the analyser for counting, the signal must be amplified because the amplitude of the signal coming from the detector through pre-amplifier is relatively small. Thus an amplifier is

required to amplify the detector signal. Another function of the amplifier is to reshape the slowly decaying pulses from the pre-amplifier and to improve the electronic signal-to-noise ratio. A good amplifier should have low input noise and high gain factor. For the present study, Canberra, USA, Model 2022 amplifier is used. It has all the characteristics necessary to make it useful with HPGe detector. The gain is adjusted through a combination of coarse and fine controls. Its salient features include high gain, low noise and selectable time constants. The gain range, temperature stability and non-linearity specifications make it suitable for long counting period.

An analyser is used for counting the pulses from the amplifier within a selected voltage amplitude intervals or channels. If this is done for only one channel at a time, the device is called a single channel analyser (SCA). A device that is capable of analysing pulses simultaneously within many different intervals or channels is called a multichannel analyser (MCA). The main component of the MCA is an analog to digital converter (ADC) which measures and sorts out the incoming pulses according to their amplitudes. The pulse amplitude range, usually 0-10 volts, is divided by the ADC into a finite number of discrete intervals or channels. The ADC converts an analog signal (voltage or pulse amplitude), which has an infinite number of possible different values, into a digital one (channel number), which has a finite number of integer values. In our system an MCA of 4000 channels, Model Canberra, USA, Series 40 is used.

The HPGe detector requires an external high voltage for operation which is called the detector bias. The detector bias supply provides the accelerating voltage for electron multiplication in the HPGe crystals. It also converts the alternating voltage provided by the line source into a direct current voltage. In the present system the Canberra, USA, 2012 detector bias voltage is used. The voltages are selected independently by 10 turn direct reading potentiometers. The polarity is controlled by a front pannel switch. A block diagram of HPGe detector system including highvoltage supply, pre-amplifier, amplifier and MCA is shown in Fig.2.

Measurements of live fish samples involve a large volumes. So it is necessary to choose a suitable "detector to sample" geometry to maximize the counting efficiency. Hence, for live counting of fish and the counting of passive biological smaple, pot geometry and petridish geometry were chosen respectively for better efficiency. This design should be nearly optimum in terms of placing the live sample as close as possible to the detector active volume. 1/2 litre capacity pot, fabricated from locally available plastic was used as live sample container (Fig.3). A fixed geometry is maintained for counting the ^{137}Cs activity through out the measurements. Fig.(4) shows the actual geometry maintained in live fish counting. The passive biological samples were counted using plastic petridishes.

Calibration of the detection system:

A fixed geometry was maintained for counting all live

fishes.. In order to use this system, the basic performance studies on various parameters, e.g., operating voltage, lower and upper level discriminations, energy calibration, relative and absolute efficiencies of the detector system for various sample volumes were carried out. The efficiency of the detector is mainly dependent on the energy of radiation and source to detector geometry. The pot geometry and petridish geometry were calibrated in this study. A known activity of ^{137}Cs in the form of solution was added to 150 gm of dry fish powder and the sample was then dried again and homogenised by grinding and mixing for a long time. To check the homogeneity of mixing, the samples were divided into five subsamples of equal weight contained in five identical plastic petridishes and each subsample was counted with identical geometry. The counts for 200s for each subsample were found approximately the same.

One subsample was then poured into a plastic pot and the geometry was made similar to that actually taken by a live fish in that pot and the counts were taken for 300s. The peak area counts were computed using an inbuilt microprocessor. The efficiency was calcualted by dividing the obtained count rate by the rate of disintegration of the standard sample. Having determined the efficiency of each geometry used in the study, the activity of the live sample of different fish species was measured throughout the duration of the experiment. Having determined the integral counts under the gamma energy peaks, the gamma activity was calculated from the measured efficiency of the detector by the following relation;

$$A = C / (\varepsilon(E)p)$$

where, A = Activity in dps

C = Peak area in cps

$\varepsilon(E)$ = Efficiency of the detector at energy E (MeV) and

p = Photon emission probability at energy E (MeV).

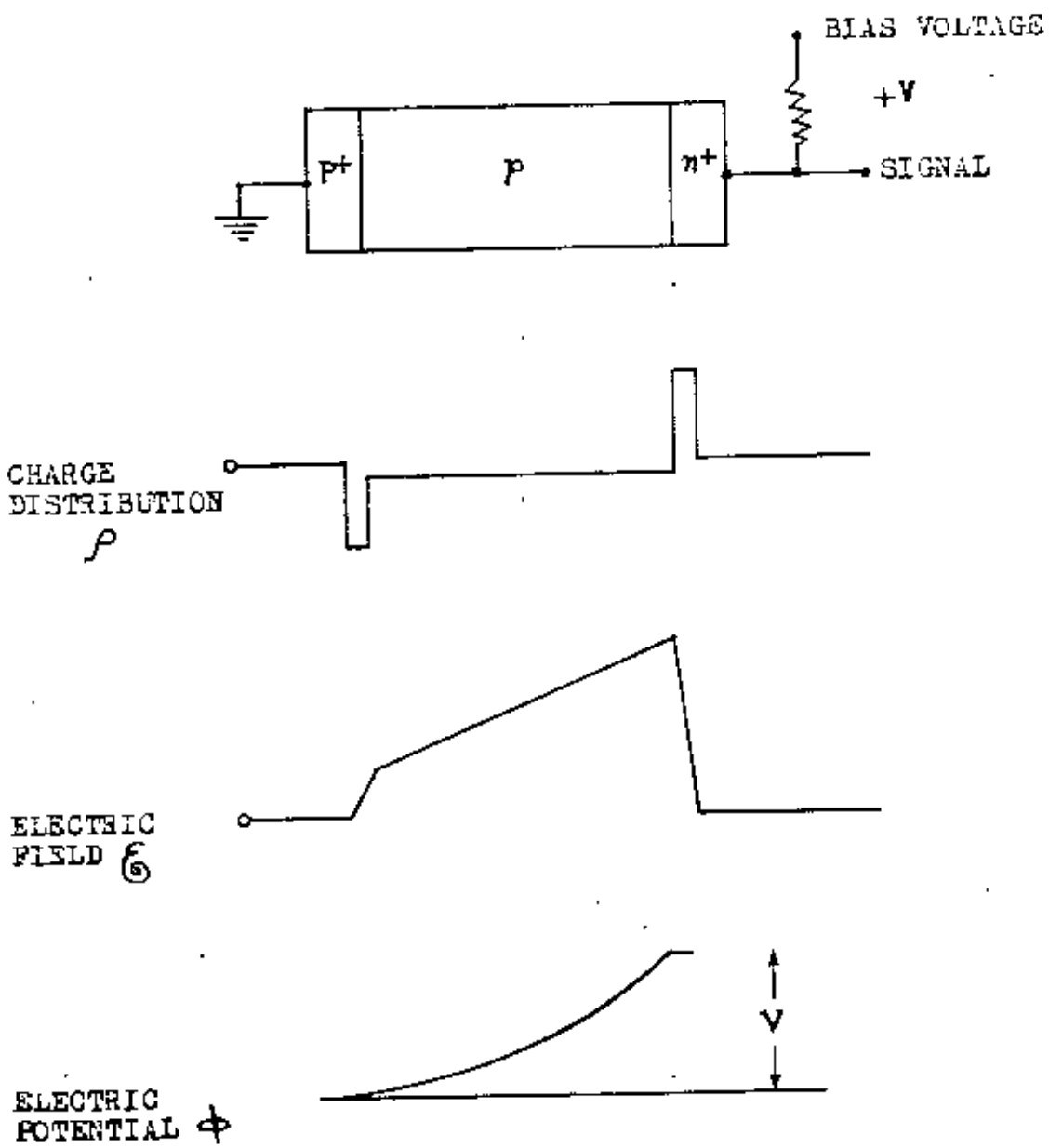


FIG.1. THE BASIC CONFIGURATION OF AN INTRINSIC GERMANIUM DETECTOR. THE P-TYPE CENTRAL REGION IS MADE OF GERMANIUM OF HIGHEST AVAILABLE PURITY AND THE n^+-p JUNCTION IS REVERSE BIASED. THE ELECTRIC FIELD CONFIGURATION SHOWN IS FOR A RELATIVELY LARGE "OVERVOLTAGE" FOR WHICH THE DETECTOR IS FULLY DEPLETED.

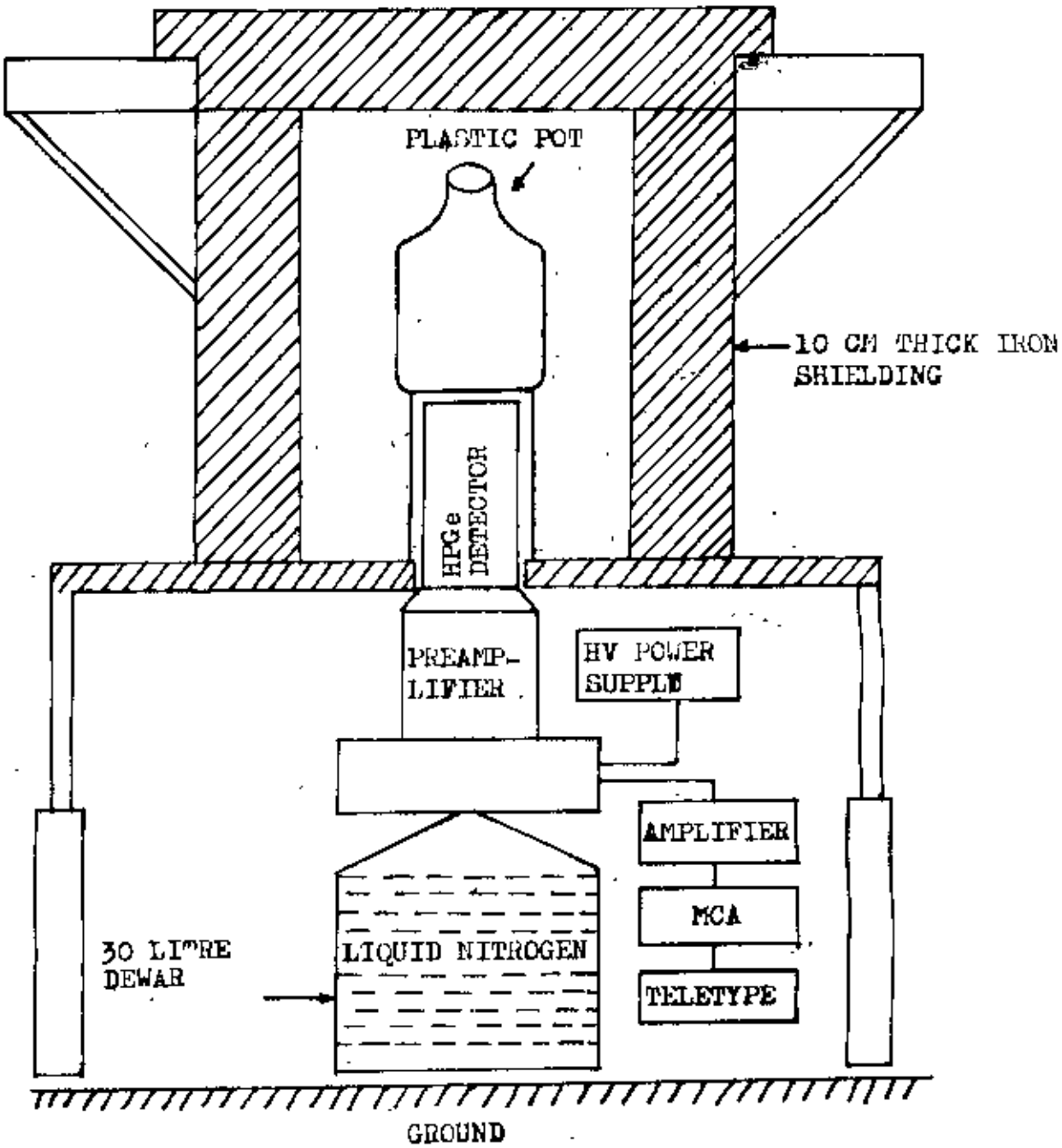


Figure 2: Block diagram of HPGe counting system

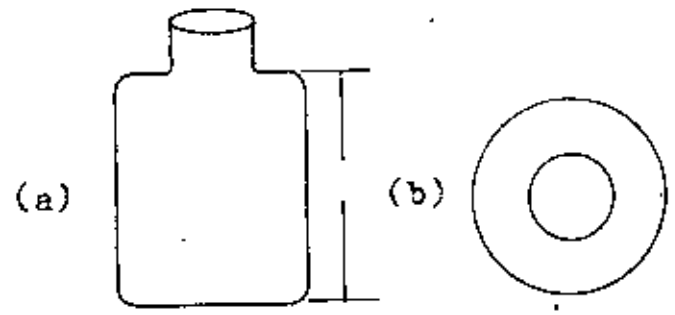


FIG.3. PLASTIC POT USED TO MEASURE THE RADIOACTIVITY IN LIVE FISH.
(a) SIDE VIEW, (b) TOP VIEW.

