Radiological Risk Assessment for Fish and Fish Egg of Karachi Coastal Area

By

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- Environmental impact.
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A thesis submitted to Department of Environmental Sciences, International Islamic University, Islamabad as a partial fulfillment of requirement for the award of the degree of MS in Environmental Science.

FORWARDING SHEET

The Thesis entitled "Radiological Risk Assessment for Fish and Fish Egg of Karachi Coastal Area" submitted by Ms Sahrish Saleem in partial fulfillment of MS Environmental science has been completed under my supervision and guidance. I am satisfied with the quality of student's research work and allow her t submit for further processes as per IIUI rules and regulations.

Dr. Maliha Asma

Dedicated to

My Loving Parents

Whose blissful prayers, love, encouragement and help enabled me to complete this uphill task and who are constant source of Inspiration £ strength for me.

DECLARATION

I hereby declare that the work present in the following thesis is my own effort, except where otherwise acknowledged and that the thesis is my own composition. No part of the thesis has been previously presented for any other degree.

Date __________

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Sahrish Saleem

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LIST OF ABBREVIATIONS

Acronym	Abbreviation
μ	Micro
ALARP	as low as reasonably practicable
Bq	Becquerel
CRs	Concentration Ratios
DOE	Department of Energy's
EMCLs	Environmental Media Concentration Limits
ERICA	Environmental Risk from Ionizing Contaminants: Assessment and Management
Gy	Grey
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
NCRP	National Council on Radiation Protection & Measurements
NORM	Naturally occurring radioactive material
PINSTECH	Pakistan Institute of Nuclear Science and Technology
RBE	relative biological effectiveness
RQ	Risk Quotient
SI	System International
Sv	Sievert
UF	uncertainty factor
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
US EPA	United States Environmental Protection Agency
Α	Alpha
Β	Beta
Γ	Gamma

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ABSTRACT

The assessment of radionuclide dose rate and risks to marine biota resulting from exposure to radionuclides from anthropogenic as well as from natural sources is of growing international concern. Radioactivity levels of radionuclide namely ^{137}Cs, ^{226}Ra, ^{228}Ra and ^{40}K in seawater, sediments and marine fauna (fish, mussels and crab) were used to calculate radiological risk assessment and dose rate for marine fauna in different zones of Karachi coast. Assessment was carried out by two different approaches i.e., point source distribution and Erica tool software. Dose rate is the amount of radiation absorbed per unit of time. "Point Source Dose Distribution" is a commonly used approach that is useful tool as it can be applied to combination of different radiation sources using equations given in the literature. ERICA Tool is a software system that has a structure based upon the tiered ERICA Integrated Approach that is used to assess the radiological risk to marine biota. The risk quotients were calculated using Tier 1 and Tier II levels based on media concentration and use pre-calculated environmental media concentration limits (EMCLs).

Total dose rate calculated by point source distribution was $1.81E^{-05}$mG/h, 1.36×10^{-05} mG/h, 3.47×10^{-06} mG/h. and 1.36×10^{-05}mG/h for benthic fish, pelagic fish, fish egg and shrimp respectively along South East Coast. Total dose rate for pelagic fish, benthic fish and fish eggs along North west coast was 1.24×10^{-05}mG/h, 1.34×10^{-05}, and 3.47×10^{-06} mG/h respectively. Dose rate at Manora channel to benthic and pelagic fish was1.45×10^{-05}mG/h while for fish eggs and mussels it was 3.47×10^{-06} and 9×10^{-06} mG/h respectively. Radiation dose rates to marine biota calculated by Point source distribution for zones in this study was far below than the guideline value given by U.S. Department of Energy's (DOE) indicating no deleterious effect of radioactivity for marine biota at all coasts of Karachi.

Dose rate in terms of risk quotient as calculated through Erica Tool at Tier-II at South East Coast for pelagic fish and benthic fish was 0.3371 and 0.3543 respectively. Risk quotient at North West Coast for pelagic and benthic fish was 0.2247 and 0.2348 respectively. At Manora Channel risk quotient to pelagic fish, benthic fish and crab was 0.1126, 0.1181 and 0.123 respectively. Risk Quotient revealed that there is no evidence of deleterious effect of radionuclide for marine biota at any coast of Karachi.

Radiological risk assessment calculated using point source distribution approach and ERICA Tool indicated no risk to the marine biota with present levels of radioactivity in the marine environments of Karachi Coast. The present study is focused on baseline data for radiological risks assessment and calculation of total dose to fish and other marine biota. This study will serve as a benchmark for the future radiological risk assessment for marine fauna found along Karachi coast.

INTRODUCTION

1. Background

Radioactivity is defined as particles released from nuclei as a result of nuclear instability. The nucleus experiences strong fight between the two strongest forces naturally, it should not be astonishing that many isotopes are unstable and emit some kind of energy that leads to radioactive decay. Radioactive decay is generally stated in terms of their half-lives that are related to its radiation risk. Different types of radioactivity lead to different decay paths which transform the nuclei into other chemical elements (Clark, 1989).

There are three types of radiations in the universe. These are:

i. **Alpha particles** are made up of 2 protons and 2 neutrons. These are the particles with high energy, but because of large volume they cannot deeply penetrate into the matter, and are impassable by even a single paper (Bishayee *et al.*, 2000).

ii. **Beta particles** are generally identical to electrons. These are the particles with energy less than the alpha particles but these particles can easily penetrate into the skin. Beta particles will be very hazardous when consumed (Kennish, 1996).

iii. **Gamma rays** are generally electromagnetic waves that are similar to X-rays and can go through the entire body in addition to internal organs easily. Gamma rays, though significantly less effective because alpha particles, but these are unsafe because they are invasive (Kennish, 1996).

Environmental radioactivity is a natural occurrence, it is the mixture of different nuclear activities. Differences in the stability of radionuclides determines which are plentiful and which of them are occasional in the world. Of the more than 5000 nuclides known, about 95% are radioactive; they are the Naturally Occurring Radioactive Materials (NORM) rather than the exception. Virtually all materials and environments on our planet are exposed to radioactive (Monitoring, 1998).

Naturally occurring nuclides are generally resulting from enduring of mineral deposits inside earth's crust and from cosmic rays, while manufactured radionuclides are generally introduced to the aquatic environment from a number of previous and existing anthropogenic activities related to the nuclear industry and military uses. Radioactivity occurs within the Earth's natural environment in soil, rocks, plants, water and air. Terrestrial gamma radiation from Earth is the main contributor towards the average annual gamma dose received in soft tissues by individuals (Radiation, 1988).

1.1 Radionuclides in Marine Environment

Radionuclides that enter into the marine environment comes from natural as well as man-made sources. Natural radioisotopes are also present in sediments, where radionuclides are accumulated through enduring, erosion and deposition of different geological materials (Lu & Zhang, 2008; Lu *et al.*, 2008), showing increasing concentrations when the size of grain particle decreases (He & Walling, 1996). Many anthropogenic activities can change natural marine radioactivity levels, these activities includes; oil and gas processing, coal power plants, metal scrap recycling and smelting (Landa & George, 2007; Paschoa & Steinhäusler, 2010; Rodriguez, 2008).

Radionuclides in the marine environment are classified as;

1. **Primordial nuclides** can have stable isotopes as well, most significant of these nuclides are ^{40}K and ^{87}Ru;
2. **Primordial parent nuclides** are of three naturally decaying series: ^{238}U, 235U and ^{232}Th and the short-lived daughter isotopes.
3. **Naturally occurring radionuclides** are other than the daughter products of primordial nuclides constantly made by natural nuclear progressions. These includes ^{3}H, ^{7}Be, ^{10}Be, ^{14}C, ^{26}Al, ^{32}Si, ^{32}P, ^{33}P, and ^{36}Cl.
4. **Artificial nuclides** produced by nuclear activities. These includes ^{3}H, ^{14}C, ^{60}Co, ^{90}Sr, ^{135}Cs, ^{139}I, ^{209}Pu (Kennish, 1996).

1.1.1 Major Natural Radioactive Nuclides

Seawater is naturally radioactive, mostly due to the presence of ^{40}K, but it also contains uranium and thorium and receives a constant input of tritium through the activity of extraterrestrial rays. Table 1.1 show the levels of natural radioactivity in surface seawater (Clark, 1989). ^{40}K is a β and γ-emitter having half-life of 1.3 x 10^9 years. It is present in rocks and soil, as well as muscles of animals. The richness of ^{40}K in the environment makes it a major source of both internal and external doses from naturally occurring radiation. ^{40}K in rocks, soils and building materials is also a major contributor to external background radiation (Monitoring, 1998). According to UNSCEAR (1988), about 40% of the average annual dose to humans from external radiation is due to ^{40}K in the surroundings.

Other natural sources of radiation occur from the disintegration of ^{238}U, ^{232}Th and to a smaller degree ^{235}U. Uranium is present in certain rocks, soils and phosphate deposits. Radon is made by the decay of ^{238}U and ^{232}Th. 54% of the Earth's background radioactivity is due to the two radioisotopes of radon (^{222}Rn and ^{220}Rn). The occurrence of radon is not homogeneously distributed around the globe but occurs in areas where the soil is rich in thorium. Radon, a noble gas, is a α-emitter and as such is very unreactive, therefore if inhaled it will not persist in the lungs long enough to cause any damage. It is present in certain minerals, seawater and water of numerous mineral springs and brackish lakes (MacKenzie, 2000).

Heavy radionuclides are having less solubility in water and can be adsorbed on to the particulate matter and accumulate in sediments. Fine sediments having large surface area adsorb more radionuclides than coarse sediments, thus while oceanic seawater has a radioactivity of about 12.6 Bq/L, marine sands have a radioactivity of 200 - 400 Bq/Kg and muds 700-1000 Bq/Kg. In some parts of the world marine sands produce high levels of natural radioactivity (Clark, 1989; Valkovic, 2000).

Table 1.1 Natural Levels of Radioactivity in Surface Seawater (Clark, 1989)

Radionuclide	**Concentration (Bq/l)**
Potassium-40	11.84
Tritium (H^3)	0.022-0.11
Rubidium-87	1.07
Uranium-234	0.05
Uranium-238	0.04
Carbon-14	0.007
Radium-228	(0.0037-0.37) x 10^{-2}
Lead-210	(0.037-0.25) x 10^{-2}

Uranium-235	0.18×10^{-2}
Radium-226	$(0.15\text{-}0.17) \times 10^{-2}$
Polonium-210	$(0.022\text{-}0.15) \times 10^{-2}$
Radon-222	0.07×10^{-2}
Thorium-228	$(0.007\text{-}0.11) \times 10^{-3}$
Thorium-230	$(0.022\text{-}0.05) \times 10^{-4}$
Thorium-232	$(0.004\text{-}0.29) \times 10^{-4}$

1.1.2 Anthropogenic Radioactivity and Its Sources

Before 20^{th} century, artificial radioactive sources were limited to chemical isolation and concentration of natural radionuclides. The development of linear accelerators which had that ability to produce beams of particles that could also be used to artificially transmute nuclei (Monitoring, 1998). However, the greatest change in the nuclear industry was the application of nuclear fission. By nuclear fission man produced large quantities of artificial radionuclides that were then used for both peaceful and military purposes. In most situations the most radiologically important fission products are ^{89}Sr, ^{90}Sr, ^{131}I and ^{137}Cs, although only ^{90}Sr and ^{137}Cs are important in the long term due to their yields, half-lives and chemical properties. Typical activation products include ^{51}Cr, ^{54}Mn, ^{55}Fe, ^{60}Co, ^{63}Ni,^{64}Cu, ^{65}Zn, ^{69}Zn, ^{110}Ag, ^{109}Cd, ^{134}Cs, ^{236}U and ^{239}U (Monitoring, 1998).

1.1.2.1 Nuclear warfare and testing

Nuclear weapons explosions have provided the largest inventory of radionuclide of both fission and activation products in the global environment and many of these have been, and remain, detectable world-wide (Monitoring, 1998). Nuclear devices are of two types i.e. fission and fusion. ^{235}U and ^{239}Po are the essential products of fission reactions. Fusion of light elements e.g. isotopes of hydrogen, produces small amounts of radioisotopes. Small nuclear explosions for the experiments are generally produced by fission reaction while larger explosions usually involve both fission and fusion reactions (Valkovic, 2000).

1.1.2.2 Nuclear power industry

Uses of radionuclides or their associated radiations generate some form of active waste. Main sources of waste include the nuclear fuel cycle (ore mining and uranium extraction, uranium enrichment, reactor operation and spent fuel reprocessing), reactor operation and fuel reprocessing at coastal sites. Nuclear fuel cycle is the most significant in terms of both the total activity involved and its concentration at the various stages (Woodhead, 1984). Another source of radiation pollution is the disposal of packaged radioactive wastes from a variety of sources into the deep ocean.