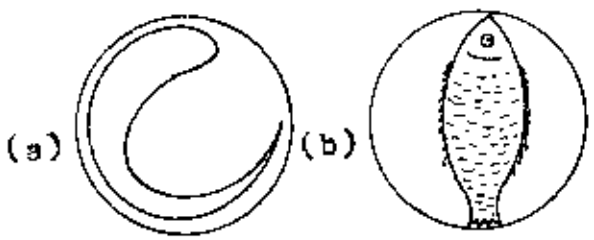


FIG.4. TOP VIEW OF THE GEOMETRY TAKEN BY THE LIVE FISH WHEN PLACED INTO THE POT.
(a) FOR SINGHI, MAGUR AND SOIEL FISHES, (b) FOR KOI FISH.

BIBLIOGRAPHY

KNOLL, G.F., Radiation detection and measurement, John Wiley and Sons Inc., New York, 1979.

CHAPTER 5

THEORY FOR ERRORS IN THE EXPERIMENTS

CHAPTER 5

THEORY FOR ERRORS IN THE EXPERIMENT

Experimental observations always have inaccuracies. In using numbers which result from experimental observations, it is almost always necessary to know the extent of these inaccuracies. If several observations are used to compute a result, one must know how the inaccuracies of the individual observations contribute to the inaccuracy of the result. If one is comparing a number based on a theoretical prediction with one based on experiment, it is necessary to know something about the accuracies of both of these if one is to say anything about whether or not they agree. If one has some knowledge of the statistical behaviour of errors of observation, it is often possible to reduce the effect of these uncertainties on the final result.

The error of a measurement is the deviation of the measurement from its normal value. Normally there are two types of errors: (i) Systematic errors and (ii) Random errors.

Systematic errors occur due to inadequate experimental design, malfunctioning of equipment, etc. It produces results that differ consistantly from the correct ones by some fixed amount. The same result may be obtained in repeated measurements although it is a wrong result to some extent.

The random errors, sometimes, called uncertainty in the measurements, are variations in results from one measurement to the next. It can not be eliminated completely although it is possible to minimize it by careful measurement technique, refixed

instrumentation, personal skillness, etc. The terms accuracy and precision are often used to distinguish between systematic and random errors. If a measurement has small systematic errors, the measurement has high accuracy and if small random errors, then it has high precision.

The error prediction: The range of the individual measurements from the average value of a series of measurements describes the precision or reproducibility. It is designated by the standard deviation (σ) value:

$$\sigma = \pm\sqrt{\bar{n}}$$

where, $\bar{n}$ is the average value for a series of measurements. If only one measured value n is available then the standard deviation may be estimated as $\pm\sqrt{n}$ by assuming that the value n represents the mean.

In a normal distribution 68.3 percent of all measured values fall within $\pm 1\sigma$ on either side of the mean, 95.5% within $\pm 2\sigma$ and 99.7% within limits of $\pm 3\sigma$.

The standard deviation is some times used to characterize the spread or dispersion of the measurements. The standard deviation can also be referred to as the root-mean-square deviation, in that it is the square root of the mean of the squares of the deviations.

For a set of experiment

$$= \sqrt{\frac{1}{N}\sum_{i=1}^{N}(n_i - \bar{n})^2}$$

where N is the number of measurements from which the sample mean n is determined and n_i represents the individual measurement. The quantity N is termed the "number of degrees of freedom". σ always has the same unit as the n_i and it is always positive, because any negative residuals is eliminated by squaring the each deviation, $(n_i - n)$. The square of the standard deviation, σ^2 is called the variance of the set of observations.

The fractional standard deviation is defined as the ratio of the standard deviation to the mean $\frac{\sigma}{n}$. The percent standard deviation is defined as $(\frac{\sigma}{n}) \times 100\%$. The fractional standard deviation is always a pure number (without units).

Precision of count rate:

The estimated standard deviation σ_e of a count rate is

$$\sigma_e = \bar{\sigma}/t$$

where $\bar{\sigma}$ is the estimated standard deviation of a count n and t is the counting time.

Since $\bar{\sigma} = \sqrt{n}$, therefore $\sigma_e = \sqrt{n}/t$

where t = counting time.

Accumulation of Errors:

If the precision of numbers A and B is denoted by standard deviations σ_a and σ_b then the standard deviations of results of arithmatic operations involving A and B may be computed using the expressions in the following table.

Table 1. Results of Arithmatic operations with Numbers A and B. (The precision of A and B is described by the standard deviations σ_a and σ_b)

Arithmatic operation	First No.		Second No.	Result ± 1sd
Addition	$A \pm \sigma_a$	+	$B \pm \sigma_b$	$(A+B) \pm \sqrt{\left(\frac{\sigma_a}{A}\right)^2 + \left(\frac{\sigma_b}{B}\right)^2}$
Subtraction	$A \pm \sigma_a$	−	$B \pm \sigma_b$	$(A-B) \pm \sqrt{\left(\frac{\sigma_a}{A}\right)^2 + \left(\frac{\sigma_b}{B}\right)^2}$
Multiplication	$A \pm \sigma_a$	X	$B \pm \sigma_b$	$(AB)\left[1 \pm \sqrt{\left(\frac{\sigma_a}{A}\right)^2 + \left(\frac{\sigma_b}{B}\right)^2}\right]$
Division	$A \pm \sigma_a$	÷	$B \pm \sigma_b$	$(A/B)\left[1 \pm \sqrt{\left(\frac{\sigma_a}{A}\right)^2 + \left(\frac{\sigma_b}{B}\right)^2}\right]$

CHAPTER 6

MEASUREMENTS

CHAPTER 6

MEASUREMENTS

A radionuclide, ^{137}Cs, of known strength was released into the experimental aquarium. The ^{137}Cs was obtained from Amersham, UK in the form of $^{137}CsCl$. The water was constantly stirred to ensure homogeneous mixing of ^{137}Cs with the water.

The experimental aquaria were made of glass of 6 mm thickness framed by old iron structure. The joints were gummed with coke pitch materials. The aquaria were cubical in shape having the dimension of 1.0m x 0.5m x 0.5m. Fig.1 shows the details of the aquarium. In order to maintain the volume of water in the aquarium constant, fresh tap water was supplied from time to time. Before the release of fishes into the radioactive water in the aquarium, a series of experiments were performed to find out the abosrption of ^{137}Cs by aquarium materials. An amount of 100 ml of radioactive water was taken from the aquarium and the activity of ^{137}Cs was measured by an HPGe detector. The radioactivities were measured twice a week over a period of one month. Table 1 shows the results which indicate that there were no significant absorption or adsorption of ^{137}Cs by the acquarium materials. The pH of radioactive water was measured once a week for one month. During the experiment the pH values changed from 6.64 to 9.14 and finally decreased to 8.44.

A total of 15 'Magur', 16 'Singhi', 9 'Koi' and 5 'Soiel' fishes were released into the aquaria containing the ^{137}Cs spiked water. Magur and Singhi were released into the aquarium no.1 and aquarium no.2 respectively. After the conclusion of the

experiment with these Magur and Singhi fishes new experiments were started with Koi and Soiel fishes. Koi and Soiel were kept in the aquarium no.1 and aquarium no.2 respectively. All fishes were acclimatized for 30 days under identical experimental conditions. To facilitate rapid capture of fishes from the aquarium, each group of fishes of each species was placed inside the aquarium in plastic cages of common dimension of 0.37m x 0.28m x 0.25m. Each aquarium contained three such plastic cages. The cages were placed on the bottom of the aquarium and about two-third of the cage was filled with ^{137}Cs spiked water.

The fishes were fed with sliced shrimp boiled with hot water. The other food stuff like worms, corns, oil cake were also supplied as food, but the major food item was shrimp. All the feed were directly put into the acquaria once a day. The residuals of the food stuff were removed by conventional methods by adopting adequate radiation safety measures. The random and rapid motion of the fishes into the water ensure the mixing of oxygen from normal air to the radioactive water. However, to ensure the presence of oxygen in the water at normal level fresh air was supplied into the water at regular interval by an air pump.

After a few days algea of green colour formed and other suspended particles were also observed and consequently, the water turned turbid. These necessiated filtering the water. Two types of water filters were used: the conventional water filter locally available was used at regular interval. The total amount

of water was completly filtered by using a specially designed filter bed. Successive layers of the bed were made by stone and brick chips of different sizes and ordinary and coarse sand. Stone chips of large sizes were poured into a PVC pipe of 91.34 cm long X 7.62 cm diameter which stood at the bottom of the pipe at vertical position. Upon this stone bed, brick chips of very small sizes were placed. Then the sand beds were made. Upon the sand bed two other different beds (one brick and another stone made) were also ereceted. A schematic diagram of the filter is shown in Fig.2. Fig.3 shows the photgraph of the actual experimental setup.

Upon filtering, the radioactivity of the water solution was reduced, because CsCl has strong affinity of mixing with the suspended particle, algea, etc. in the water. The reduced radioactivity was compensated by further addition of calculated ^{137}CsCl into the water and measuring the radioactivity at different stages.

Fishes were withdrawn from the aquarium containing ^{137}Cs and washed with 4-5 litres of fresh tap water in a plastic bucket with proper rinsing in order to decontaminate the superficially attached ^{137}Cs on the outer layer of fish skin pulps. Since CsCl is highly soluble in water, the washing was repeated 3 to 4 times to ensure complete decontamination of superficially attached CsCl. Some fishes were measured for ^{137}Cs activity before and after the rinsing at constant geometry. The results are shown in Table 2.

Each individual fish was poured in plastic pot of different sizes to accommodate the fishes of different sizes. Each pot with individual fish contained in it was placed on the HPGe detector for taking the whole body (live) counting for 200 s. The counting was repeated three times and the mean of three readings was taken. After taking the counts for every fish of a group, the mean count rate was determined for each group with one standard deviation ($\pm$1sd). For Magur and Singhi, the experiments were continued for 21 days after which usually most of the fishes died. For Koi and Soiel the experiments were continued for 37 days.

After the cessation of uptake experiments some fishes of all species were sacrificed and boiled individually with fresh water at nearly 100^{0}C in order to help proper segregation of edible and non-edible parts. These parts were kept in plastic petridishes of identical size and measured for ^{137}Cs activity. The distribution of ^{137}Cs in edible and non-edible parts of the fish was determined from these measurements.

After 21 days of exposure to ^{137}Cs, three 'Singhi' fishes and after 37 days of exposure to ^{137}Cs six Koi fishes of different lengths and weights and one Soiel fish were removed from the ^{137}Cs spiked water at a time for retention studies. In this study, 'Singhi' fishes were released individually into plastic buckets which contained 3 to 4 litres of fresh tap water, and the Koi and Soiel fishes were kept in different aquarium which contained 24 to 30 litres fresh tap water. Thus every Koi fish has 3 to 4 litres of fresh water and every Soiel fish has 24

to 30 litres of fresh water. The water was changed at a regular interval. All fishes were counted alive for whole body ^{137}Cs regularly (at constant geometry adopted for each species of fishes) in order to determine the elimination behaviour of ^{137}Cs from the fishes.

Table 1. Counts of radioactive aquarium water taken at different times (counting time: 200s).

Elasped time (day)	Counts/100 ml of water
1	12717±55
3	12080±75
8	12647±56
11	12153±45
15	12430±166
18	12644±10
21	12512±32

Table 2. Counts of fish taken before and after rinsing (counting time: 200s).

Live fish sample	Counts before rinsing	Counts after rinsing
1	6857±20	6750±98
2	4363±26	4107±43
3	9689±491	9188±29
4	5038±15	4812±138
5	18443±94	16406±114

The aquaria (two for radioactive water and one for fresh water) were placed in a restricted area located at INST lawn which ensured the ambient conditions, i.e., the normal temperature, pressure, humidity, light, etc. Arrangement was made for night time illumination as and when necessary. A small camp was erected beside the aquaria providing a table, one chair and a stool under the roof for handling, manipulation of the samples, feeding the fishes, recording the data and for miscellaneous works.

To prevent the experimental set up from excessive or direct sunlight and rain, undesired dust/other particles falling from the atmosphere and dew at night, the entire experimental set up was roofed with canvass.

To collect the radioactive waste produced from the aquarium house, waste management equipment such as remote handling tongs disposable hand gloves and the plastic/galvanised tin drums for safely storing the wastes were used.

8 number of plastic bucket, nylon net, 12 number of plastic pot of different sizes for measurement of radioactivity in the live sample were used. The plastic buckets were used for proper rinsing of the fishes before the counting. The nylon net was used to prevent fishes from jumping out from the aquaria.

Arrangements were made for supply of fresh water to the aquaria. Arrangements were also made for collection of non-radioactive wastes in course of the experiment.

All works pertaining to radiation protection were performed under the direct supervision of the Divisional Head of the Health Physics and Radiation Protection Division, INST, AERE, Savar. The radiation area was marked by the standard trifoil symbol. All aquaria filled with radioactive water were properly marked with symbols for radioactive materials. Drums for collecting/storing radioactive wastes were also marked with the symbols for radioactive materials as per international norms and practices.

The radiation workers were provided with P.M. film badges and pocket dosimeters to evaluate the dose received during the course of experiment. To keep the received dose to a minimal, the radioactive materials were handled from a safe distance by remote handling tongs. To prevent internal contamination of the relevent radiation workers the following radiation protection and safety guidelines were followed during the course of the experiment within the experimental zone:

a) No eating, drinking or smoking.

b) No mouth operations.

c) Any wound, if present on the body was covered with water proof dressing.

d) Ordinary handkercheif was not used; disposable duster towel, tissue paper , etc. were used.

e) Disposable gloves were used in all times during the experiment.

Standard and adequate house keeping was maintained and the protective clothes/shoes were used by the radiation workers.

Two types of low level radioactive wastes (solid and liquid) were produced. The solid wastes consisted of the contaminated fish, tissue papers, trash papers, filter papers, disposable gloves, cloths, towels and some consumable items, such as, pertridish, syringe, etc. The wastes were properly collected into a galvanized iron drum of about 0.04 m^3 volume for interim safe storage.

The liquid wastes were collected into plastic drums of about 0.08 m^3 volume. The liquid waste from rinsing the contaminated fish was of very low level. After the level of radioactivity of liquid waste coming down to a safe level by 'delay', 'decay' and 'dilution' the same was discharged into the local sewer by properly evaluating the safety aspects in accordance with the international norms.

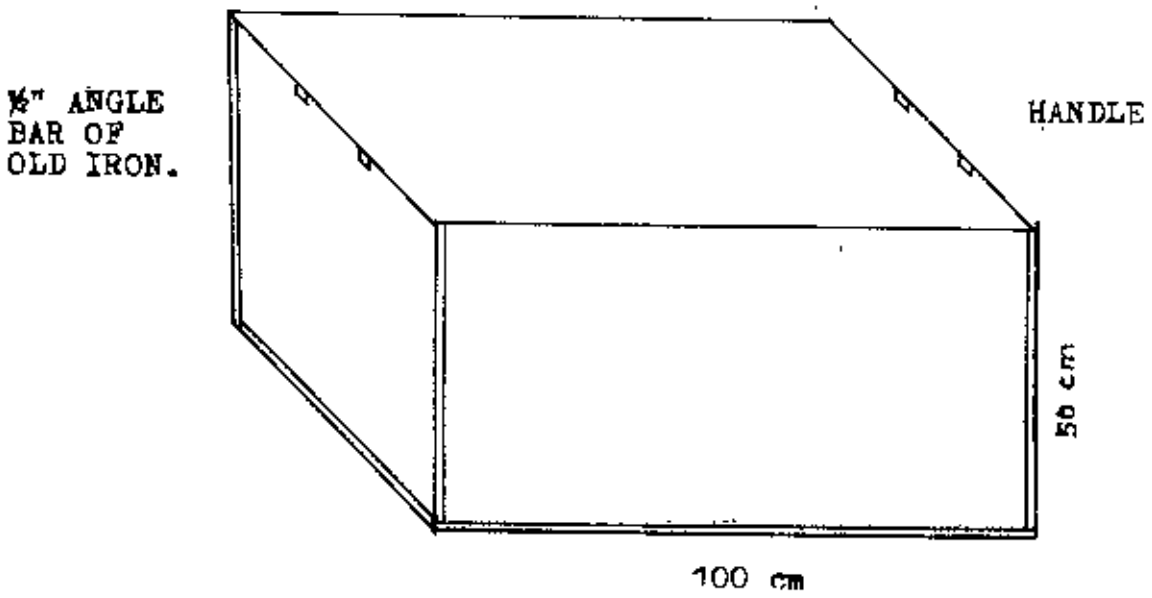


FIG.1(a) THE MAIN AQUARIUM (glass thickness 6cm.)

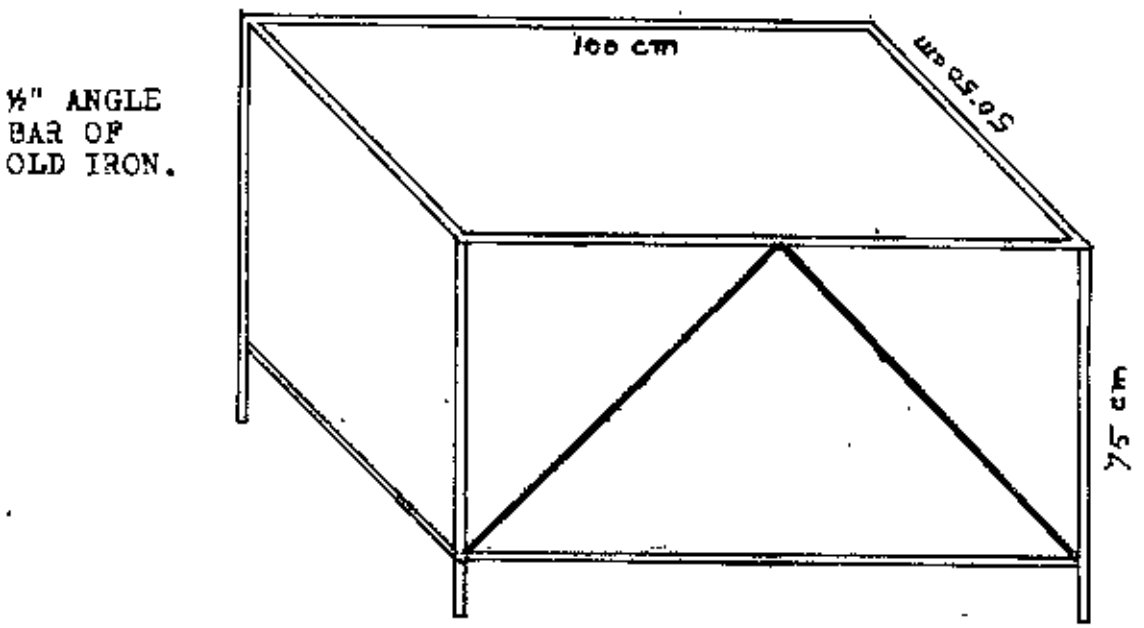


FIG.1(b) THE AQUARIUM STAND.

FIG.1 THE SCHEMATIC DIAGRAM OF AQUARIUM USED IN THE EXPERIMENT.

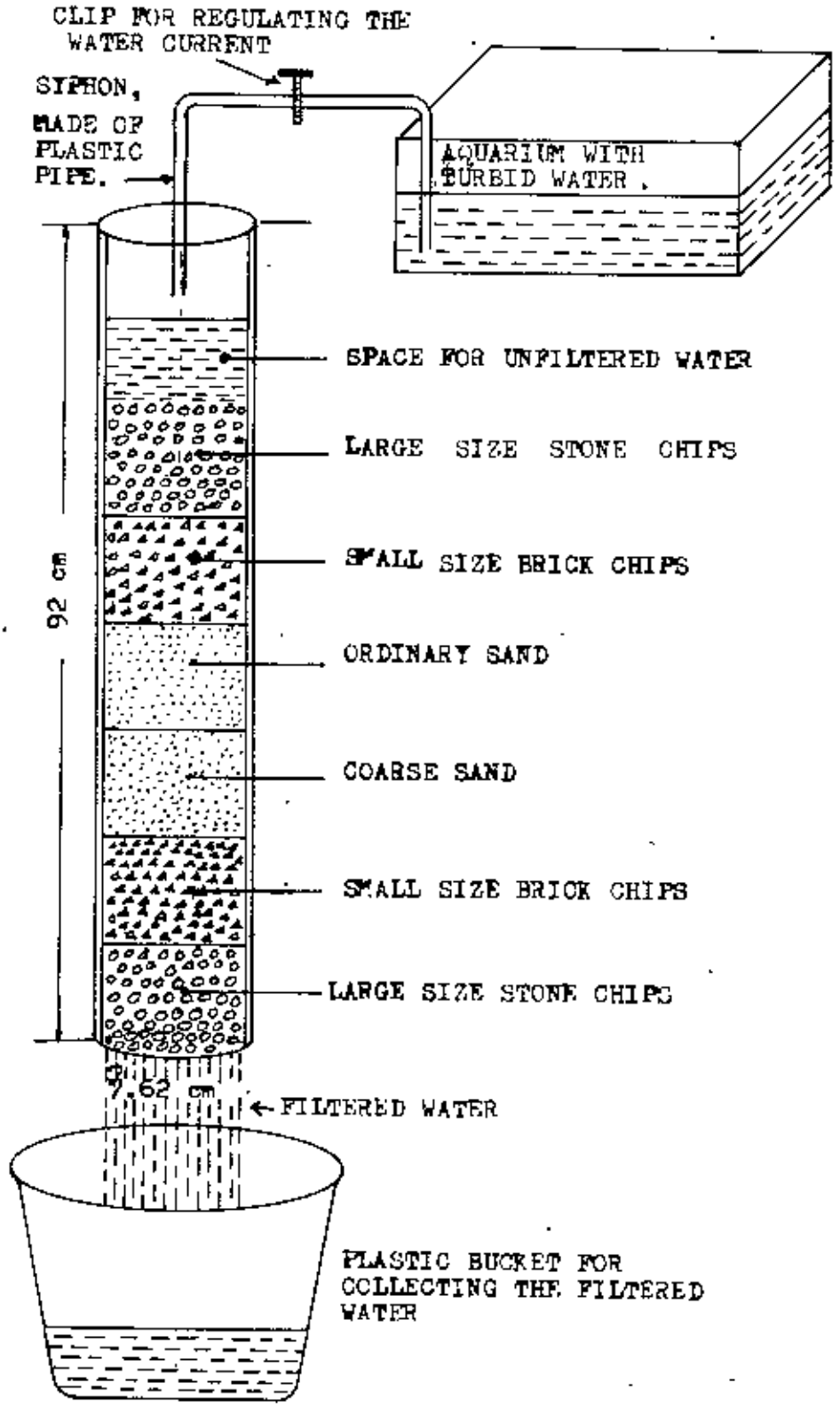


FIG. 2. SCHEMATIC DIAGRAM OF FILTER BED. SPECIALLY DESIGNED FOR FILTER THE TURBID WATER IN AQUARIUM.