1.1.2.3 Nuclear accidents

In addition to discharges of radionuclides in the atmosphere as a result of various anthropogenic activities, several undesirable accidents have taken place in different parts of the world causing great concern for human and environmental health. For example Three Mile Island near Harrisburg, Pennsylvania, Chernobyle (Ukraine) and recently Fukhushima accidents (Japan) (Zakrzewski, 1991).

1.2 Radionuclides in the Biosphere

Three environmental processes are responsible for the entrance of radioactive elements into the marine biota are:

- Adsorption,
- Absorption, and
- Ingestion.

Accumulation of radioactive elements occur through the food chain. This is mainly the incident with filter feeders e.g. Mussels, that swallow debris material with a high degree of radionuclide association, and that's why mussels are internationally recognized as biological indicators of pollution due to radioactivity (Phillips, 1980) that has become now a days one of most important subject to environmental scientists as well as to the governments all around the world (Gouvea *et al.*, 1987; Phillips, 1977a, 1977b; Woodhead, 1984).

1.2.1 Accumulation from water

Radionuclides are taken from water by adsorption which means onto the cell or biota surfaces, and by absorption such as through cell membranes, gill and gut, or active transport through biota surfaces. Toxin concentrations in marine biota are in a state of equilibrium. This equilibrium is controlled by numerous factors and that's why concentration factors are observed as ranges rather than as absolute values. Concentration factor is defined as the ratio of the amount of radionuclide per unit fresh weight to the amount of radionuclide dissolved in an equal weight of seawater.

Depending on the biota, radionuclide concentration factors range from 10^0-10^6 (IAEA, 2004). Radionuclides with highest concentration factors are those that are most freely transported by the marine biota. Instead radionuclides that are less reactive and act more conventionally in seawater such as ^{137}Cs and ^{99}Tc have very low concentration factors (Fisher, 1982; Fowler et al., 1981).

Phytoplankton rapidly takes up radionuclides reaching very high concentration factors due to large surface area to volume ratio (Davies, 1979; Fisher *et al.*, 1983; Fisher & Reinfelder, 1995).

Many larger zooplankton take elements directly from seawater but also accumulate them by digestion of swallowed food (Fowler, 1982; Wang *et al.*, 1996). Direct uptake of radionuclide from seawater is done by adsorption onto the body surfaces and absorption through body surfaces (Mason & Jenkins, 1995). Uptake rates depends on the element having equilibration times from numerous hours to numerous days (Fowler, 1982; Wang & Fisher, 1998).

1.2.2 Accumulation from food

From food radionuclides are absorbed in the gut that is then transported to the several tissues by the circulatory system. Accumulation of radionuclides depends on the absorption proficiency and the amount that is retained by the tissues of body. The biologically important radionuclides are quickly absorbed from the gut and adjusted into the tissues of marine biota (Fowler, 1982; Fowler & Small, 1975). On the other hand, radionuclides of unimportant elements are often poorly assimilated and are expelled from the body through excretion (Fowler & Guary, 1977; Guary *et al.*, 1982; Pentreath, 1981; Swift, 1985). In the case of marine species, radionuclides that comes from food usually accumulate in the liver (Pentreath, 1977, 1978).

The degree to which the food pathway for radionuclide uptake dominates depend on; the span of radionuclide exposure to the marine biota, and food availability to them. As a common rule, influence of the food pathway is significant for radionuclides of radioelements with great assimilation efficiencies (Reinfelder & Fisher, 1991; Kasamatsu & Ishikawa, 1997; Pentreath, 1977; Zhao *et al.*, 2001).

1.2.3 Accumulation from sediments

Sediments are eventual marine sink for radionuclides, and these sediments act as source of radionuclides for benthic organisms (Aarkrog, 1977; Bowen *et al.*, 1975). The accumulation process can occur either by sediment or suspension feeding organisms consuming polluted sediment there in, or by uptake of the radionuclide from the seawater where it is in equilibrium with that adsorbed to sediment grains (K_d value). Depending upon the source term, subsequent radionuclide assimilation and metabolism occur by the same processes as they do following uptake from water or from food. Furthermore, epifauna and benthopelagic organisms living in close proximity to sediments can also accumulate radionuclides released from the sediments to the overlying waters (Osterberg *et al.*, 1963; Pearcy & Vanderploeg, 1972).

1.3 Effects of Radioactivity on Ecosystems

The procedures for the protection of human beings from radioactivity are well established, with a system in place to limit the effects of individuals that are based on guidelines from the International Commission on Radiological Protection (ICRP). At present, an internationally recognized approach for environmental impact assessment of ionizing radiation does not exist and up to now the approach taken has relied on recommendations from the ICRP first made in 1977, and modified in 1990 (David Copplestone *et al.*, 2001). The environment is a complex interaction of fauna and flora and the interaction of radiation with this environment may present changes in the rates and ratios of uptake and exposure of radionuclides to various organisms. Figure 1.1 represents a summary of the transfer pathways of radionuclides in marine ecosystem. Essentially radionuclides behave chemically in the same way as their non-radioactive naturally occurring isotopes, but the possibility of bioaccumulation and biomagnification in food chains has greater significance if the substance accumulated is radioactive.

Radioactivity in water is quickly diluted and translocated. Translocation takes place through bulk water movement (currents), by sedimentation of particulate matter, and in association with living organisms. The spread of activity is more complex in the sea than in fresh water, simply because there is a larger volume of seawater (Thornburn, 1972).

Complex interactions of physical, chemical and biological factors act to disperse, dilute or concentrate radioactive substances in estuarine and marine (Cetina *et al.*, 2000). Total uranium activity, uranium ratios, and distribution factors were found to vary with pH and changes in uranium activity was probably due to leaching and dilution which depends on pH and salinity (Rodriguez, 2008). As radionuclides behave the same as other chemicals in the same column of the periodic table of elements, radionuclides such as ^{45}Ca, ^{90}Sr, ^{140}Ba, ^{226}Ra and ^{45}Ca behave like calcium and ^{40}K, ^{86}Rb and ^{137}Cs behave like potassium. Consequently, ^{90}Sr accumulates largely in shells, exoskeletons or bones, and ^{137}Cs collects in the soft tissue of an organism's body (Kennish, 1996).

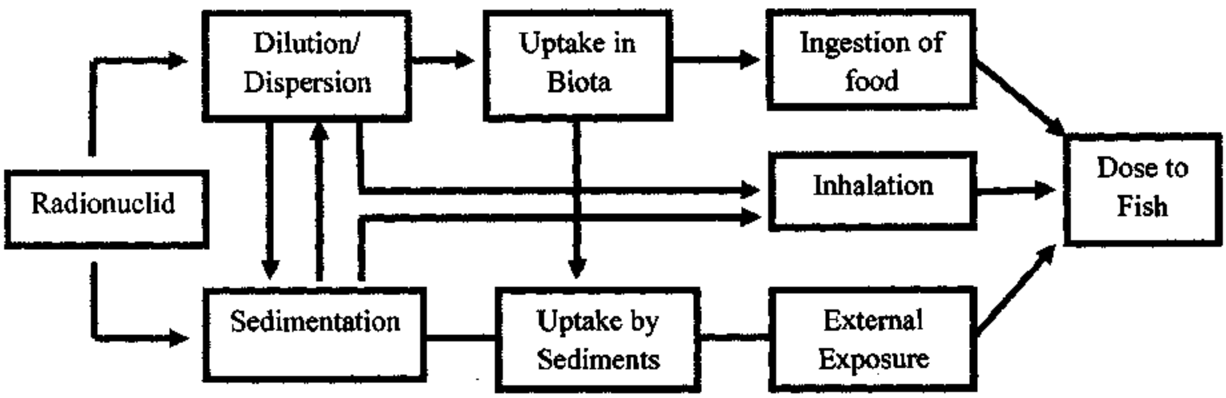

Fig 1.1 Summary of the transfer pathways of radionuclides in different ecosystem components and potential factors that may influence their distribution (Copplestone et al., 2001).

1.4 Health Impacts of Radionuclides

Because of the potential for radiation contamination in the food web to badly influence human and ecological well-being, and also the interest to understand the comparative influences of local and worldwide sources to present and upcoming radionuclide concentrations, many scientific efforts have been started to characterize radionuclides in the marine environment that includes biota, seawater and sediments (Holder *et al.*, 2003; Povinec *et al.*, 2005).

Radioactivity is related to energy that is released from radionuclides in the form of radiation. Ionizing radiation is produced as electromagnetic rays. These radiations are the cause of genetic, reproductive and cancerous effects in the living organisms. That's why, these radiations have the potential to cause bad effects on marine biota at population level and affect human health via seafood consumption. The potential for harm via radiation depends on factors that includes; the properties of radionuclides, the amount of energy absorbed by marine biota from radionuclides i.e. the dose and the pathway through which they are exposed: γ rays and β-particles can enter the skin, while α-particles cannot but are mostly hazardous if swallowed or gasped (IAEA, 2004; Thébault *et al.*, 2008).

1.5 Risk Assessment

Risk assessment is the determination of quantitative or even qualitative value of risk that is associated to a concrete situation along with recognized threat. Regarding radiation protection, risk assessment is basically about evaluating risk of radiation exposure in order to alleviate that exposure, certifying doses are as low as reasonably practicable (ALARP) and surely below dose limits. Assessment radioactivity that is released to the environment is vital for the protection of community health, particularly if the released radioactivity can enter the food chain. There are four steps in the process of risk assessment:

- Hazard identification,
- Dose-response assessment,
- Exposure assessment, and
- Risk characterization (IAEA, 2004; Thébault *et al.*, 2008).

The process of assessing risk to the marine environment includes a quantification of activity concentrations in environmental media and marine biota, using concentration ratios, CRs that are also referred to as concentration factors or bioaccumulation factors (Balonov *et al.*, 2010; IAEA, 2004; Thébault *et al.*, 2008).

1.5.1 Radiological Risk and Dose Assessment

Radiological risk assessment is an estimation of the possibility of a lethal cancer over the lifetime of an exposed individual. Radiation cancer health risks are expressed in terms of mortality (death) and morbidity (incidence). A *radiological dose assessment* calculates the amount of radiation energy that is absorbed by an exposed individual as a result of a specific exposure. *External doses* occur when the body is exposed to radioactive material outside from the body; this is mainly a concern for gamma radiation. *Internal doses* occur from exposure to radioactive material that is taken into the body by breathing or ingestion; this is a concern for alpha, beta radiation and gamma radiation. Depending on the radionuclide, the dose can be localized to specific organs, or distributed across the whole body.

Calculating the radionuclide concentration in marine biota is generally based on the steady-state approach that is used in risk assessment models (Avila *et al.*, 2010; Hedin, 2004), which assumes biogeochemical balance between the radioactivity concentration in seawater as well as in marine biota via concentration ratio. However, a number of factors must be considered in evaluating the applicability of available CRs for marine organisms: CR values for one functional group of marine organisms may be based on data for a wide range of species (IAEA, 2004; Thébault *et al.*, 2008).

Considerable research has been devoted to modeling and prediction of radionuclide transport of ^{137}Cs and ^{90}Sr in surface water (Håkanson *et al*, 2003; Margvelashvili *et al.*, 2002; Zheleznyak *et al.*, 1992) and in seawater (Heling & Bezhenar, 2009; Lepicard *et al.*, 2004), but rather less attention has been paid to predicting the behavior other important radionuclides in the marine environment.

1.5.2 Radiological assessment of ocean radioactivity

The radiological protection standards are those promulgated by International Commission on Radiological Protection (ICRP). A sophisticated system has evolved to protect man and whilst this has been sufficient in most environments to protect other species. The radiological assessment process is described using a pathway approach with simple models as examples to describe the consequences of the different marine environmental processes. Ingestion, inhalation and external dose assessments are discussed. For assessment of compliance with dose limits, the selection of an appropriate 'critical group' is a central feature, and this is based on the results of habits surveys. Collective dose is also a consideration in the ICRP methodology and this too is described. There is then a comparative assessment of sources of ocean radioactivity, looking first at doses due to natural radionuclides, then those due to artificially-enhanced natural radioactivity. Artificial sources due to weapons-test fallout, operations of the nuclear industry, ocean dumping of solid radioactive waste, dumping in the sea are all compared in terms of critical group dose and collective dose.

Though there are fluctuations near particular sources, generally the highest doses from marine sources derive from natural radionuclides, followed by those from artificially-enhanced natural radionuclides. Weapons-test fallout is the next most significant source of dose in collective terms, but being diffuse, individual doses are very low. Doses via marine pathways due to the nuclear industry, waste dumping operations and the accident have also produced low doses by comparison with natural sources.