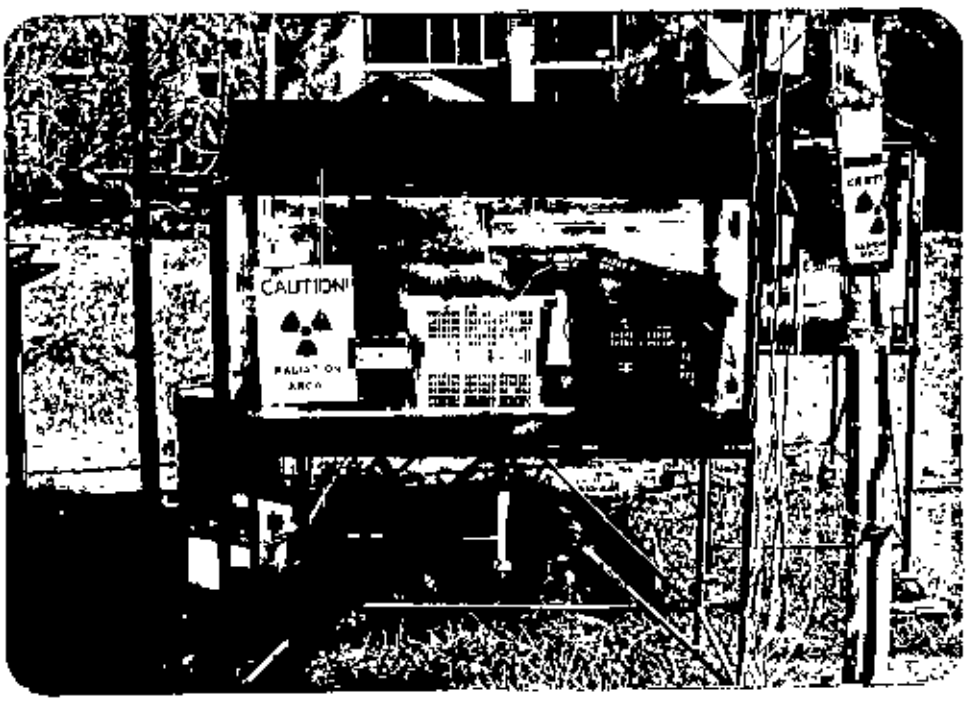


Fig.3(a). The figure showing the aquarium (1.00m x 0.50m x 0.50m) on the stand (0.75m height). The glass sheet used is 0.006m thick. The plastic cages inside the aquarium are to facilitate for catching and identification of the fishes. The bamboo pillers near the aquarium are used to set the canvass tent over the aquarium.

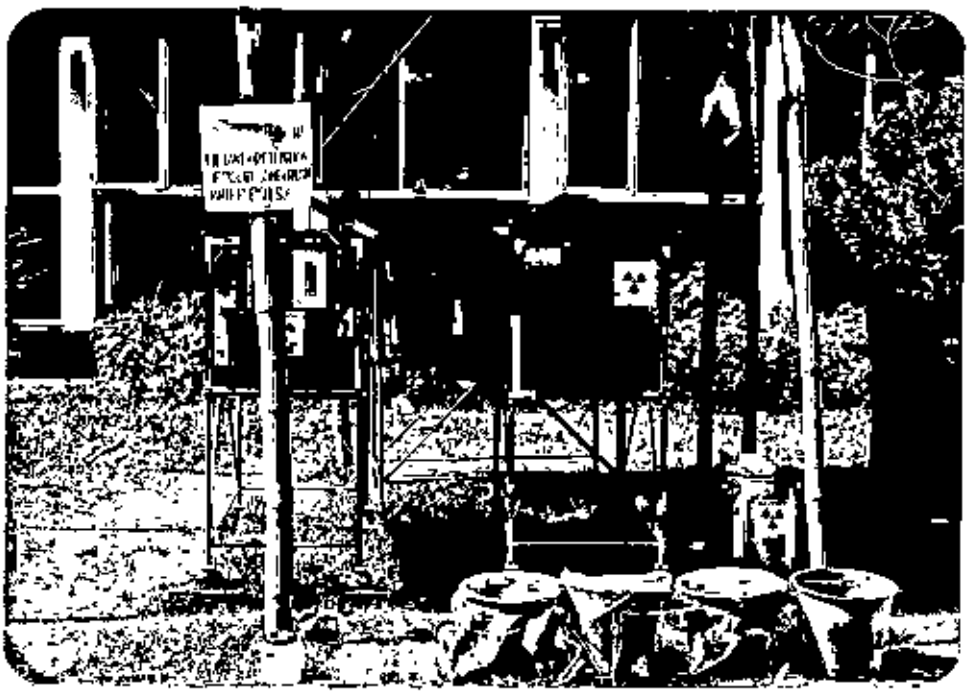


Fig.3(b). "CAUTION" symbol is set at the side of the other two aquaria. The plastic buckets seen used to culture the Cs-137 accumulated live fish in fresh water contained in it for elimination study.

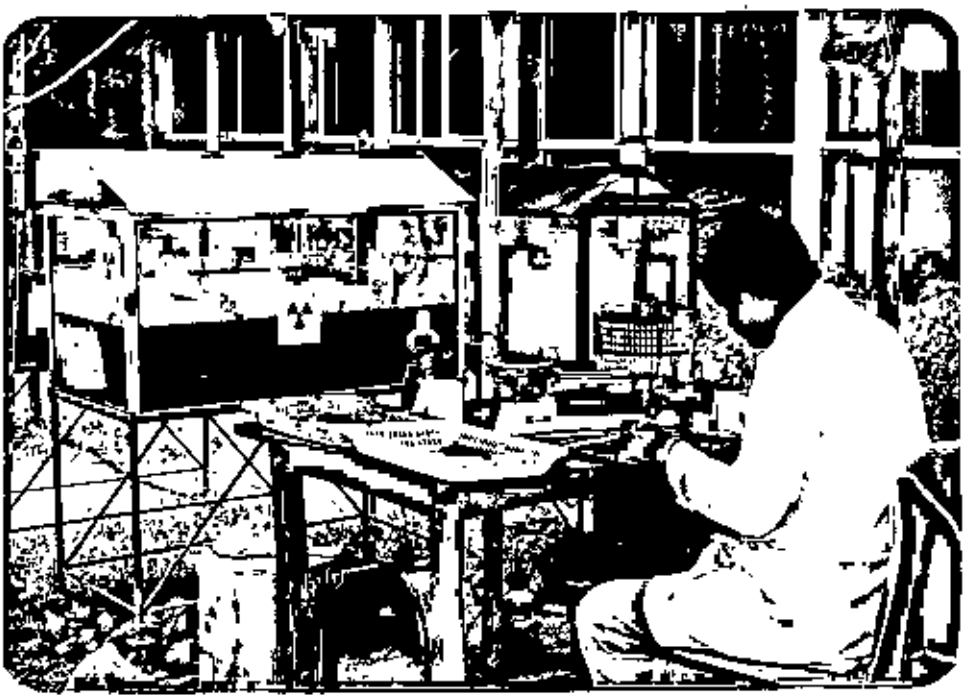


Fig.3(c). The wooden table under the tent is used for preparation of sample. The author is dissecting the fish to determine the level of radioactivity in different parts of the fish. The cylindrical container seen beside the aquarium is used to collect the low level solid wastes. The plastic pot seen beside the bucket is used to measure the radioactivity in live fish. Please also see Fig.3.

CHAPTER 7

RESULTS AND DISCUSSION

CHAPTER 7

RESULTS AND DISCUSSION

The detailed experimental data and results are shown through Tables 1 to 12. Table 1 is a familiarization of the fish species under the scope of this study and Table 2 gives the information about the grouping and size measurements of the fish species under investigation. Each species of the fish was divided into three groups, namely, group 1 (large size), group 2 (intermediate size) and group 3 (small size). A total of 14 'Magur', 16 'Singhi', 9 'Koi' and 5 'Soiel fishes were taken in this study. In the first phase, experiments on Magur and Singhi fishes were conducted simultaneously and in the second phase, experiments on Koi and Soiel fishes were performed simultaneously. The ^{137}Cs concentration for respective fish species and the average weight of a fish species in a particular group are shown in Table 3.

Tables 4 to 7 show the bioaccumulation factors (BFs) of ^{137}Cs by the concerned fish species at different exposure times from the ^{137}Cs spiked water. Table 4 shows the data of BFs for 'Magur' fish for five sampling periods and Table 5 gives the data of BFs for 'Singhi' fish for four sampling periods. Tables 6a, 6b and 6c indicate data of BFs for 19 samples for Koi fish and table 7 stands for those of Soiel fish; also for the same sampling period.

Column 3 of the Tables 4 and 5 and column 2 of the Tables 6a, 6b, 6c and 7 show the mean counts with one standard deviation expressed in cps of a whole body fish averaged over a group of a fish species. Column 4 of the Tables 4 and 5 and column 3 of the

Tables 6a, 6b, 6c and 7 give the ^{137}Cs concentration in the fish tissue expressed in Bq/gm. This concentration of ^{137}Cs is obtained from the cps divided by the 'averaged' whole body weight and the efficiency of the detector.

Column 5 of the Tables 4 and 5 and column 4 of the Tables 6a, 6b, 6c and 7 show the bioaccumulation factors with one standard deviation. The standard deviation stands for the overall uncertainty in the whole experiemental procedure. The BF is obtained from the data of the previous concentration of the whole fish species due to ^{137}Cs divided by the concentration of ^{137}Cs in the water of respective aquarium.

Tables 4 and 5 show the complete data about BFs for Magur and Singhi respectively while those of Koi fish are given in Tables 6a, 6b and 6c. Data of BFs for each group of Koi fish cover the entire Table, Table 6a for group 1, 6b for group 2 and 6c for group 3. Accidental death of all the Soiel fishes except one in group 2 limits the data of BFs for group 1 and 3, hence the data of BFs for Soiel fish are covered by only Table 7. The difficulties were encountered in keeping the Magur and Singhi fishes alive for a longer period of time and consequently the sampling periods were reasonably limited.

Figs. 1, 2, 3 and 4 are drawn from the data of Tables 4, 5, 6 and 7 respectively . These figures illustrate the general pattern of Cs-137 uptake behaviour by the whole body Magur, Singhi, Koi and Soiel fish species. Figs. 1 to 4 and Tables 4 to 7 , indicate significant accumulations of ^{137}Cs by the Magur,

Singhi, Koi and Soiel fish species. Moreover, the curves for each species indicate that the uptake of ^{137}Cs initially increases rapidly followed by a more gradual accumulation. However, a steady state concentration could still not be reached at the end of this experiment. The uptake of radionuclide may be defined as the increase of bioaccumulation factor with time. It is also evident that the uptake rates are different for different fish species. The uptake rates observed are shown in decreasing order rate Koi > singhi > Magur > Soiel. Again the uptake rates differ with the size of the fish, intermediate size of each species accumulates ^{137}Cs more than the other two sizes (i.e. small and large size). The BFs reported here are for whole body of fishes. Since concentration of ceasium does not vary greatly among the organs, flesh or whole body, bioaccumulation factors mentioned may apply to other organ(s) as well].

Tables 8 to 10 represent the data for biological elimination of Cs-137 from the Singhi, Koi and Soiel fish species respectively. Based upon the data contained in Tables 8 to 10, the curves for effective half-lives drawn in the Figs.5, 6 and 7 illustrate the general pattern for biological elimination of ^{137}Cs by the concerned fish species. The ^{137}Cs counts remaining in the whole body at the different time periods after transfer to non-radioactive water were plotted on a semi log paper to show the rate of loss from biological elimination. The slopes of these curves showed that only one rate of loss is involved. The slopes of the curves are simply the effective elimination constants $\lambda_{(eff)}$, which may be expressed as $\ln A = \ln A_0 - \lambda_{(eff)} t$. Thus

$\lambda_{(eff)}$ is found to be

$$\lambda_{(eff)} = (\ln A_1 - \ln A_2)/(t_2 - t_1).$$

The effective half-live $T_{1/2(eff)}$ is calculated by using the formula $T_{1/2\ eff} = 0.693/\lambda_{(eff)}$. The $\lambda_{(eff)}$ and the half-life $T_{1/2(eff)}$ represent the quantitites usually designated as elimination rate or biological half-lives which indicate the rates at which radionuclide incorporated into the tissues or whole body are excreted. Table 11 shows the values of the effective half-lives of the Singhi, Koi and Soiel fish as obtained from the curves of Figs. 5, 6 and 7 respectively. The effective half-lives are found to vary among the fish species but they do not vary with the sizes of the fish species. The large variation of half-life of Koi fish of small size from the other two sizes (Table 11) may be probably due to the experimental errors. The effective half-lives are found to be 33.60±3.53, 151.27±10.18 and 217.04±8.87 days for 'Singhi', 'Koi' and 'Soiel' fishes respectively. The half-life of Magur fish can not be calculated due to accidental deaths of all the Magur fishes while conducting this experiment on half-life..

Table 12 shows the tissue distribution of ^{137}Cs in Magur, Singhi, Koi and Soiel. Due to accidental deaths of all soiel fishes except one, data for only one specimen is given. The fishes were disected into edible parts (muscle) and the non-edible parts (bone, gillflaps, palps, visceral mass etc.) It is difficult to separate the edible parts completely from the bone - specially from the bone of head portions. Percentages of ^{137}Cs in edible parts are found to be 87.20±5.06, 85.03±4.23, 76.65±3.88

and 88.31 ± - for Magur, Singhi, Koi and Soiel fishes respectively; the maximum percentage being in Soiel (~88%) while the minimum in Koi (~76%).

The effective retention time is influenced by biological and physical half-lives. The biological half-life may be calculated by the formula

$$T_{1/2(eff)} = T_{1/2(Bio)} \times T_{1/2(Phy)} / T_{1/2(Bio)} + T_{1/2(Phy)}$$

Environmental conditions such as temperature, humidity, etc. influence radionuclide retention in fishes considerably. Also mode of accumulation of radionuclide as well as rate of excretion may have significant effects on the effective half-life.

In the event of large scale radioactive contamination of the environment with Cs-137 having long effective half-life Cs-137 would remain in the fish for a longer period of time and thus would constitute more health hazard to public via consumption of fishes from the related environment.

Suggestions for further works

This is for the first time that this type of experiments ha : been carried out in Bangladesh. Due to lack of previous experiences and adequate facilities, more significant contribution could not be achieved in the field. One difficulty was encountered in procuring the fishes with desired physical conditions. Although plenty of fishes of identical species are available in the local markets, the fishes collected from these markets do not remain alive in the acquarium beyond a few days. The major cause for the premature death of fishes was observed

due to infections of their skin, pulps, mouth, etc. After catching from the pond, swamps, etc., the fishermen generally store the fishes of various species mixed up together in a container and as a result almost all the fished get injured eventually by struggling among themselves. There were no fish farms available in the vicinity at that time from which the fish species of interest could be collected as per requirements. However, we were able to collect 5 kg of Singhi and Magur free from all types of probable injuries and diseases from the Crescent Farming Complex, Nakchala, Gazipur, Dhaka. The Koi and Soiel fishes were collected by withdrawing all the water from a pond located in an interior rural area of the district of Dhaka. The fishes were caught and transported very carefully in order to get the fishes free from all types of injuries before sampling. Inspite of all possible precautions, it was unfortunately not possible to keep the fishes alive for longer period of time. The water quality could not be uniformly maintained during the experiments due to the farmentation of the organic substances from food stuff, fish excreta, etc. These organic substance were removed from the water in order to keep the water clear and suitable for survival of the fishes.

Initially, the readings were not taken for Singhi and Magur at more frequent intervals due to difficulty in counting of a large number of fish samples. Otherwise the relevent uptake curves would have been much better as found in Koi and Soiel fishes.

From the experiences gained in this investigation, the

following further works on the uptake and retention studies for various radionuclides by different fish species of fresh water and marine water commonly consumed by the people of Bangladesh may be performed in near future:

1. Uptake of radionuclides by the fishes under laboratory and field conditions using artificial and miniature ponds.

2. The uptake of radionuclides in various concentrations by the same/identical fish species.

3. The uptake of radionuclides by fishes in presence of various quantity of the corresponding stable nuclides.

After knowing the bioaccumulation factors of the various radionuclides for the different fish species commonly consumed by the people of Bangladesh and concentration of respective radionuclides in the relevent water reserviour and other parameters, the annual dose equivalent received by a standard man from the habit of fish consumption may be calculated.

Table 1. Identification of fish species.

Local name	English name	Biological name
'Magur'	Cat Fish	*Clarius Batrachus*
'Singhi'	Cat Fish	*Heteropneustes Fossilis*
'Koi'	Climbing Perch	*Anabas Testudineus*
'Soiel'	Murrel	*Channa Striatus*

Table 2. Grouping and size measurements of fish species based on their lengths and weights.

Fish species	Fish group	No.of fishes in each group	Range of weight (g)	Range of length (cm)	Remarks
1	2	3	4	5	6
Clarius Batrachus ('Magur')	1	4	139-165	26-28	Large size
	2	7	77-100	22-24	Intermediate size
	3	3	35-44	12-16	Small size
Heteropneustes Fossillis ('Singhi')	1	4	79-94	24-25	Large size
	2	7	47-62	22-24	Intermediate size
	3	5	40-49	18-20	Small size
Anabas Testudineus ('Koi')	1	3	60-94	16-19	Large size
	2	3	58-67	12-14	Intermediate size
	3	3	39-56	9-11	Small size
Channa Striatus ('Soiel')	1	1	219	30	Large size
	2	2	157-158	27-28	Intermediate size
	3	2	98-100	20-22	Small size

Table 3. Parameters for uptake of ^{137}Cs by fish species.

Fish species	Cs-137 conc. in water (Bq/ml)	Fish group	Average wt. of fish (g)	Efficiency of the detector at the counting geometry.
1	2	3	4	5
'Magur'	165.56±3.97	1	140.00±15.5	4.266×10^{-3}
		2	90.00±7.78	4.166×10^{-3}
		3	40.00±3.68	4.166×10^{-3}
'Singhi'	122.87±0.20	1	85.50±5.58	4.226×10^{-3}
		2	54.00±5.00	4.166×10^{-3}
		3	43.80±3.43	4.166×10^{-3}
'Koi'	55.15±0.47	1	73.66±20.85	5.033×10^{-3}
		2	64.66±6.13	5.033×10^{-3}
		3	47.00±9.00	5.033×10^{-3}
'Soiel'	50.97±0.97	1	-----	-----
		2	158.00±0.00	4.266×10^{-3}
		3	-----	-----

Table 4. Data for uptake of ^{137}Cs by 'Magur' fish at different exposure times.

Fish group	Exposure time(day)	Average count rate (cps)	Concentration of Cs-137 in fish tissue(Bq/g)	Bioaccumulation factor.
1	2	3	4	5
	2	5.50±3.31	9.2090±5.3651	0.0556±0.0340
	8	33.54±9.02	56.1667±16.3406	0.3392±0.0990
	16	70.82±17.46	118.5704±32.0542	0.7162±0.1943
	18	71.78±40.00	120.1945±26.9622	0.7256±0.1637
	20	73.62±7.36	123.2586±18.3872	0.7445±0.1124
2	2	3.41±1.02	9.1118±2.8321	0.0550±0.0171
	8	23.54±6.43	62.7834±17.9877	0.3792±0.1090
	16	63.34±7.40	168.9470±24.5524	1.0205±0.1503
	18	65.44±2.92	174.5479±16.9738	1.0543±0.1156
	20	70.21±7.88	187.2699±26.5391	1.1311±0.1625
3	2	1.28±0.41	7.6812±2.5598	0.0464±0.0155
	8	6.15±0.51	36.9059±4.5912	0.2239±0.0282
	16	23.48±2.75	143.1229±21.3158	0.8644±0.1303
	18	24.44±1.65	146.6634±16.7540	0.8858±0.1033

Standard deviations were calculated for n = 4 for group 1, n = 7 for group 2 and n = 3 for group 3.

Table 5. Data for uptake of ^{137}Cs by 'Singhi' fish at different exposure times.

Fish group	Exposure time(day)	Average count rate(cps)	Concentration of Cs-137 in fish tissue(Bq/g)	Bioaccumulation factor.
1	2	3	4	5
1	3	4.42±1.06	11.6246±3.0130	0.0949±0.0246
	10	13.45±4.21	36.8752±11.8148	0.3011±0.0964
	17	35.45±8.86	97.0820±25.1564	0.7928±0.2054
	21	33.94±6.08	93.0655±17.7928	0.7600±0.1453
2	3	3.39±1.05	15.0913±4.8721	0.1228±0.0396
	10	11.02±3.01	49.0078±14.1284	0.3988±0.1149
	17	41.60±8.57	184.9184±41.7861	1.5049±0.3401
	21	41.60±6.70	184.9407±34.3738	1.5051±0.2797
3	3	2.50±0.44	13.7018±2.6643	0.1115±0.0216
	10	6.72±1.43	37.1093±8.4090	0.3020±0.0684
	17	21.48±1.76	117.7174±13.3620	0.9581±0.1087
	21	20.31±0.87	111.3054±9.8445	0.9058±0.0880

Standard deviation were calculated for n = 4 for group 1 , n = 7 for group 2 and n = 5 for group 3.

Table 6.a. Data for uptake of ^{137}Cs by 'Koi' fish of large size at different exposure times.

Exposure time(day)	Average count rate(cps)	Cs-137 concentration in fish tissue(Bq/g).	Bioaccumulation factor.
1	2	3	4
1	1.04±0.23	2.9642±1.0719	0.0537±0.0194
3	3.36±0.66	8.5235±2.9546	0.1545±0.0535
4	3.98±0.63	10.0963±3.2908	0.1830±0.0597
7	4.46±0.61	16.3876±4.9234	0.2971±0.0893
8	7.47±0.94	18.9497±5.9143	0.3413±0.1065
10	9.54±1.28	24.2135±7.6401	0.4390±0.1385
11	10.47±1.59	26.5601±8.5965	0.4815±0.1559
13	13.54±1.75	34.3480±10.7317	0.6228±0.1946
15	14.78±1.28	37.5063±11.1974	0.6800±0.2030
17	14.99±1.77	38.0263±11.7573	0.6895±0.2132
20	17.08±1.22	43.3409±12.7590	0.7858±0.2312
22	17.51±1.09	44.4190±12.9846	0.8054±0.2355
24	18.66±0.94	47.3490±13.7301	0.8585±0.2490
27	18.61±0.74	47.2095±13.6138	0.8560±0.2569
29	18.61±0.74	47.1968±13.6102	0.8557±0.2468
31	20.77±1.96	52.6763±15.8496	0.9551±0.2874
34	22.21±1.98	56.3419±16.8541	1.0216±0.2992
36	23.13±0.86	58.6757±16.8985	1.0639±0.3065
38	24.62±0.13	62.4429±17.8375	1.1322±0.3233

Table 6.b. Data for uptake of ^{137}Cs by Koi fish of intermediate size at different exposure times.