1.5.3 Standards for Radiological Risk

a. Quantities, units and perspectives

The generally accepted system of radiological units is part of the System International (SI), in which the basic quantity of radiation exposure, 'absorbed dose', the energy absorbed per unit mass of matter, has the units gray (Gy) ($1Gy = 1J\ kg^{-1}$). The gray is a large unit, equivalent to 100 rads in the older system of units, thus submultiples mGy and pGyare in common use. In human tissue, the radiological effect of an absorbed dose is acquired by weighting the captivated dose by a quality factor Q, which depends on the relative biological effectiveness (RBE) of the type of radiation as well as other factors. The result is now termed the 'equivalent dose', for which the unit is the sievert (Sv). Again, this is a large unit (= 100 remin the older system) with submultiples mSv, pSv, etc (Radiation, 2000).

b. The basis of radiological protection criteria

The commonly accepted standards for radiological protection approved by international organizations, are based on the guidelines of the ICRP. Radiological risks have been subject to intensive study and form part of the basis for ICRP standards. Current estimates for stochastic effects, which have not changed a great deal from those used in ICRP-60, suggest a minimal cancer risk of 5×10^{-5} per mSv for all population. The ICRP suggested dose limit of 1 mSv y^{-1} for the public is reliable with a level of risk among 1 in 10^4 and 1 in 10^5 as the maximum acceptable involuntary risk for a single adherent of the population. ICRP Publication 80 (Valentin, 1998) give further guidance on radiation protection as applied to long-lived waste disposal and prolonged exposures, which are relevant to radioactivity in the oceans. The uncertainties in calculating collective doses over long time period are stressed.

1.6 Dose Assessment Methodologies

Assessment of doses to man or the environment involves consideration of the potential pathways by which radioactivity can be transmitted through the environment and lead to exposure. The contributions to exposure from each pathway will be additive, but in many cases a particular pathway (the critical pathway) will dominate (Taylor, 1979).

Assessments are often classed as 'prospective' (i.e. predictive of doses due to a proposed release scenario and often carried out for the purposes of setting authorized limits) and 'retrospective'(i.e. looking back at the effects of an existing or former scenario, often done to judge compliance with dose limits). Both types of assessment rely on appropriate models, but the retrospective assessment can make use of measured concentrations of radioactivity in the environment as a result of monitoring programmes provided these levels are detectable (Taylor, 1979).

1.6.1 Models to estimate radionuclide activity concentrations in non-human biota

The need for a system to safeguard the environment from radioactivity is generally accepted globally (Podgorsak, 2005; Valentin, 2003, 2007). A number of assessment methodologies have been established by different national and international projects including the United States Department of Energy (Energy, 2002), the England and Wales Environment Agency (Copplestone *et al.*, 2001) and European Community projects (Beresford *et al.*, 2007; Brown *et al.*, 2003; Larsson *et al.*, 2004). These approaches are nowadays used for radiological risk assessment (Copplestone *et al.*, 2005; Balonov *et al.*, 2008). So far, authentication of these approaches may be confined (Beresford *et al.*, 2007) and little effort has been made to compare the outputs of the various models. These models are described below;

1.6.1.1 ECOMOD (Russia)

ECOMOD is applied only on freshwater environments. In this approach values of Concentration Factors (CR) are taken from Russian language literature. ECOMOD also has capability to use stable chemical analogues and ratios of radionuclides to calculate the concentrations of these radionuclides in freshwater biota (Sazykina, 2000). values of CR in this approach are taken from the review of literature to calculate the activity concentrations in biota (Copplestone *et al.*, 2001). Guidance is also provided in the literature on how to calculate the CR values if they are missing for a given radionuclide (Copplestone *et al.*, 2003).

1.6.1.2 FASSET

The FASSET framework was established in the EC 5th Framework project (Beresford *et al.*, 2007; Beresford *et al.*, 2008; Brown *et al.*, 2003; Copplestone *et al.*, 2003; Copplestone *et al.*, 2005; Batlle *et al.*, 2007; Larsson *et al.*, 2004; Sazykina, 2000). Transfer of radionuclides from polluted environment is calculated using CRs taken from the literature (Avila *et al.*, 2004). absent CR values are calculated by the guidelines given by Copplestone *et al.*, 2003.

1.6.1.3 ERICA

ERICA was the project of EC 6th Framework. It provides an assimilated method for scientific, managerial and societal issues due to radioactivity having bad ecological effects (Larsson *et al.*, 2004). Significant effort was done for the collection of complete, and quality controlled CR values for a larger set of radionuclides and reference organisms. Where empirical data was not available default CR values for screening purposes were used taken from the guidance proposed by Copplestone *et al.*, 2003. Values of CR that are applied in this study are taken from the ERICA databases generated in December 2006.

1.6.1.4 LIETDOS-BIO (Lithuania)

LIETDOS-BIO model is established to address the contamination issues related to nuclear activities. Though this model uses site specific CR databases but also uses a general database when these values are missing. CR values used in this model are mostly taken from documentation in Russian language along with FASSET (Nedveckaite *et al.*, 2007).

1.6.1.5 RESRAD-BIOTA (USA)

RESRAD-BIOTA is a code that provides a tool for the execution of the approach given by US DOE and evaluates dose rates to aquatic as well as terrestrial biota (Energy, 2002). This code comprises a kinetic allometric approach (Higley *et al.*, 2003) to calculate the transmission of radioactive elements including Am, Co, Cs, Eu, I, H, Pu, Ra, Sb, Sr, Tc, Th, U, Zn and Zr from source to the biota.

1.6.1.6 DosDiMEco (Belgium)

DosDiMEco is a model that is made by SCK_CEN (Belgium). Values of concentration ratio for biota are mainly taken from literature review (Garten & Dahlman, 1978; Linsalata *et al.*, 1989; Martinez-Aguirre *et al.*, 1997; Radhakrishna *et al.*, 1996; Sample *et al.*, 1997; Santschi & Honeyman, 1989; Sweeck *et al.*, 1998).

As obvious from the descriptions above, the above mentioned approaches are not independent as some models source transmit data from more specific sources.

1.6.1.7 Point Source Dose Distribution

"Point Source Dose Distribution" (Blaylock & Trabalka, 1978; Woodhead, 1979) is truly the advantageous approach given as it will be applied to diverse radiation resources. For the nonpoint source of radioactivity, dose rate at a definite place can be attained by the integration of a suitable point source dose. Though it is possible to derive hypothetical expressions via guidelines, these type of computations are usually difficult due to the diversity of intake along with scattering phenomena that should be taken into account (Blaylock & Trabalka, 1978). Table 1.2 shows an overview of the approaches described.

Table 1.2 Summary overview showing the differences and linkages between the participating approaches

Model/ Approach	**Description of parameterisation of the transfer components of participating models**
ECOMOD	Predominantly CFs derived from Russian language
FASSET	Predominantly literature derived CF values[a]
ERICA	Predominantly literature derived CF values based on comprehensive review and building on the FASSET database; limited use of EA R&D128 values for freshwaters[a]
LIETDOS-BIO	CFs selected from Russian language literature of FASSET documentation
RESRAD-BIOTA	Allometric–kinetic model for terrestrial/riparian mammals and birds; CF values from literature for other organisms
DosDiMEco	Terrestrial mammals and birds estimated using food chain model; CF values from literature for other organisms
Point source dose distribution	literature derived CF values based on comprehensive review and CF values given by IAEA

[a]To provide a complete set of CF values, these approaches applied documented guidance to select CF values if missing for a given radionuclide organism combination (Beresford *et al.*, 2008; Brown *et al.*, 2003; Copplestone *et al.*, 2003).

1.7 Objectives

The aim of this study is to give a methodology for environmental risk assessment to marine biota that are exposed to radioactivity released into the marine environment resulting from anthropogenic activities. Specific objectives of the study are:

- To calculate radiological risk assessment for commonly found fish and fish egg in Karachi coastal area by point source distribution and Erica tool software.
- To develop a baseline of dose rate to fish commonly found in the area which will serve as a benchmark for the future radiological risk assessment.

1.8 Significance of the Study

The recent events in Fukushima and the subsequent release of radioactivity into the environment have underlined the need for a robust system that enables assessment of risks and the protection of biota from the hostile environmental effects of this harmful radioactivity. There has been an extensive international effort on a regulatory and scientific level to develop a worldwide system for the safety of marine biota from radiological risks. There is an increasing interest of international organizations for the assessment radiation doses and associated risks to the marine biota that comes from different man-made sources (Andersson *et al.*, 2008; Larsson, 2008; Valentin, 2003). Now a days different models have been developed for the risk assessment to biota from radionuclides (Beresford *et al.*, 2008; Batlle *et al.*, 2007). ERICA Tool is one of these models (Brown *et al.*, 2008), that is applied as ERICA Integrated Approach (Beresford *et al.*, 2007; Larsson, 2008) made in the 6th Framework Programme of EC. ERICA Tool calculates dose rates to biota for terrestrial, freshwater and marine ecosystems (Beresford *et al.*, 2008; Hosseini *et al.*, 2008; Ulanovsky *et al.*, 2008)

An assessment of the dose rate for the marine biota is needed to investigate whether the marine ecosystem has kept its integrity from the effect of the radiation contamination. The present study estimates the radiation dose rate of marine biota using point source distribution and Erica Tool with the measured seawater and sediment activity concentrations at Karachi Coast. The estimated dose rates are compared with the benchmark values for environmental protection from ionizing radiation.

MATERIAL & METHODS

2.1 Study Area

Broadly Karachi coast is divided into three zones namely: North West Coast, South East coast and Manora Chanel.

2.1.1 North West Coast

The North West Coast includes rocky shores with terraces, cliffs and boulders are common features between Hub River Fall and the Cap Monze, Pacha, Paradise Point up to the Buleji coasts. Cap Monze has high cliffs projecting from the Arabian Sea. Close to Cap Monze there are frequently occurring raised beaches in between the river beds and the low slopes of the adjoining hill sand dunes are frequent. There are sandy beaches conceivable between Paradise Point and Pacha coast. The shore terraces and sea cliffs are common form Buleji towards the west. There is bay (Hawks Bay) between Buleji and Manora coast with sandy beaches along Sandspit coast.

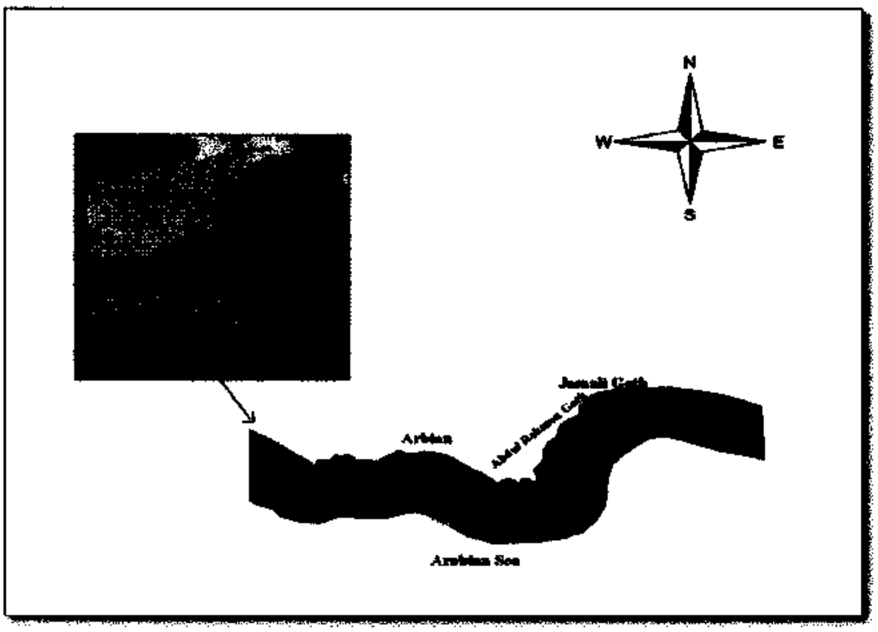

Figure 2.1 Map of North West Coast

2.1.2 South East Coast

The southeast coast is present between Clifton and Khuddi creek. The eastern coast has tidal creek with mangrove and mudflats that are connected with a system of creeks of Indus delta and that covers the most widespread and ecologically sensitive area of coast. The sea floor of the eastern and south-eastern coast is plane and even as illustrated by the bed contours. South East coast also host Korangi creek.

Korangi Creek is located at the south east coast of Karachi and portrays an atmosphere that is exposed to an anthropogenic stress. The Korangi creek area have mangroves which help as a breeding ground for many economically important marine biota. (Qureshi, 2005; Shahzad & Ahmed, 2009).