Exposure time(day)	Average count rate(cps).	Cs-137 concentration in fish tissue(Bq/g).	Bioaccumulation factor.
1	2	3	4
1	1.28±0.22	3.9176±0.7691	0.0710±0.0139
3	3.78±0.78	11.6146±2.6445	0.2106±0.0479
4	4.56±1.33	14.0113±4.3092	0.2540±0.0781
7	7.51±1.48	23.0604±5.0683	0.4181±0.0919
8	8.86±1.55	27.2238±5.4282	0.4936±0.0986
10	11.44±1.39	35.1513±5.4314	0.6373±0.0986
11	13.03±0.59	40.0368±4.2101	0.7259±0.0758
13	16.42±0.80	50.4378±5.3843	0.9145±0.0973
15	18.06±0.74	55.4923±5.7272	1.0062±0.1042
17	19.31±0.61	59.3178±5.9287	1.0755±0.1078
20	21.82±1.21	67.0456±7.3542	1.2156±0.1337
22	23.51±1.86	72.2384±8.9179	1.3098±0.1620
24	24.79±1.28	76.1868±8.2315	1.3814±0.1497
27	25.13±1.74	77.2161±9.0788	1.4001±0.1650
29	26.94±1.77	82.9623±9.5548	1.5006±0.1732
31	27.48±1.96	84.4521±9.9128	1.5313±0.1802
34	28.66±1.91	88.0626±10.1965	1.5967±0.1853
36	29.08±1.20	89.3378±9.2700	1.6199±0.1664
38	31.38±1.25	96.4049±9.9192	1.7480±0.1804

Table 6.c. Data for uptake of ^{137}Cs by Koi Fish of small size at different exposure times.

Exposure time(day)	Average count rate (cps).	Cs-137 concentration in fish tissue (Bq/g).	Bioaccumulation factor.
1	2	3	4
1	2.27±1.07	8.9637±4.5402	0.1625±0.0823
3	6.58±2.65	25.9259±11.5828	0.4701±0.2101
4	7.54±2.78	29.7084±12.7690	0.5386±0.2243
7	11.31±4.18	44.5626±18.5884	0.8080±0.3371
8	13.16±4.28	51.8518±19.6201	0.9402±0.3558
10	19.58±3.51	77.1473±20.4774	1.3988±0.3715
11	24.33±6.38	95.8431±31.2332	1.7378±0.5665
13	26.87±8.37	105.8516±38.8329	1.9193±0.7043
15	28.94±7.75	114.0267±41.8329	2.0765±0.7587
17	29.18±7.63	114.9724±37.9229	2.0847±0.6365
20	30.02±8.96	118.2624±42.0651	2.1443±0.6729
22	31.54±8.02	124.2513±39.7176	2.2529±0.7106
24	32.08±8.62	126.3987±41.8466	2.2919±0.7590
27	32.43±8.67	127.7777±42.1625	2.3169±0.7645
29	33.00±8.93	130.0236±43.2478	2.3576±0.7844
31	34.01±8.21	133.9834±41.4321	2.4294±0.7515
34	35.37±9.62	139.3814±46.5121	2.5273±0.8422
36	36.03±8.92	141.9621±44.5989	2.5741±0.8089
38	38.15±6.65	150.2955±39.1471	2.7252±0.7102

Table 7. Data for uptake of ^{137}Cs by Soiel fish of intermediate size at different exposure times.

Exposure time(day)	Average count rate(cps).	Cs-137 concentration in fish tissue(Bq/g).	Bioaccumulation factor.
1	2	3	4
1	0.52±0.07	0.7714±0.1038	0.0151±0.0021
3	1.23±0.07	1.8245±0.1038	0.0353±0.0021
4	1.16±0.03	2.3886±0.0617	0.0468±0.0015
7	3.14±0.08	4.6585±0.1260	0.0913±0.0030
8	3.48±0.05	5.1555±0.0814	0.1011±0.0025
10	5.66±0.05	8.3972±0.0742	0.1647±0.0034
11	6.35±0.16	9.4201±0.2299	0.1848±0.0057
13	8.31±0.11	12.3288±0.1557	0.2418±0.0055
15	9.36±0.05	13.8792±0.0741	0.2723±0.0054
17	10.39±0.21	15.4073±0.3114	0.3022±0.0084
20	13.57±0.16	20.1401±0.2597	0.3951±0.0091
22	13.94±0.16	20.6816±0.2373	0.4057±0.0090
24	14.17±0.38	21.0303±0.5717	0.4126±0.0136
27	15.44±0.09	22.8996±0.1334	0.4492±0.0189
29	16.89±0.06	25.0509±0.0815	0.4914±0.0095
31	19.28±0.03	28.6189±0.0371	0.5614±0.0107
34	20.72±0.20	30.7406±0.2976	0.6031±0.0129
36	25.26±0.19	37.4761±0.2893	0.7352±0.0151
38	23.66±0.39	35.0949±0.5784	0.6885±0.0173

Table 8. Biological elimination of ^{137}Cs from 'Singhi' fish.

Elasped time (day)	Counts/200 s.		
	Large size	Intermediate size	Small size
1	7986±33	6234±63	-
4	7434±69	6151±105	-
7	7341±14	6293±14	3963±66
8	7235±66	6352±50	3823±57
9	6501±49	5662±59	3543±56
10	5151±46	5297±80	3613±12
11	6460±112	5175±15	3657±40
14	6122±45	5196±67	3131±67
15	5942±32	5017±61	2834±35
17	5860±21	4648±81	2818±13
18	5625±26	4373±38	2641±16
21	5466±90	4322±30	2501±55
22	5256±60	4001±59	2451±13
24	5183±28	3859±31	2414±11
25	4800±27	3706±83	2317±31
28	4504±20	3678±30	2259±31
29	4281±64	3508±65	2194±61
31	4249±23	3488±44	1923±50
35	3913±19	3016±12	2154±28
36	3916±28	2917±49	1966±68
37	3397±58	3063±48	2024±19
38	2606±70	3115±102	1802±27
39	3426±38	2872±39	1773±109
43	3546±59	2641±30	1736±18

Table 9. Biological elimination of ^{137}Cs from 'Koi' fish.

Elasped time (day)	Counts/200 s.		
	Large size	Intermediate size	Small size
1	4923±25	6275±250	8960±429
6	4954±17	6503±251	9410±107
7	4920±76	6367±228	8875±20
13	4647±244	5869±283	8846±57
15	4439±55	5754±364	8622±92
18	4561±68	5469±74	----
20	4277±35	5597±248	8560±111
22	4218±155	5558±271	8278±83
25	4043±280	5442±207	8286±32
27	4119±205	5364±197	8086±235
29	4147±30	5395±223	8340±79
32	4232±120	5234±341	7940±124
34	4109±58	5179±136	7975±10
36	3967±50	5289±153	8231±43
39	4140±94	5346±368	8052±40
41	4085±62	5174±285	8205±62
43	4148±82	5102±284	7929±52
46	3929±89	5173±315	8288±43
50	4030±29	5114±280	4030±29
60	3821±32	4745±297	8279±89

Note: Number of fish in large size was 3, in intermediate size was 2 and in small size was 1.

Table 10. Biological elimination of ^{137}Cs from 'Soiel' fish.

Elasped time (day)	Counts/200 s.		
	Large size	Intermediate size	Small size
1		4731±78	
4		4863±32	
6		4442±87	
7		4400±15	
13		4295±41	
15		4179±51	
20		3902±60	
22		4000±152	
25		4000±24	
27		4005±147	
29		3922±114	
32		4151±64	
34		4058±99	
36		3843±29	
39		3939±40	
41		3940±142	
43		3818±23	
46		3994±24	
50		3994±24	
60		3936±10	

Note: Number of fish in intermediate size was 1. All fishes in the large and small sizes accidentally died.

Table 11. Calculation for effective half-lives of fish species.

Fish species.	Curve for each fish group in each species.	Points in each curve.	X-axis, time (day).	Y-axis, in log scale.	Half-life of indiv. fish(day)	Average half-life of a group. (day).	Average half-life : (day).
1	2	3	4	5	6	7	8
'Singhi'	1	1	5.00	3300	37.78		
			18.00	2600			
		2	14.00	2800	38.21	38.43±0.64	
			20.25	2500			
		3	22.60	2400	39.31		
			27.60	2200			
	2	1	4.60	6000	31.92		
			13.00	5000			
		2	10.00	5400	30.42	30.97±0.67	33.60±3.53
			20.00	4300			
		3	30.00	3500	30.56		
			36.80	3000			
	3	1	4.60	5000	35.38		
			16.00	4000			
		2	12.00	4300	35.96	35.41±0.44	
			19.80	3700			
		3	25.60	3300	34.89		
			30.40	3000			
	4	1	10.00	6800	30.06		
			20.00	5400			
		2	12.00	6500	28.82	29.58±0.54	
			18.20	5600			
		3	33.20	4000	29.84		
			40.20	3400			

Note: The last portion of this table is in the next page.

Table 11. Calculation for effective half-lives of fish species (Cont'd).

Fish species.	Curve for each fosh group in each species.	Fish No. in each group.	X-axis, time (day).	Y-axis, in log scale.	Half-life of indiv. fish(day)	Average half-life of a group. (day)	Average half-life (day).
1	2	3	4	5	6	7	8
'Koi'	1	1	18.00 31.25	8400 8200	380.00		
		2	19.00 45.00	8400 8000	369.22	378.34±6.88	
		3	31.25 45.00	8200 8000	385.82		
	2	1	16.25 25.00	5600 5400	166.70		
		2	25.00 33.75	5400 5200	160.64	161.45±4.00	151.27±10.19
		3	43.25 52.50	5000 4800	157.00		
	3	1	11.25 15.50	4600 4500	134.00		
		2	25.25 30.00	4300 4200	147.23	141.08±5.44	
		3	30.00 40.00	4200 4000	142.01		
'Soeil'	1	1	34.00 11.25	4000 4300	218.10		
		2	19.00 41.00	4200 3900	205.69	217.04±8.87	217.04±8.87
		3	51.25 60.00	3800 3700	227.33		

Table 12. Data for tissue distribution of the fish species.

Fish species.	Fish group in each species.	No. of fishes in a group	Wt. of edible part (g)	Wt. of non-edible part (g)	Activity in edible part. (cps)	Activity in non-edible part (cps)	Total activity. (cps)	% of edible part
1	2	3	4	5	6	7	8	9
'Magur'	1	2	60.00	26.00	17548	2670	20218	86.79
			72.00	27.00	13868	3898	17766	78.00
	2	4	22.20	12.10	10594	874	11468	92.38
			29.50	18.40	12241	1616	13857	88.33
			30.00	14.00	10165	1994	12159	83.60
			35.00	16.00	10251	1705	11956	85.00
	3	3	8.50	1.50	4244	297	4541	93.46
			22.11	11.15	4243	274	4518	93.94
			7.00	4.00	2528	504	3032	83.35
'Singhi'	1	4	30.00	11.10	8724	1498	10222	85.34
			32.00	13.00	9656	1291	10946	88.20
			28.00	16.00	5512	1087	6599	83.52
			40.00	20.00	4824	735	5559	86.77
	2	4	12.00	5.00	7580	1530	9110	83.20
			13.00	5.50	11138	1177	11315	90.44
			9.00	4.00	7434	1970	8404	79.05
			10.00	5.00	8970	1203	10173	88.17
	3	2	9.00	4.00	4538	566	5104	88.91
			8.00	3.50	371	113	484	76.65
'Koi'	1	3	28.00	46.00	2655	956	3611	73.52
			18.00	23.00	2163	718	2855	74.82
			26.00	30.00	2061	664	2627	78.50
	2	3	20.00	23.00	2086	679	2766	75.42
			11.00	16.00	2139	394	2532	84.44
			18.00	28.00	2328	851	3179	73.21
'Soeil'	3	1	89.00	31.00	3578	877	4455	80.31

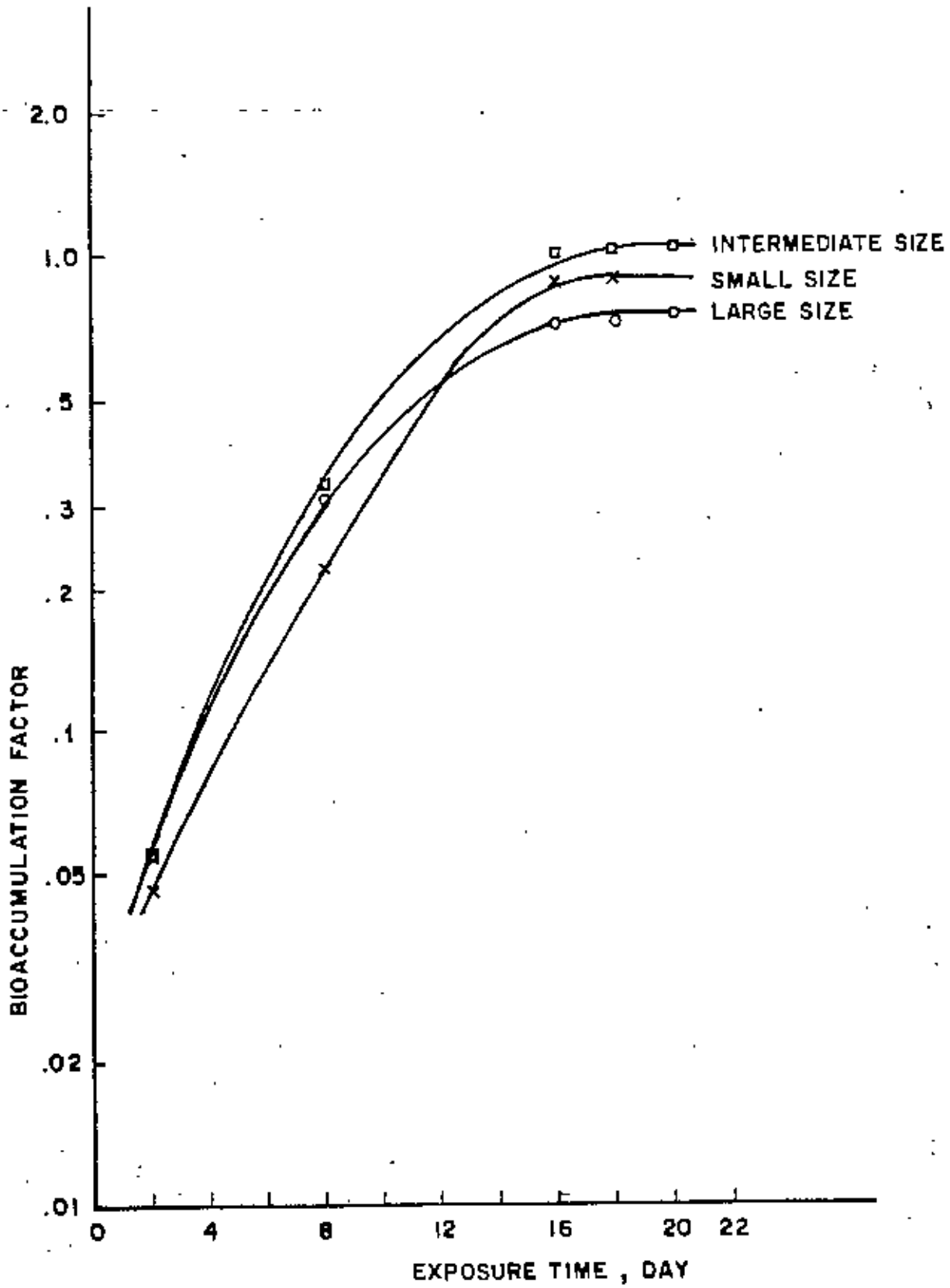


FIG. 1. UPTAKE OF ^{137}Cs BY MAGUR FISH.

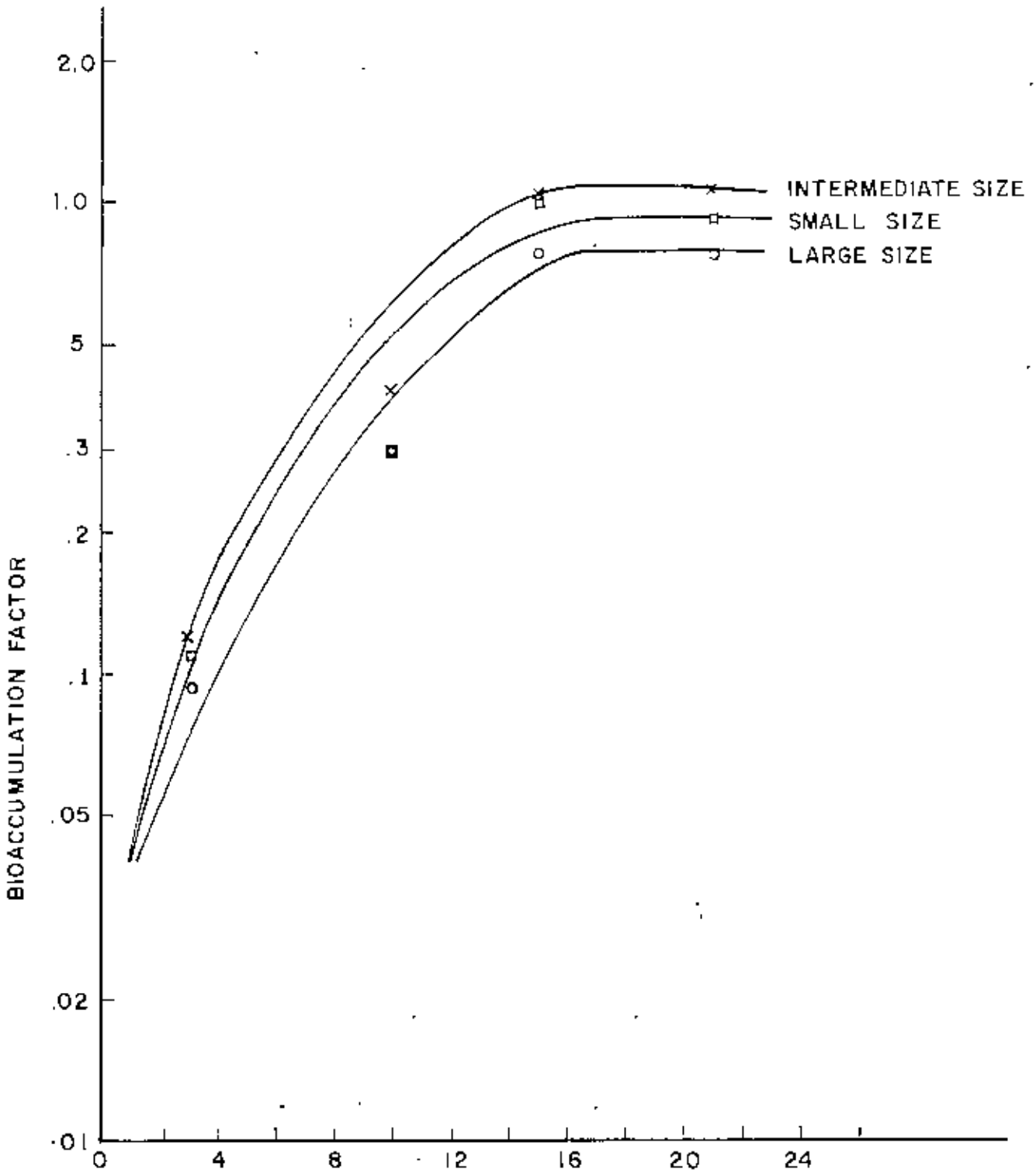


FIG 2. UPTAKE OF ^{137}Cs BY SINGHI FISH

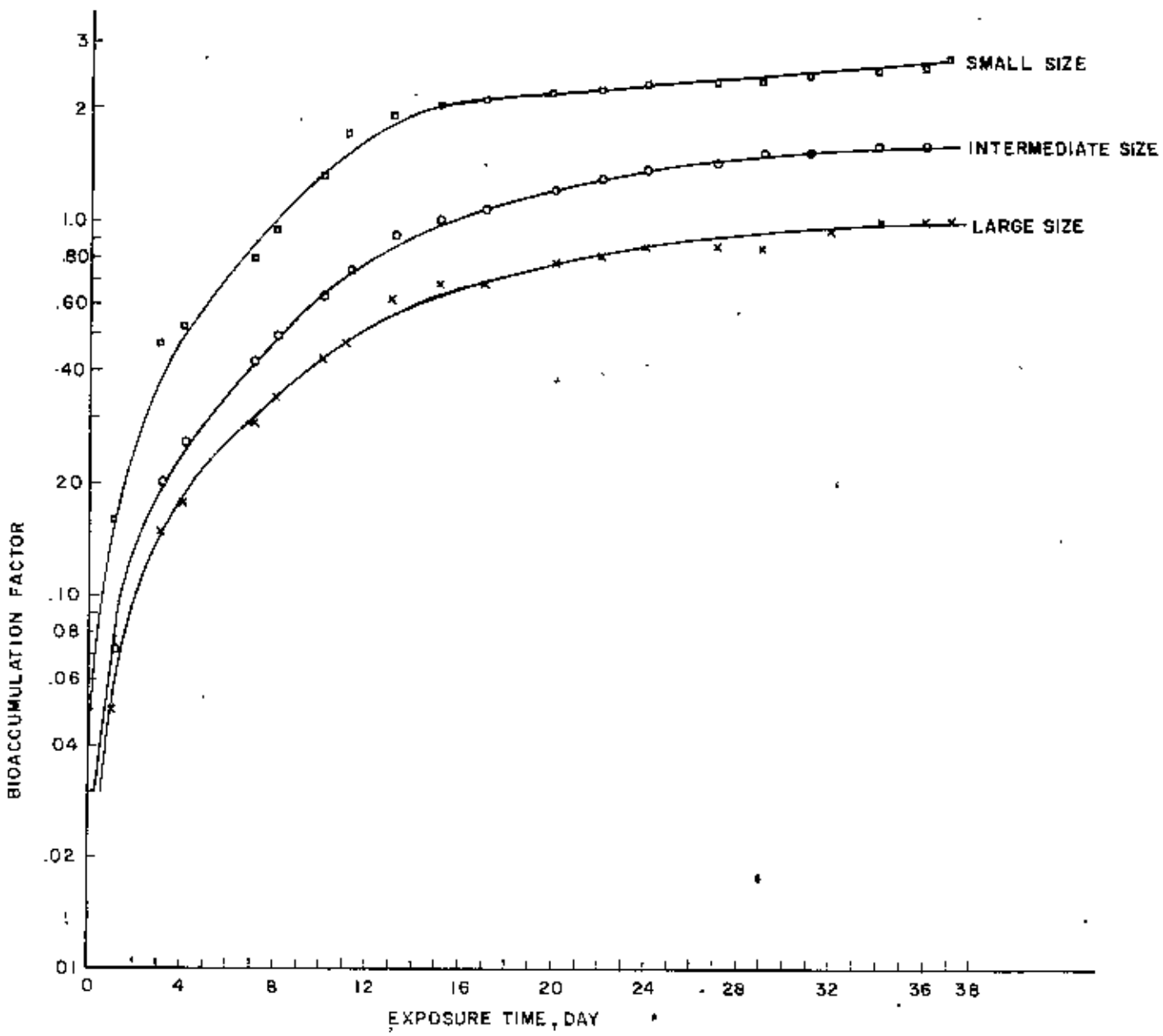


FIG. 3. UPTAKE OF ^{137}Cs BY KOI FISH.