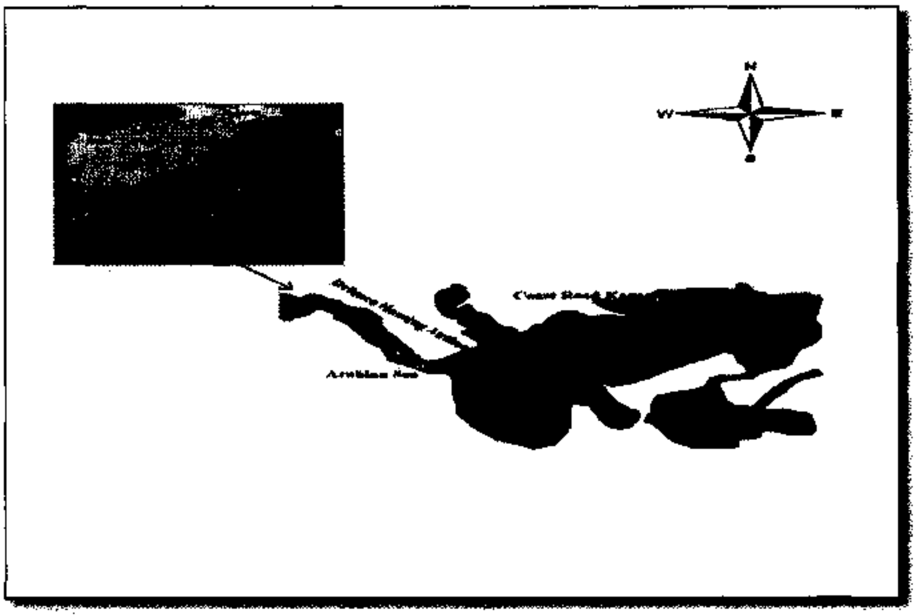

Figure 2.2 Map of South East Coast

2.1.3 Manora Channel

Manora is a small headland of $2.5km^2$ located near the Port of Karachi. Manora Channel is linked to the inland by a walkway that is called Sandspit. Manora and its adjacent islands makes a shielding blockade to the south between Karachi harbor and the Arabian Sea. The western side of the port comprises threatened mangrove forests that borders the Island of Manora.

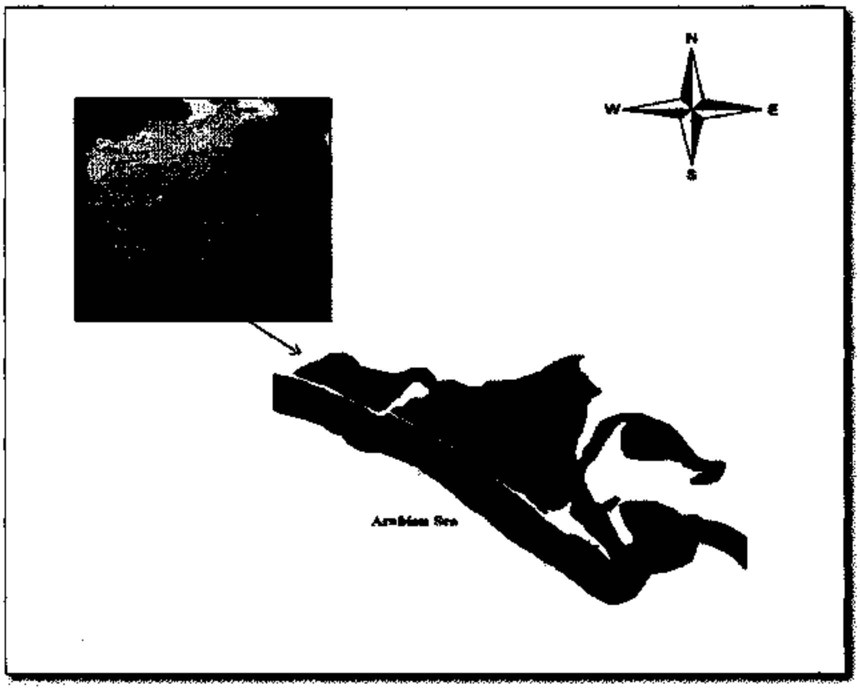

Figure 2.3 Map of Manora Channel

2.2 Methodology

The available radioactivity data from Karachi Coast was used to calculate the radiological risk assessment in marine biota through;

1. Dose Rate Calculations by Point Source Dose Distribution
2. ERICA Tool

2.2.1 Point Source Dose Distribution

Dose rate to marine biota was calculated as described by Blaylock et al 1991. Point Source Dose Distribution is applied to diverse radiation resources. For the nonpoint cause of ionizing radiation, dose rate at a certain place can be obtained by the integration of a suitable point source dose over the source geometry. Although it is possible to derive theoretical expressions from via guidelines, these type of computations are usually difficult due to the multiplicity of intake along with scattering phenomena which should be considered. For simple computation, simple empirical expressions are given for establishing doses to marine biota (Blaylock & Trabalka, 1978; Woodhead, 1979).

In the present investigation dose rate due to gamma radiating radionuclide namely: ^{40}K, ^{226}Ra, ^{228}Ra and ^{137}Cs is studied. A brief description of calculation is explained below:

For large organisms having magnitudes larger than a few cm, energy captivation and scattering becomes important; so, a factor should be applied for the interpretation of these processes. Monte Carlo calculations are made to include absorption and scattering for a number of geometries, and these calculations can be adapted for marine organisms (Brownell *et al.*, 1968; Ellett & Humes, 1971). The results that comes from these calculations are given in terms of the absorbed fraction that is defined as:

$$\Phi - \frac{\text{photon energy absorbed by target}}{\text{photon energy emitted by source}}$$

Absorbed fractions (Φ) that are derived for the biota as a function of γ-ray energies (ICRP, 1991) given in the figure 2.4.

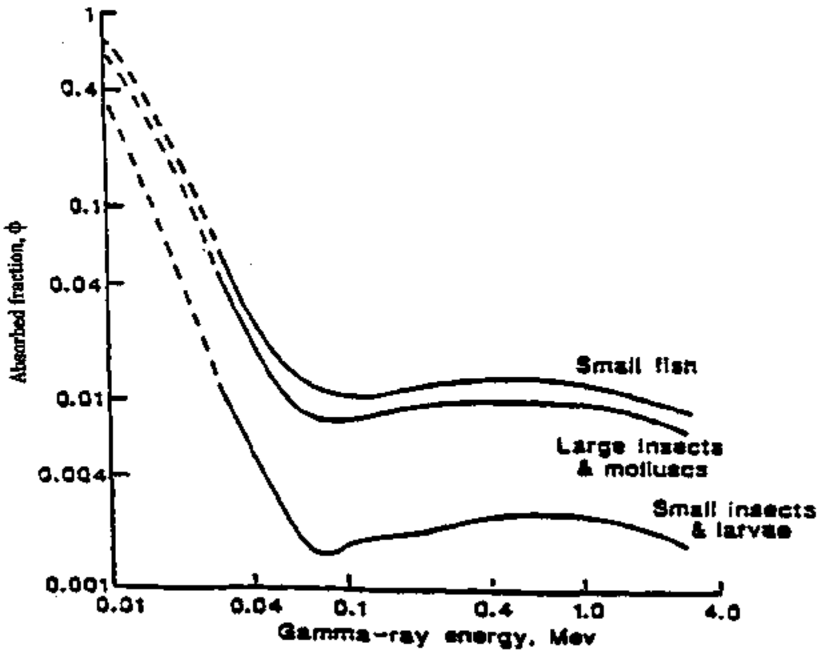

Figure 2.4 Derived absorbed fractions as a function of γ-ray energies

Table 2.1 contains the average energy per transformation for a selected group of gamma emitters. These values were taken from ICRP Report 38 (1983) and can be used in place of E_γ and n_γ in the preceding equations to calculate the total (-radiation dose rate in one step.

Table 2.1 Average Energies of Radionuclides (Blaylock *et al.*, 1993)

Radionuclides	Biological Concentration Factor*	Radiological Half-life	Average Gamma Energy (MeV)
Plutonium-239	30	$2.41E^{04}$ y	$7.96E^{-06}$
Plutonium-240	30	$5.54E^{04}$ y	$1.73E^{-03}$
Thorium Series			
Thorium-232	100	$1.41E^{10}$ y	$1.33E^{-03}$
Radium-228	50	5.75 y	$4.14E^{-09}$
Actinium-228	--	6.13 h	$9.30E^{-01}$
Thorium-228	100	$1.91E^{03}$	$3.30E^{-03}$
Radium-224	50	3.64 d	--
Radon-220	--	55 s	$3.85E^{-04}$
Polonium-226	50	0.15 s	$1.69E^{-05}$
Lead-212	300	10.64 h	$1.48E^{-01}$
Bismuth-212	10	60.6 m	$1.85E^{-01}$
Polonium-212 (64% yield)	50	306 μs	--
Neptunium Series			
Americium-241	30	458 y	$3.24E^{-02}$
Neptunium-237	30	$2.14E^{06}$ y	$3.43E^{-02}$
Prolactinium-233	10	27 d	$2.03E^{-01}$
Uranium-233	10	$1.59E^{05}$ y	$1.31E^{-03}$
Thorium-229	100	$7.34E^{03}$y	$9.54E^{-02}$
Radium-225	50	14.8 d	$1.37E^{-02}$
Actinium-225	--	10 d	$1.79E^{-02}$
Francium-221	--	4.8 m	$3.10E^{-02}$
Aslatlne-217	--	0.032 s	$3.08E^{-04}$
Bismuth-213	10	47 m	$1.33E^{-01}$
Polonium-213	50	4.2 μs	--
Lead-209	300	3.3 h	--
Uranium Series			
Uranium-238	10	$4.51E^{09}$ y	$1.36\ E^{-03}$
Thorium-234	100	24.1 d	$9.34\ E^{-03}$
Protactinium-234	10	1.17 m	$1.13E^{-02}$
Uranium-234	10	$2.47E^{05}$ y	$1.73E^{-03}$
Thorium-230	100	$7.7E^{04}$ y	$1.55E^{-03}$
Radium-226	50	$1.26E^{03}$ y	$6.47E^{-03}$
Radon-222	--	3.823 d	$3.98E^{-04}$
Polonium-218	50	3.05 m	$9.12E^{-06}$
Lead-214	300	26.8 m	$2.48E^{-01}$
Astatine-218 (.02% yield)	--	2 s	$6.72E^{-03}$
Bismuth-214	10	19.7 m	$1.46E^{+00}$
Polonium-214	50	167 μs	$8.33E^{-05}$
Lead-210	300	22.3 y	$4.81E^{-03}$
Bismuth-210	10	5.01 d	--

Radionuclides	Biological Concentration Factor*	Radiological Half-life	Average Gamma Energy (MeV)
Polonium-210	50	138.4 d	$8.50E^{-06}$
Actinium series			
Uranium-235	10	$7.04E^{+08}$ y	$1.54E^{-01}$
Thorium-231	100	25.5 h	$2.55E^{-02}$
Protactinium-231	10	$3.28E^{+04}$ y	$4.76E^{-02}$
Actinium-227	--	21.77 y	$2.31 E^{-04}$
Thorium-227	100	18.7 d	$1.06E^{-01}$
Radium-223	50	11.43 d	$1.33E^{-01}$
Radon-219	--	4.0 s	$5.58E^{-02}$
Polonium-215	50	1.78 ms	$1.76E^{-04}$
Lead-211	300	36.1 m	$5.03E^{-02}$
Bismuth-211	10	2.15 m	--
Thallium-207	10000	4.79 m	$2.21E^{-03}$

The γ radiation dose rate from internal contamination is expressed as:

$$D_{\gamma} = 5.76 \times 10^{-4} E_{\gamma} n_{\gamma} M\, C_{o}\ \mu Gy\, h^{-1} (1)$$

Where

E_{γ} is the photon energy radiated during transition from higher to a lower energy state (MeV)

n_{γ} is the proportion of disintegrations producing a γ ray

Φ is the absorbed fraction of energy (MeV)

C_{o} is the concentration of the radionuclide in the organism (Bq kg^{-1}wet weight).

If a γ emitter produces photons of different energy levels, then the doses from all major γ emissions are included in the dose rate calculations.

It follows that the γ radiation dose rate to the organism from radionuclides present in water away from the sediment is:

$$D_{\gamma} = 5.76 \times 10\ E_{\gamma} n_{\gamma} (1-\Phi)\, C_{w}\ \mu Gy\, h^{-1} (2)$$

Where

C_{w} is the concentration of the radionuclide in water (Bq L^{-1})

The γ radiation dose rate to marine organisms at the sediment-water line from homogeneously contaminated sediment is:

$$D_\gamma = 2.88 \times 10\ E_\gamma n_\gamma (1\text{-}\Phi)\ C_s R\ \mu Gy\ h^{-1}\ (3)$$

Where

C_s Is the concentration of the radionuclide in sediment (Bq kg^{-1} wet weight). (0.75 is used for converting sediment from dry weight to wet weight).

R fraction of time that marine organism spends at the sediment and water interface.

Decay of the radionuclides and the variability in the rate of radionuclide due to the deposition of sediments, sediment hardly shows a uniform source of gamma radiation. Consequently, equation 3 overvalue the dose of radionuclide to marine biota at the sediment-surface water interface in maximum cases. In situations where complete details are not accessible, 0.5 times the D_γ in equation 3 is used to calculate the dispersal of radionuclides in the sediment (Blaylock & Trabalka, 1978; Woodhead, 1984).

Average energy per modification for a respective gamma emitting radioisotopes is shown in Table 2.1. The standards are occupied from ICRP Report 38 (1983).

2.2.1.1 Dose rate calculation for fish eggs

Dose rate calculation to fish eggs for respective radionuclides in the sea water is very tough process and it depends on different factors including:

(i) accumulation of radionuclide

(ii) uniform distribution of radionuclides,

(iii) diameter of egg,

(iv) Location of developing embryo (eggs float, sink to the bottom).

Mathematical models are also used to calculate the dose rate to fish eggs (Adams & McCord, 1969; Blaylock & Trabalka, 1978; Ellett & Humes, 1971; Vennart, 1979; Woodhead, 1970). Fish eggs are very small in size they are no greater than a centimeter in the diameter; so dose rate from internal radiation emitters is negligible (Blaylock & Trabalka, 1978; Ellett & Humes, 1971; Vennart, 1979). Equation for Dose rate calculations to an egg from radionuclides is;

$$D_\gamma = 5.76 \times 10^{-4} E_\gamma n_\gamma (1-\phi) C_o \qquad \mu Gy\ h^{-1}$$

Where

C = concentration of the radionuclide in water (Bq/l)

And

$$D_\gamma = 2.88 \times 10^{-4} E_\gamma n_\gamma (1-\phi) Cs\, R \qquad \mu Gy\ h^{-1}$$

Where

Cs = the concentration of the radionuclide in sediment (Bq kg^{-1} wet weight).

R = fraction of time that the organism spends at the sediment-water interface.

The average energy per transformation for a selected radionuclide is taken from the table 2.1.

2.3 Risk Assessment through ERICA Tool

ERICA Tool is a software based on the tiered approach to measure the radiological risk to terrestrial, freshwater and marine biota. Tool has simple models embedded to allow conventional estimations activity concentrations of media from the data. ERICA tool can be understood through ERICA assessment tool flowchart (Fig 2.5).

2.3.1 Application of the ERICA Assessment Tool

Version 1.0 of ERICA Assessment Tool launched in February 2013 was used for the calculation of dose rates from radionuclides to marine biota. This Tool has tiered approach that allows measured activity concentrations in biota as an input at all Tiers 1,2 and 3 (Brown *et al.*, 2008). The radiological risk assessment in this study was carried out at Tier 2. Estimated values of activity concentrations in marine biota, seawater and sediments were used as input, as suggested by Brown *et al.*, (2008). Default reference organisms that were used in this study for the calculations are given in Table 2.4.

ERICA Tool contains a parameter that is called occupancy factor defines which is defined as the fraction of time an organism spends at a given location. For marine biota, these locations are water surface, seawater, sediment surface and sediment (Oughton *et al.*, 2008).

Calculation of dose conversion coefficients that are used in the Erica Tool is explained by Ulanovsky *et al.*, 2008. Default factors for radiation weighting are 10, 3 and 1 were used in the tool for gamma radiation (Oughton *et al.*, 2008). Results are given as total, internal and external dose rates at Tier 2 (Brown *et al.*, 2008). total dose rates are then compared to the screening dose rate to allow radiological risk assessment to biota (Brown *et al.*, 2008). Screening dose rate of 10 $mGyh^{-1}$ was used in the software as recommended by Andersson *et al.* (2008), Beresford *et al.*, (2007a) and Garnier-Laplace *et al.*, (2008).

2.3.2 Assessment at Different Tiers

Erica Tool offers a tiered approach that allows the input of measured activity concentrations in marine biota and the respective media at a specific location at Tiers 1, 2 and 3. Following section provide details of assessment at different tiers.

Tier 1 Assessments

Tier 1 assessment is a simple and conservative and needs a minimum input data. The default screening criterion at tier 1 is $10\mu Gy\ h^{-1}$ for all ecosystems and organisms. The predefined screening dose rate is calculated to yield EMCLs for all reference organism. The Tool compares the input media concentrations with the most limiting EMCL for each radionuclide and determines a RQ. If the RQ is less than one, then the tool suggests to exit the assessment process. If the RQ is greater than one, then it is advised to continue with the assessment.

Tier 1 is relatively simple, so that it can be easily used; it requires minimum input and is highly conventional. It is expected that many assessments will be screened out (that is, judged to be of negligible concern with a high degree of confidence) using this tier.

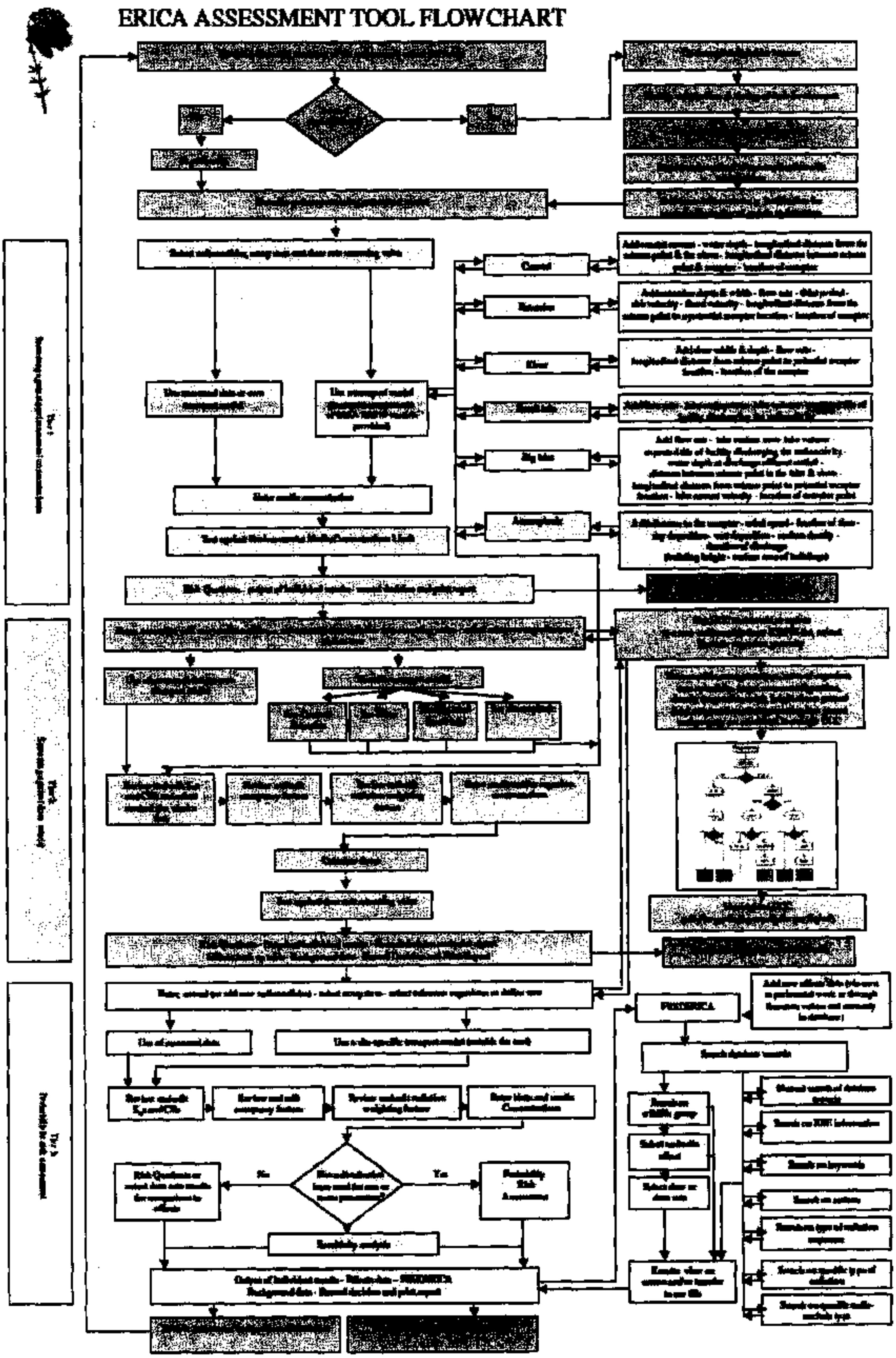

Fig. 2.5 ERICA Assessment Tool Flow Chart

Table 2.2 Reference organisms used in the model calculations

Sample	Reference organism selected in the ERICA Tool
Cat fish - Arius halassinus	Benthic Fish
Eel - Muraenesox Spp.	Benthic Fish
Croaker - Nibea Spp.	Benthic Fish
Sand tiger shark - Carcharhinustaurus.	Benthic Fish
Malabar Grouper – Eqinephelusmalabaricus	Benthic Fish
Eel - Muraenesox Spp.	Benthic Fish
Blackspotted Croaker - Protonibeadiacanthus	Benthic Fish
Emperor Red Snapper - Lutjanus Spp.	Benthic Fish
Spangled Emperor - Lethrinus Spp.	Benthic Fish
Black Pomfret – Parastromateusniger	Benthic Fish
Ribbon fish - Trichurus Spp.	Pelagic Fish
Sole – CynoghlossesSpp	Pelagic Fish
Silvery Grunter - P. argyreus	Pelagic Fish
Queen fish - Scomberoides Spp.	Pelagic Fish
Black sea bream -Spondyliosomacantharus	Pelagic Fish
Silver Pomfret – Pampusargenteus	Pelagic Fish
Indian Mackerel - Rastreligerkanagruta	Pelagic Fish
Salmon – Eleutheronematetradactylum	Pelagic Fish
Silvery Grunter - P. argyreus	Pelagic Fish
Spotted Mackerel –Scomberomorusguttatus	Pelagic Fish
MatutaPalanipes	Crustacean
Acrocalanus spp.	Zooplankton
Paracalanus spp.	Zooplankton

The risk quotient (RQ) offers a simple means of assessing risk. Within the ERICA Integrated Approach, the risk quotient assimilates contact and effects data to determine radiological risk by calculating the quotient of estimated exposure and benchmark dose rate. The benchmark dose rate is the dose rate which is assumed to be environmentally 'safe'. The RQ is defined as:

$$RQ = \frac{\textit{predicted environmental dose rate}}{\textit{benchmark dose rate assumed to be environmentally ' safe'}} \quad (5.1)$$

ERICA has a screening incremental dose rate of 10 μGy h^{-1} for chronic exposure to human activities that use radioactive substances and increase the levels of ionising radiation in the environment.

The ERICA Tool uses conservative EMCL values, set at five per cent. An example of the probabilistic derivation of an F value is provided in Fig 2.6.

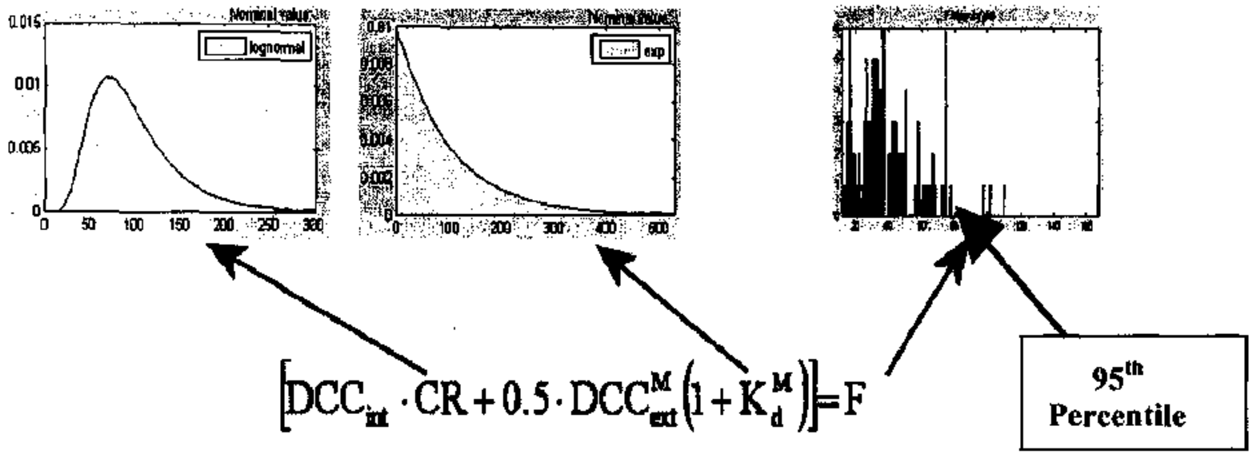

Fig 2.6 Example of the use of probabilistic calculations in the derivation of EMCLs. The equation shown here is for benthic organisms living at the water-sediment interface

In addition to having EMCL values calculated for the ERICA screening dose rate, the ERICA Tool allows the user to select two alternatives:

- Values of 40 μGy h^{-1} for terrestrial animals and 400 μGy h^{-1} for terrestrial plants and all aquatic species (Cao *et al.*, 2002; Radiation, 1996; DoE, 2002).