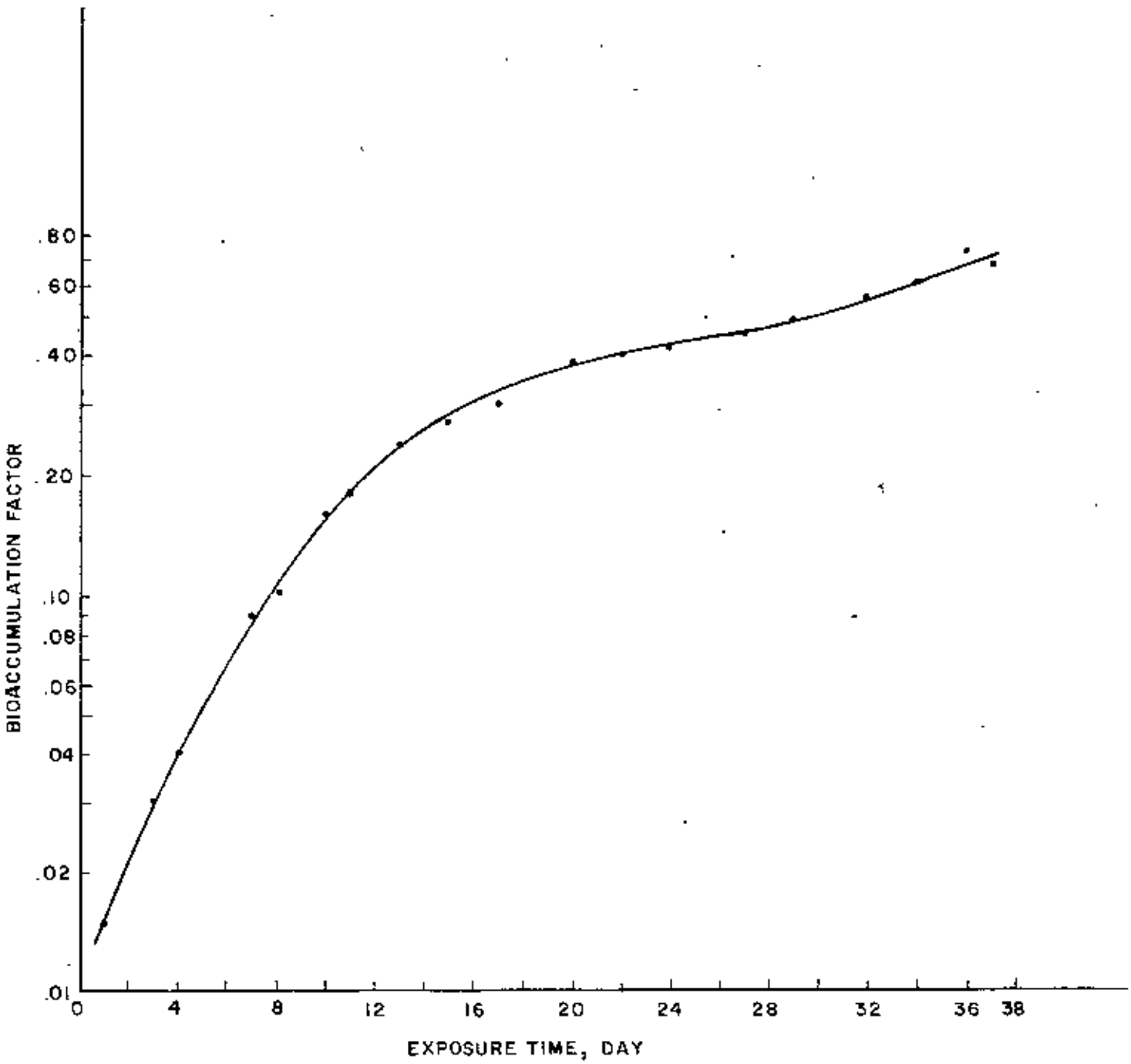


FIG 4. UPTAKE OF ^{137}Cs BY SOIEL FISH.

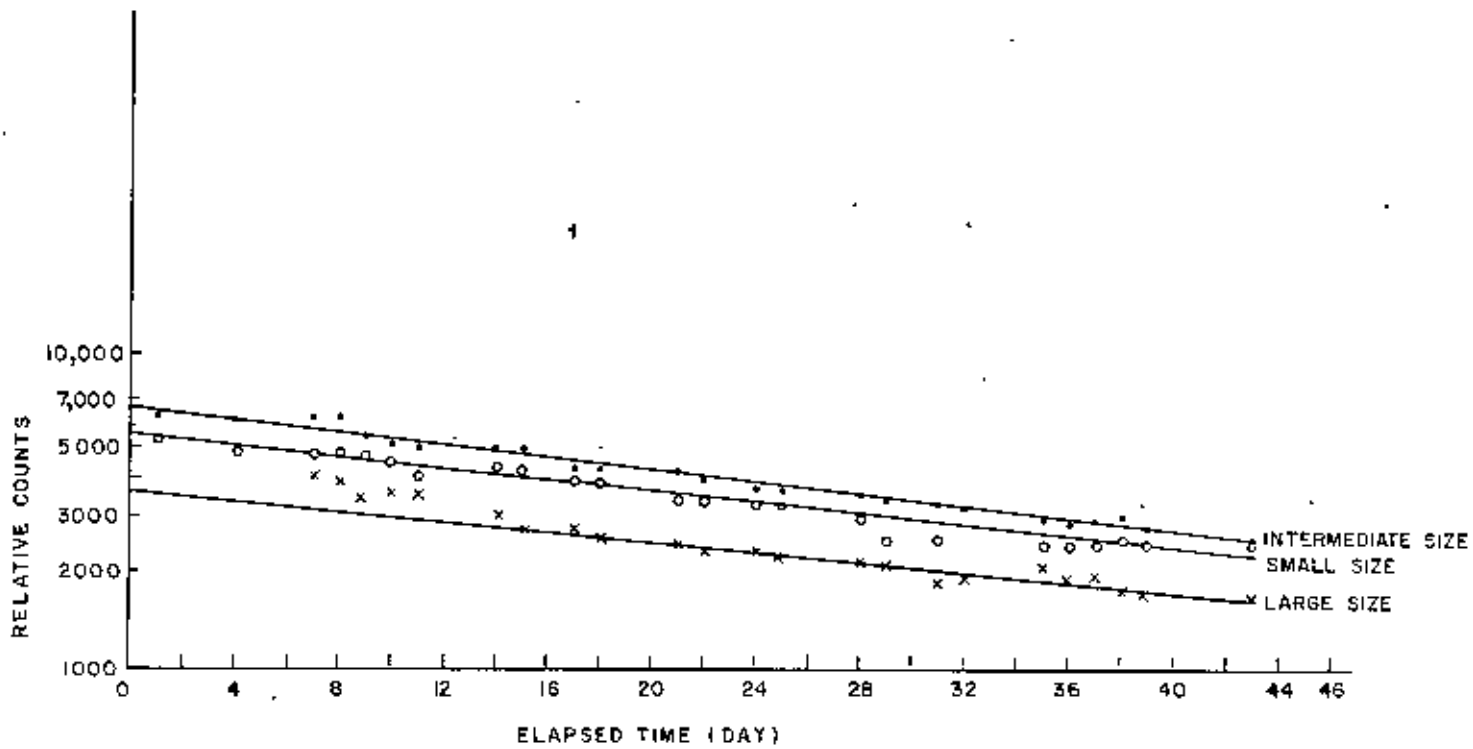


FIG 5 ELIMINATION OF ^{137}Cs FROM SINGHI FISH

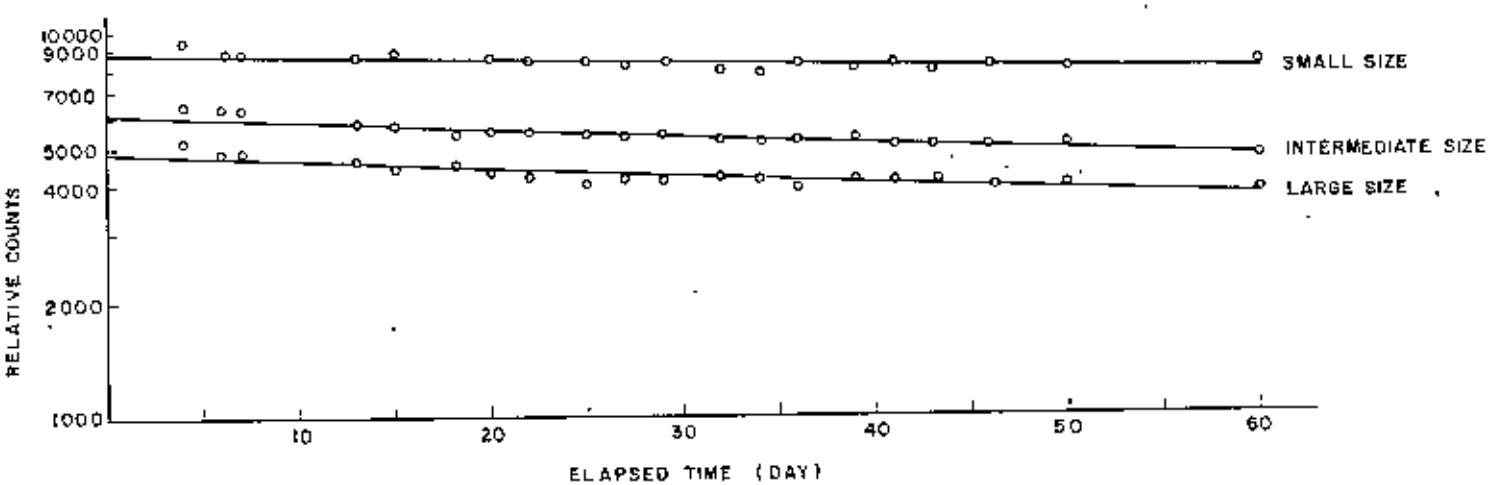


FIG 6. ELIMINATION OF ^{137}Cs FROM KOI FISH.

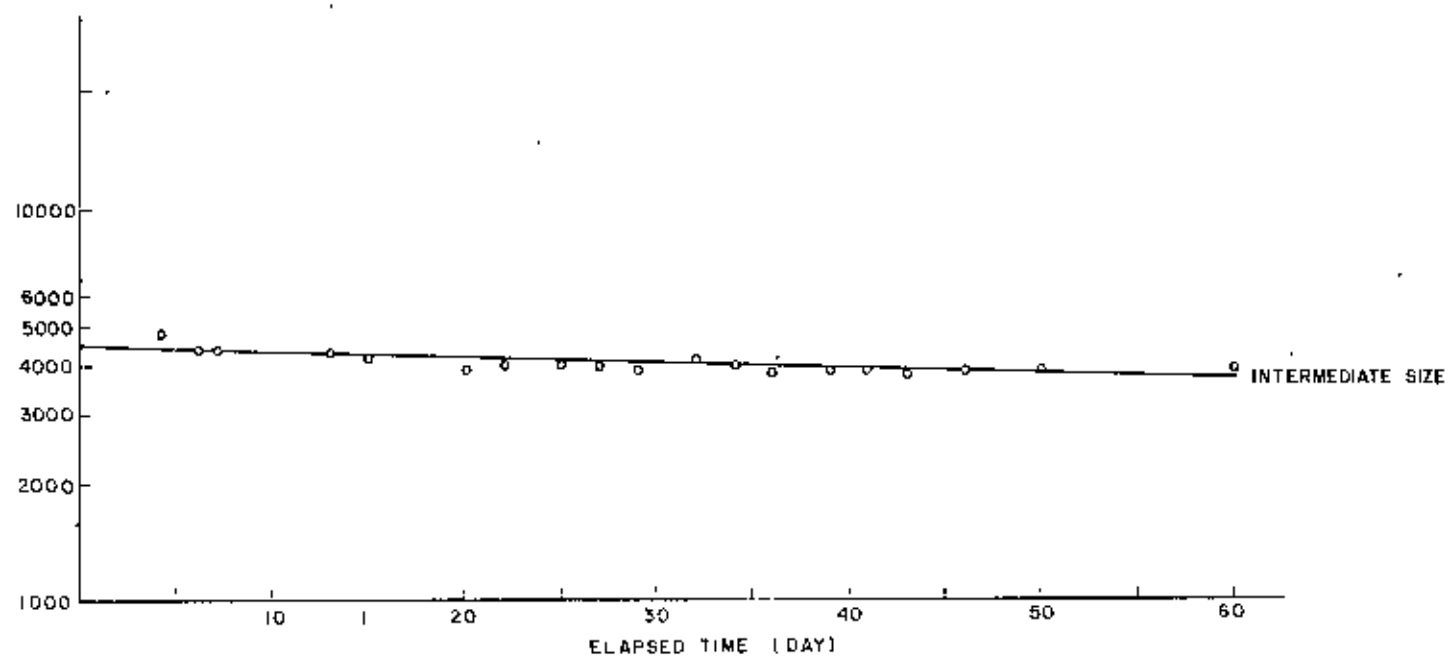


FIG. 7. ELIMINATION OF ^{137}Cs FROM SOIEL FISH.