- User-defined value that allows the user to set in any number which they consider justifiable, then the resultant RQ values are derived by scaling those for the ERICA screening dose rate of 10 μGy h^{-1} by the difference between the user input dose rate and the ERICA screening dose rate; for example, if the user defines a screening dose rate of 20 μGy h^{-1}, the tool simply divides the RQs by a factor of two.

a. Screening at Tier 1

At Tier 1, the assessor is prompted to enter the measured or modeled radionuclide activity concentrations for their site. The activity concentrations entered should be either the maximum values available or other justifiable values (for example, at the edge of the mixing zone rather than the end of a discharge pipe).

The ERICA Tool compares the measured radionuclide activity concentrations with the EMCLs for the most limiting reference organism by calculating risk quotients for the respective radionuclide by the given equation. The ECMLs are then summed to provide an overall RQ for the ecosystem being assessed.

$$RQ = \frac{M}{EMCL}$$

Where

RQ	Risk Quotient for a respective radionuclide
M	Estimated or measured activity concentration for respective radionuclide in Bq l^{-1} for water, Bq kg^{-1} dry weight for sediment or Bq m^{-3}.
EMCL	Environmental media concentration limit for respective radionuclide for the most limiting reference organism

As the ERICA Tool only comprises the EMCL value for the limiting reference organism, the sum of risk quotients may be derived from different reference organisms. This will result in the overall RQ being in excess of the total RQ for any one species.

b. Interpreting the Tier 1 RQ value

The outputs of a Tier 1 assessment are the RQ values for the limiting reference organism and the sum of the individual radionuclide RQs. These enable the user to decide whether to conclude the assessment or conduct a more detailed one, as follows:

- ***If the sum of the RQs is less than one*** there is a very less possibility that the absorbed radiation dose rate to any organism surpasses the screening dose rate, and the situation may be considered to be of negligible radiological concern. ERICA Tool will suggest the user to conclude the assessment.
- ***If the sum of the RQs is greater than one*** the assessment dose rate to one or more organisms may exceed the screening dose rate, and there is

insufficient evidence to conclude that the situation is of negligible radiological concern. The ERICA Tool will suggest the user to continue the assessment using Tier 2 within the software.

Tier 2 assessments

Tier 2 of the ERICA Tool is a screening tier that allows an informed assessment and does not need to be as conventional in its approach as Tier 1 of the software. The objective of Tier 2 is to recognize situations where there is a very less possibility, for example a few percent, that the dose to the respective organism surpasses the assumed screening dose rate. Within this tier the user can:

- find risk quotient values for the respective organism within the assessment (compared to the combined ecosystem worst case RQ output in Tier 1);
- define their own organism to represent species of interest;
- add additional radionuclides;
- provide their own CR and K_d values;
- Put their results into context with effects data and typical background exposure rates.

In Tier 2, the screening dose rate is compared to the total projected entire body absorbed dose rate for each distinct organism:

$$RQ = \frac{\textit{Whole body absorbed dose rate}}{\textit{Screening dose rate}}$$

As the objective of Tier 2 is to recognize situations where there is very less possibility that the dose to the respective organism exceeds the assumed screening dose rate, the screening test is applied as follows:

- A predictable value of the risk quotient is calculated using values for the input data and the parameters;
- The 95^{th} or 99^{th} percentile of the risk quotient is projected by multiplying the anticipated value of the risk quotient by the uncertainty factor of 3 or 5 respectively. Uncertainty factor is well-defined as the ratio between the

95^{th} or 99^{th} percentile and the estimated value of the probability distribution of the dose rate.

a. Interpreting the Tier 2 Risk Quotient

As described above, two RQs are reported in Tier 2 for every organism selected in the assessment: the best estimate RQ and the conservative RQ. These are used in combination with other information given within the Tier 2 assessment, these allow the evaluator to make a decision on whether to close or continue the assessment:

- ***If the conservative RQs are below one*** for all organisms, then the assessment has not exceeded the screening level at Tier 2. If a UF of three or five (or higher) is used, there is less possibility that estimated dose rate to marine biota surpasses the screening dose rate, but the resulting risk to non-human biota is insignificant.
- ***If the conservative risk quotient is above one*** for any organism, then the probability of the assessment exceeding the screening value at Tier 2 is above that selected (as defined by the UF).
- ***If the expected value RQ (and by implication the conservative RQ) is above one*** for any organism, then the assessment has exceeded the screening value at Tier 2 and the ERICA Tool will recommended that further assessment be conducted.

In such cases in which it is suggested that the assessment should be continued, that does not mean an automatic movement to Tier 3.

RESULTS & DISCUSSION

Dose rate to fish egg due to ^{40}K, ^{226}Ra, ^{228}Ra and ^{137}Cs comes out to be 3.3 x 10^{-06}, 1.42 x 10^{-07}, 2.92 x 10^{-08} and 3.33 x 10^{-15} mG/h respectively (Table 3.2). Total dose rate to fish eggs, which is sum of individual radionuclide dose rate, is 3.47 x 10^{-06}mG/h. U.S. Department of Energy's has given the standard for dose rates of radionuclides from different sources, that suggests total dose rate of 0.4 mGy h^{-1} to marine biota, which are also recommended by NCRP report of 1991. Dose rate to fish eggs in this study is far below than the recommended value which shows that there is no evidence of deleterious effect of radioactivity for fish eggs.

Table 3.2 Total dose rate for fish eggs of Karachi Coast

Radio-Nuclide	External Dose Rate from Water (μG/h)	External Dose Rate from Sediment (μG/h)	Total Dose (μG/h)	Total Dose mG/h
K-40	0.00039	0.002982	0.003302	3.3 x 10^{-06}
Ra-226	9.07 x 10^{-06}	0.000133	0.000142	1.42 x 10^{-07}
Ra-228	2.47 x 10^{-06}	2.68 x 10^{-05}	2.92 x 10^{-05}	2.92 x 10^{-08}
Cs-137	2.92 x 10^{-13}	3.03 x 10^{-12}	3.33 x 10^{-12}	3.33 x 10^{-15}
Total Dose Rate				**3.47 x 10^{-06}**

3.1.2 Dose Rate Calculations for Fish of South East Coast

1. **Silver Pomfret - Pampusargenteus**

Silver pomfret (*Pampusargenteus*) is a benthopelagic fish species (Jing *et al.*, 2002). They have eggs that are pelagic and the breeding grounds of these fish are always located in coastal waters (Zhao *et al.*, 2010). It is commercially important fish species that is extensively dispersed along the coast of the Indo-West Pacific, Indian Ocean, Arabian Gulf, and North Sea (Davis and Wheeler, 1985; Azad *et al.*, 2007; Peng *et al.*, 2009), and wherever it exists, silver pomfret is a significant fisheries resource (Pati, 1983).

Dose rates to *Pampusargenteus* are given in Table 3.3. Dose rate to *Pampusargenteus* due to ^{40}K, ^{226}Ra, ^{228}Ra and ^{137}Cs is 1.7x 10^{-05}, 5.4 x 10^{-07}, 1.4 x $10^{-14}$and 1.2 x 10^{-07} mG/h respectively. Total dose rate to this fish is 1.81x 10^{-05} mG/h. Dose rate to *Pampusargenteus* in this study is below than the recommended value that shows no evidence of poisonous effect of radioactivity for this fish.

2. Sand Tiger Shark - Carcharhinus spp.

The sand tiger shark (*Carcharhinus Spp.*) is a coastal shark inhabiting waters (Compagno, 2001). They are often found near bottom (benthic fish), but have been found throughout the water column (Goldman *et al.*, 2006).Sand tiger sharks are migratory within its region. They have been fished throughout their range (Musick *et al.*, 1993, Castro *et al.*, 1999).

Dose rate to Carcharhinus Spp. due to ^{40}K, ^{226}Ra, ^{228}Ra and ^{137}Cs is 1.7 x 10^{-05}, 5.4 x 10^{-07}, 1.4 x 10^{-14} and 1.2 x 10^{-07}mG/h respectively (Table 3.3).Total dose rate to this fish is 1.81 x 10^{-05} mG/h. Dose rates to Carcharias spp. are given in Total dose rate to the respective specie is far below than the guideline value which shows no indication of harmful effect of radioactivity for this Carcharhinus spp.

3. Grouper –*Epinephelus morio*

The grouper (*Epinephelus morio*) is a species of family Serranidae. Its ordinary environments are open seas, shallow seas, sub tidal aquatic beds, coral reefs, coastal saline lagoons, and coastal freshwater lagoons.

Dose rate to due to Epinephelus morio ^{40}K, ^{226}Ra, ^{228}Ra and ^{137}Cs is 1.7 x 10^{-05}, 5.4 x 10^{-07}, 1.4 x 10^{-14} and 1.2 x 10^{-07} mG/h respectively. Total dose rate to this fish is 1.81 x 10^{-05} mG/h (Table 3.3). Total dose rate to this specie is also found below than the suggested value indicating no harmful effects of radioactivity for *Epinephelus morio*.

4. Indian Mackerel – Rastreliger kanagurta

Indian mackerel (*Rastrelliger kanagurta*) is a species of scombrid family (family Scombridae). It is a pelagic fish that is found in shallow, coastal waters. These are usually found in the Arabian Sea, Indian, West Pacific oceans, and their surrounding seas. It is one of the major marine fishery resources of Pakistan (Yohannan and Nair, 2002). Indian mackerel is a migratory species (Venkataraman 1970).

Dose rate to due to Rastrelliger kanagurta ^{40}K, ^{226}Ra, ^{228}Ra and ^{137}Cs is 1.3 x 10^{-05}, 5.4 x 10^{-07}, 1.6 x 10^{-14} and 1.2 x 10^{-07}mG/h respectively as presented in Table 3.4. Total dose rate to this fish is 1.36 x 10^{-05}mG/h which is less than US EPA guideline value which shows no damaging effects of radioactivity this fish.

Table 3.3 Total dose rate for *Pampusargenteus, Carcharhinus Spp. and Epinephelus morio.*

Radio-nuclide	Internal Dose Rate (μG/h)	External Dose Rate from Water (μG/h)	External Dose Rate from Sediment (μG/h)	Total Dose (μG/h)	Total Dose mG/h
Pampusargenteus					
K-40	0.0001	0.0015	0.0158	0.0174	1.7×10^{-05}
Ra-226	9.04×10^{-06}	3.8×10^{-05}	0.0005	0.0005	5.4×10^{-07}
Ra-228	1.1×10^{-13}	1.2×10^{-12}	1.2×10^{-11}	1.4×10^{-11}	1.4×10^{-14}
Cs-137	2.9×10^{-07}	1×10^{-05}	0.00011	0.00012	1.2×10^{-07}
Total Dose Rate					**1.81×10^{-05}**
Carcharhinus Spp.					
K-40	8.48 x 10-05	0.0015	0.0158	0.0174	1.7×10^{-05}
Ra-226	9.04×10^{-06}	3.8×10^{-05}	0.0005	0.0005	5.4×10^{-07}
Ra-228	1.1×10^{-13}	1.2×10^{-12}	1.2×10^{-11}	1.4×10^{-11}	1.4×10^{-14}
Cs-137	2.9×10^{-07}	1×10^{-05}	0.00011	0.00012	1.2×10^{-07}
Total Gamma Dose Rate					**1.81×10^{-05}**
Epinephelus morio					
K-40	0.0001	0.0015	0.0158	0.0174	1.7×10^{-05}
Ra-226	9.04×10^{-06}	3.8×10^{-05}	0.0005	0.0005	5.4×10^{-07}
Ra-228	1.1×10^{-13}	1.2×10^{-12}	1.2×10^{-11}	1.4×10^{-11}	1.4×10^{-14}
Cs-137	2.9×10^{-07}	1×10^{-05}	0.00011	0.00012	1.2×10^{-07}
Total Gamma Dose Rate					**1.81×10^{-05}**

5. Salmon – Eleutheronema tetradactylum

Salmon *(Eleutheronema tetradactylum)* is of family Salmonidae. Numerous species of Salmon exhibit anadromous life strategies that born in fresh water and spends most of its life in the sea and then go back to fresh water to spawn, while many others exhibit freshwater resident life strategies. This is highly commercial fish known that is used in aquaculture present over shallow muddy bottoms in coastal waters.

Dose rate to *Eleutheronema tetradactylum* due to ^{40}K, ^{226}Ra, ^{228}Ra and ^{137}Cs is given in table 3.4 and comes out to be 1.3×10^{-05}, 5.4×10^{-07}, 1.6×10^{-14} and 1.2×10^{-07} mG/h respectively. Sum of dose rate to this fish is 1.36×10^{-05} mG/h. Total dose rate to the respective specie is below than the guideline value which shows no sign of injurious effect of radioactivity for this fish.

6. Cat fish - *Arius halassinus*

Catfish (*Arius halassinus)* are benthic fish species that are found in marine freshwater habitats and coastal regions around every continent in the world. Cat fish are easily recognized by their flattened broad heads and the long whisker-like barbels. Catfish can usually be found in fast flowing rivers and streams, some catfish species have adapted to living in shallow salt-water environments while other catfish species live their lives in caves underground in the water.

Dose rate to *Arius halassinus* due to ^{40}K, ^{226}Ra, ^{228}Ra and ^{137}Cs is 1.3 x 10^{-05}, 5.4 x 10^{-07}, 1.6 x 10^{-14} and 1.2 x 10^{-07}mG/h respectively as given in Table 3.4. Total dose rate to this fish is 1.36 x 10^{-05}mG/h. Total dose rate to this fish species does not pose any deteriorating effects of radioactivity for Arius halassinus in southeast coast.

Table 3.4 Total dose rate for *Rastreliger kanagurta, Eleutheronema tetradactylum and Arius halassinus*

Radio-nuclide	Internal Dose Rate (μG/h)	External Dose Rate from Water (μG/h)	External Dose Rate from Sediment (μG/h)	Total Dose (μG/h)	Total Dose mG/h
Rastreliger kanagurta					
K-40	9.93 x 10^{-05}	0.0015	0.0113	0.0129	1.3 x 10^{-05}
Ra-226	9.04 x 10^{-06}	3.8 x 10^{-05}	0.0006	0.0006	5.4 x 10^{-07}
Ra-228	1.11 x 10^{-13}	1.2 x 10^{-12}	1.4 x 10^{-11}	1.6 x 10^{-11}	1.6 x 10^{-14}
Cs-137	2.9 x 10^{-07}	1 x 10^{-05}	0.0001	0.0001	1.2 x 10^{-07}
Total Gamma Dose Rate					**1.36 x 10^{-05}**
Eleutheronema tetradactylum					
K-40	7.20 x 10^{-05}	0.0015	0.0114	0.0129	1.3 x 10^{-05}
Ra-226	9.04 x 10^{-06}	3.8 x 10^{-05}	0.0006	0.0006	5.4 x 10^{-07}
Ra-228	1.11 x 10^{-13}	1.2 x 10^{-12}	1.4 x 10^{-11}	1.6 x 10^{-11}	1.6 x 10^{-14}
Cs-137	2.9 x 10^{-07}	1 x 10^{-05}	0.0001	0.0001	1.2 x 10^{-07}
Total Gamma Dose Rate					**1.36 x 10^{-05}**
Arius halassinus					
K-40	0.0001	0.0015	0.0114	0.0129	1.3 x 10^{-05}
Ra-226	9.04 x 10^{-06}	3.8 x 10^{-05}	0.0006	0.0006	5.4 x 10^{-07}
Ra-228	1.11 x 10^{-13}	1.2 x 10^{-12}	1.4 x 10^{-11}	1.6 x 10^{-11}	1.6 x 10^{-14}
Cs-137	2.9 x 10^{-07}	1 x 10^{-05}	0.0001	0.0001	1.2 x 10^{-07}
Total Gamma Dose Rate					**1.36 x 10^{-05}**

7. Shrimp (*Metapeniaus affinis*) at South East Coast

Shrimp (*Metapenaeus affinis)* is an Indo-West Pacific species (Holthuis, 1980).These are Benthic, living on a large variety of bottoms such as rock, mud, sand, etc. In this genus spawning takes place offshore, at depths between 10 and 80 m. This family is one of the commercially important species of shrimps in Pakistan, as well as worldwide.

Dose rate to due to *Metapenaeus affinis* ^{40}K, ^{226}Ra, ^{228}Ra and ^{137}Cs is 1.3 x 10^{-05}, 5.4 x 10^{-07}, 1.6 x 10^{-14} and 1.2 x 10^{-07}mG/h respectively. Total dose rate to the shrimp is 1.36 x 10^{-05} mG/h as presented in Table 3.5. Total dose rate to the shrimp is below than the given US EPA guideline value which shows no sign of deteriorating effects of radioactivity for the shrimp at South East Coast.

Table 3.5 Total dose rate for *Metapeniaus affinis*

Radio-Nuclide	Internal Dose Rate (μG/h)	External Dose Rate from Water (μG/h)	External Dose Rate from Sediment (μG/h)	Total Dose (μG/h)	Total Dose mG/h
K-40	7.20 x 10^{-05}	0.00146	0.01135	0.0129	1.3 x 10^{-05}
Ra-226	9.04 x 10^{-06}	3.8 x 10^{-05}	0.00055	0.0006	5.4 x 10^{-07}
Ra-228	1.11 x 10^{-13}	1.2 x 10^{-12}	1.4 x 10^{-11}	1.6 x 10^{-11}	1.6 x 10^{-14}
Cs-137	2.9 x 10^{-07}	1 x 10^{-05}	0.0001	0.0001	1.2 x 10^{-07}
Total Gamma Dose Rate					**1.36 x 10^{-05}**

Comparison of total dose due to radionuclides to different fish spp.and shrimp of south east coast is shown in figure 3.1.

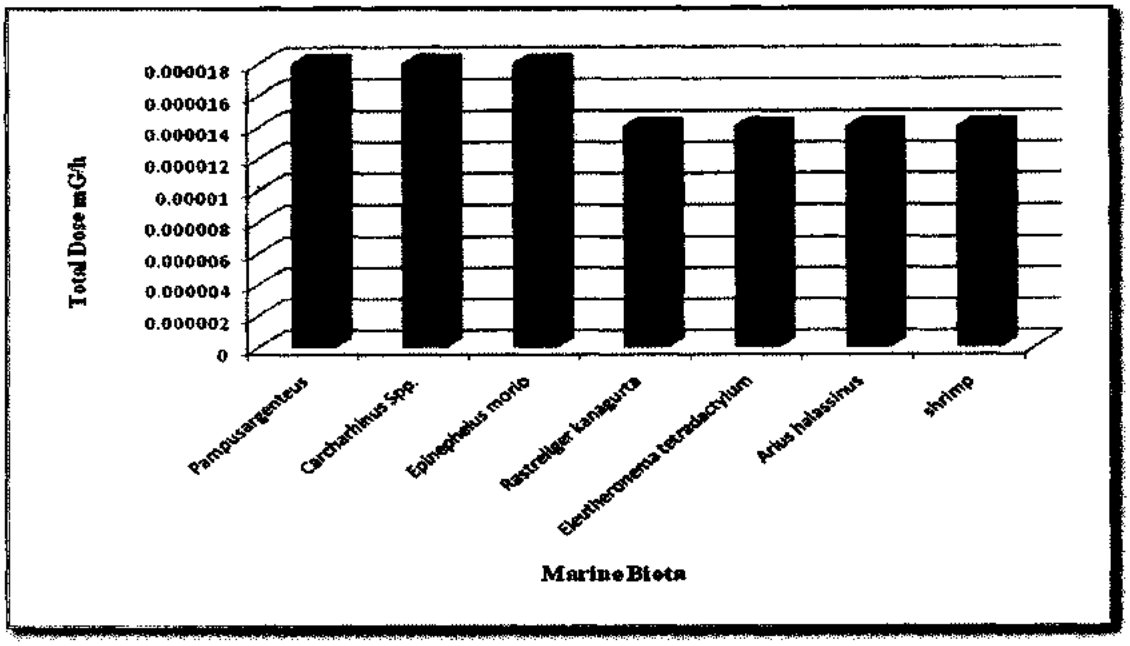

Figure 3.1 Dose rate to marine biota of South East Coast

3.1.3 Dose Rate Calculations for Fish at North West Coast

1. **Cat fish - *Arius halassinus***

Dose rate to due to Cat fish *(Arius halassinus)* ^{40}K, ^{226}Ra, ^{228}Ra and ^{137}Cs is 1.18 x 10^{-05}, 5.63x 10x 10^{-07}, 1.46 x $10^{-14}$and 1.21 x 10^{-07}mG/h respectively as given in Table 3.6.Total dose rate to *Arius halassinus* is 1.36 x 10^{-05}mG/h. Total dose rate to *Arius halassinus* is less than the guideline value which has no harmful effects of radioactivity for this fish.

2. **Ribbon Fish – *Trachipteridae***

Ribbon fish *(Trachipteridae)* are ray-finned fish. These are pelagic and are seldom seen alive because they live in bottomless waters, however these are not benthic. They are recognized by their anatomy i.e. long, compressed, tape-like bodies, short head, narrow mouth and feeble teeth.

Dose rate to Trachipteridae due to ^{40}K, ^{226}Ra, ^{228}Ra and ^{137}Cs is 1.18 x 10^{-05}, 5.63x 10x 10^{-07}, 1.46 x $10^{-14}$and 1.21 x 10^{-07}mG/h respectively (Table 3.6). Total dose rate to respective fish is 1.36 x 10^{-05}mG/h. Total dose rate to *Trachipteridae* is lower than the suggested value given by US EPA that shows no indication of adverse effect of radioactivity for this fish.

3. **Sole – *Cynoghlossus Spp.***

Sole (*Cynoghlossus Spp.*) is of the family Soleidae. They are recognized by the presence of a long hook on the snout overhanging the mouth, and the absence of pectoral fins. Their eyes are both on the left side of their body having no pelvic fin. They are found in tropical and sub-tropical oceans.

Dose rate to Cynoghlossus Spp. due to ^{40}K, ^{226}Ra, ^{228}Ra and ^{137}Cs is 1.18 x 10^{-05}, 5.63 x 10^{-07}, 1.46 x 10^{-14} and 1.21 x 10^{-07}mG/h respectively as given in Table 3.6.Total dose rate to this fish is 1.36 x 10^{-05}mG/h. Total dose rate to the fish is below than the guideline value which has no indication of deleterious effects of radioactivity for Cynoghlossus Spp.

4. Eel - *Mastacembelus armatus*

Eel *(Mastacembelus armatus)* is a ray-finned, spiny eels and is present in the rivers of India, Pakistan, Sri Lanka, Thailand, and other parts of South East Asia. This is a large elongated fish having snake-like body that lacks pelvic fins. This is used as a food fish.

Dose rate to *Mastacembelus armatus* due to ^{40}K, ^{226}Ra, ^{228}Ra and ^{137}Cs is 1.18 x 10^{-05}, 5.63 x 10^{-07}, 1.46 x 10^{-14} and 1.21 x 10^{-07}mG/h respectively (Table 3.6). Total dose rate to this fish is 1.36 x 10^{-05}mG/h. Total dose rate to this fish is well below than the recommended value which shows no sign of adverse effects of radioactivity for Mastacembelus armatus.

Table 3.6 Total dose rate for *Arius halassinus, Trachipteridae, Cynoghlossus Spp. and Mastacembelus armatus.*

Radio-nuclide	Internal Dose Rate (μG/h)	External Dose Rate from Water (μG/h)	External Dose Rate from Sediment (μG/h)	Total Dose (μG/h)	Total Dose mG/h
Arius halassinus					
K-40	8.69 x 10^{-05}	0.0014	0.0103	0.0118	1.18 x 10^{-05}
Ra-226	9.05 x 10^{-06}	5.54 x 10^{-05}	0.0005	0.0006	5.63 x 10^{-07}
Ra-228	1.11 x 10^{-13}	1.21 x 10^{-12}	1.33 x 10^{-11}	1.46 x 10^{-11}	1.46 x 10^{-14}
Cs-137	2.88 x 10^{-07}	1.02 x 10^{-05}	0.0001	0.0001	1.21 x 10^{-07}
Total Gamma Dose Rate					**1.24 x 10^{-05}**
Trachipteridae					
K-40	0.0001	0.0014	0.1028	0.0118	1.18 x 10^{-05}
Ra-226	9.04 x 10^{-06}	5.53 x 10^{-05}	0.0005	0.0006	5.63 x 10^{-07}
Ra-228	1.11 x 10^{-13}	1.21 x 10^{-12}	1.33 x 10^{-11}	1.46 x 10^{-11}	1.46 x 10^{-14}
Cs-137	2.88 x 10^{-07}	1.02 x 10^{-05}	0.000111	0.00012	1.21 x 10^{-07}
Total Gamma Dose Rate					**1.24 x 10^{-05}**
Cynoghlossus Spp.					
K-40	0.0001	0.0014	0.1028	0.0118	1.18 x 10^{-05}
Ra-226	9.04 x 10^{-06}	5.53 x 10^{-05}	0.0005	0.0006	5.63 x 10^{-07}
Ra-228	1.11 x 10^{-13}	1.21 x 10^{-12}	1.33 x 10^{-11}	1.46 x 10^{-11}	1.46 x 10^{-14}
Cs-137	2.88 x 10^{-07}	1.02 x 10^{-05}	0.000111	0.00012	1.21 x 10^{-07}
Total Gamma Dose Rate					**1.24 x 10^{-05}**
Mastacembelus armatus					
K-40	0.0001	0.0014	0.1028	0.0118	1.18 x 10^{-05}
Ra-226	9.04 x 10^{-06}	5.53 x 10^{-05}	0.0005	0.0006	5.63 x 10^{-07}
Ra-228	1.11 x 10^{-13}	1.21 x 10^{-12}	1.33 x 10^{-11}	1.46 x 10^{-11}	1.46 x 10^{-14}
Cs-137	2.88 x 10^{-07}	1.02 x 10^{-05}	0.000111	0.00012	1.21 x 10^{-07}
Total Gamma Dose Rate					**1.34 x 10^{-05}**

Comparison of total dose due to radionuclides to different fish spp. of North West Coast is shown in figure 3.2.

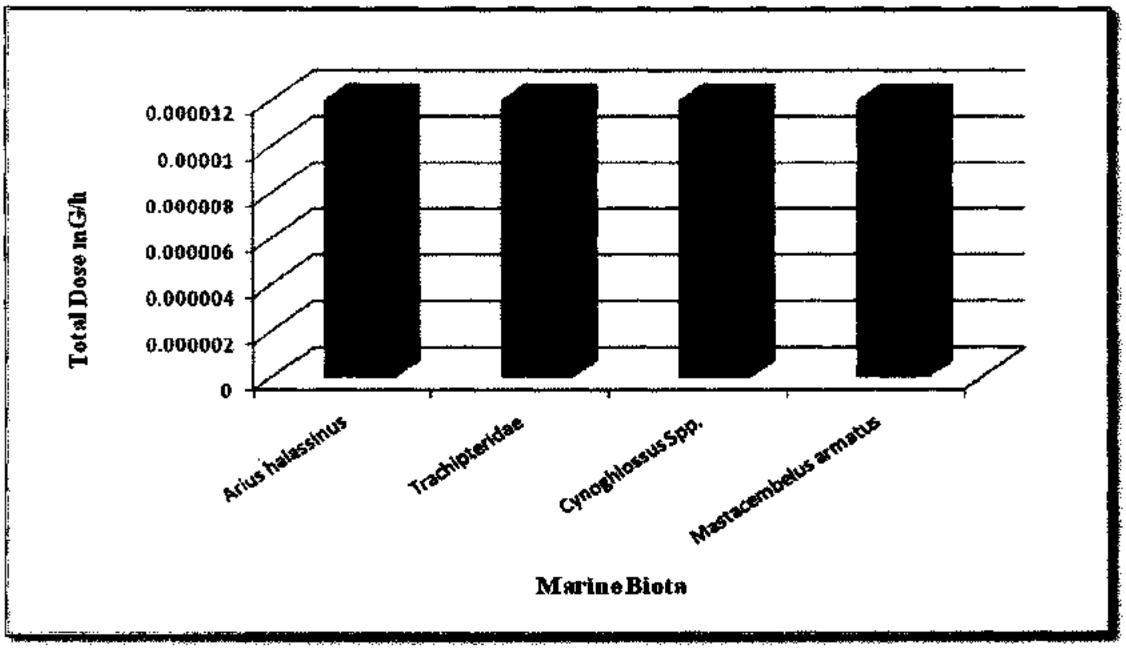

Figure 3.2 Dose rate to marine biota of North West Coast

3.1.4 Dose Rate Calculations for Fish at Manora Channel

1. Queen Fish– *Scomberoides lysan*

Queen fish *(Scomberoides lysan)* is a game fish. It is benthic fish ranges present in Indian, Pacific Oceans and Arabian Sea. They are silver in color, with dark coloration on the dorsal and caudal fins. Queen fish eat small crustaceans, crabs, and fishes.

Dose rate to Scomberoides lysan due to ^{40}K, ^{226}Ra, ^{228}Ra and ^{137}Cs is 1.4 x 10^{-05}, 6 x 10^{-07}, 1.4 x $10^{-14}$and 1.2 x 10^{-07}mG/h respectively (Table 3.7).Total dose rate to this fish is 1.45 x 10^{-05} mG/h. Total dose rate to Scomberoides lysan is less than the US EPA guideline value which shows no indication of harmful effects of radioactivity for this fish.

2. Croaker - *Nibea Spp.*

Croaker (*Nibea Spp.)* is a ray-finned fish of family Sciaenidae. The name croaker are expressive of the noise that the fish makes by vibrating strong muscles against the swim bladder, that acts like a hollow chamber like a drum. They are benthopelagic fish of shallow waters and evade brackish conditions. They have traditionally been used for food.

Dose rate to *Nibea Spp.* due to ^{40}K, ^{226}Ra, ^{228}Ra and ^{137}Cs is 1.4 x 10^{-05}, 6 x 10^{-07}, 1.4 x 10^{-14} and 1.2 x 10^{-07}mG/h respectively presented in Table 3.7. Total dose rate to this fish is 1.45 x 10^{-05} mG/h which is less than the guideline value indicating no adverse effects of radioactivity for *Nibea Spp.*

3. Silvery Grunter - *Pomadasys argyreus*

Silvery grunter (*Pomadasys argyreus*) is found in the Indian Ocean and western Pacific, where they live in brine, salty and freshwater habitats. This has large eyes, a flat ventral profile and a large caudal fin. These are is silver in color.

Dose rates to *Pomadasys argyreus* are given in Table 3.7. Dose rate to *Pomadasys argyreus* due to ^{40}K, ^{226}Ra, ^{228}Ra and ^{137}Cs is 1.4 x 10^{-05}, 6 x 10^{-07}, 1.4 x 10^{-14} and 1.2 x 10^{-07} mG/h respectively. Total dose rate to this fish is 1.45 x 10^{-05}mG/h. Total dose rate to Pomadasys argyreus is below than the guideline value signifying no harmful effects of radioactivity for this fish at Manora Channel.

Table 3.7 Total dose rate for *Scomberoides lysan, Nibea Spp., Pomadasys argyreus and Spondyliosoma cantharus*

Radio-nuclide	Internal Dose Rate (µG/h)	External Dose Rate from Water (µG/h)	External Dose Rate from Sediment (µG/h)	Total Dose (µG/h)	Total Dose mG/h
Scomberoides lysan					
K-40	9.3 x 10^{-05}	0.0013	0.0124	0.0138	1.4 x 10^{-05}
Ra-226	9 x 10^{-06}	3.8 x 10^{-05}	0.0006	0.0006	6 x 10^{-07}
Ra-228	1.1 x 10^{-13}	1.2 x 10^{-12}	1.3 x 10^{-11}	1.4 x 10^{-11}	1.4 x 10^{-14}
Cs-137	2.9 x 10^{-07}	1 x 10^{-05}	0.00011	0.00012	1.2 x 10^{-07}
Total Gamma Dose Rate					**1.45 x 10^{-05}**
Nibea Spp.					
K-40	0.0001	0.0013	0.0124	0.0138	1.4 x 10^{-05}
Ra-226	9 x 10^{-06}	3.8 x 10^{-05}	0.0006	0.0006	6 x 10^{-07}
Ra-228	1.1 x 10^{-13}	1.2 x 10^{-12}	1.3 x 10^{-11}	1.4 x 10^{-11}	1.4 x 10^{-14}
Cs-137	2.9 x 10^{-07}	1 x 10^{-05}	0.0001	0.0001	1.2 x 10^{-07}
Total Gamma Dose Rate					**1.45 x 10^{-05}**
Pomadasys argyreus					
K-40	0.0001	0.0013	0.0124	0.0138	1.4 x 10^{-05}
Ra-226	9 x 10^{-06}	3.8 x 10^{-05}	0.0005	0.0006	6 x 10^{-07}
Ra-228	1.1 x 10^{-13}	1.2 x 10^{-12}	1.3 x 10^{-11}	1.4 x 10^{-11}	1.4 x 10^{-14}
Cs-137	2.9 x 10^{-07}	1 x 10^{-05}	0.00011	0.00012	1.2 x 10^{-07}

Radio-nuclide	Internal Dose Rate (μG/h)	External Dose Rate from Water (μG/h)	External Dose Rate from Sediment (μG/h)	Total Dose (μG/h)	Total Dose mG/h
Total Gamma Dose Rate					**1.45×10^{-05}**
Spondyliosoma cantharus					
K-40	0.0001	0.0013	0.0124	0.0138	1.4×10^{-05}
Ra-226	9×10^{-06}	3.8×10^{-05}	0.0006	0.0006	6×10^{-07}
Ra-228	1.1×10^{-13}	1.2×10^{-12}	1.3×10^{-11}	1.4×10^{-11}	1.4×10^{-14}
Cs-137	2.9×10^{-07}	1×10^{-05}	0.00011	0.00012	1.2×10^{-07}
Total Gamma Dose Rate					**1.45×10^{-05}**

4. **Black Sea Bream –*Spondyliosoma Cantharus***

Black Sea bream *(Spondyliosoma cantharus)* is of family Sparidae. They are identified by oval compressed body and jaws containing 4-6 rows of slender teeth. They are silver in color with blue and pink dashes and broken longitudinal gold lines.

Dose rate to *Spondyliosoma cantharus* presented in Table 3.7 due to ^{40}K, ^{226}Ra, ^{228}Ra and ^{137}Cs come out to be 1.4×10^{-05}, 6×10^{-07}, and 1.4 x 10-14 and 1.2 x 10-07 mG/h respectively. Total dose rate to this fish is 1.45×10^{-05}mG/h which is well below than the guideline value indicating no deleterious effects of radioactivity for Spondyliosoma cantharus.

3.1.5 Dose Rate Calculations for Mussels at Manora Channel

1. ***Perna viridis***

Perna viridis (Asian green mussel) is a commercially important mussel. Its shell ends in a downward-pointing bill. The organic coating or "skin" of mussel is dark green. Younger mussels are bright green and that becomes darker as it ages. The mussel has a large foot that it uses to climb vertically from sediments. The Asian green mussel is found in the coastal waters of the Indo-Pacific region. *P. viridis* grows fastest at 2 meters below the surface, in high salinity and high concentration of phytoplankton. *P. viridis* is garnered as a food source due to its fast growth.

Dose rates to *Perna viridis* are given in Table 3.8.Dose rate to *Perna viridis* due to ^{40}K, ^{226}Ra, ^{228}Ra and ^{137}Cs come out to be 8.08×10^{-06}, 7.1×10^{-07}, 1×10^{-14} and 4.8×10^{-08} mG/h respectively. Total dose rate to this mussel is 9×10^{-06}mG/h which is less than the recommended value that shows no indication of adverse effects of radioactivity for Perna viridis.

Table 3.8 Total dose rates for Mussel (*Perna viridis*) and Zooplankton

Radio-nuclide	**Internal Dose Rate (μG/h)**	**External Dose Rate from Water (μG/h)**	**External Dose Rate from Sediment (μG/h)**	**Total Dose (μG/h)**	**Total Dose mG/h**
Perna viridis					
K-40	0.0048	0.0003	0.0030	0.0081	8.08×10^{-06}
Ra-226	0.0006	9.07×10^{-06}	0.0001	0.0007	7.1×10^{-07}
Ra-228	7×10^{-12}	2.9×10^{-13}	3×10^{-12}	1×10^{-11}	1×10^{-14}
Cs-137	1.8×10^{-05}	2.5×10^{-06}	2.7×10^{-05}	4.8×10^{-05}	4.8×10^{-08}
Total Gamma Dose Rate					$\mathbf{9 \times 10^{-06}}$
Zooplankton					
K-40	0.0049	0.0003	0.0030	0.0082	$8.08E^{-06}$
Ra-226	0.0006	9.1×10^{-06}	0.0001	0.0007	7.1×10^{-07}
Ra-228	7×10^{-12}	2.9×10^{-13}	3×10^{-12}	1×10^{-11}	1×10^{-14}
Cs-137	1.8×10^{-05}	2.5×10^{-06}	2.7×10^{-05}	4.8×10^{-05}	4.8×10^{-08}
Total Gamma Dose Rate					$\mathbf{9 \times 10^{-06}}$

3.1.6 Dose Rate Calculations for Zooplanktons at Manora Channel

Zooplankton are heterotrophic planktons.Zooplanktons is usually microscopic, but some are larger and visible. Although zooplanktons are primarily transported by water currents, many of them have locomotion that is used to avoid predators or to increase prey encounter rate.

Dose rates to zooplanktons are given in Table 3.8.Dose rate to zooplanktons due to ^{40}K, ^{226}Ra, ^{228}Ra and ^{137}Cs come out to be 8.08×10^{-06}, 7.1×10^{-07}, 1×10^{-14} and 4.8×10^{-08} mG/h respectively. Total dose rate to this mussel is 9×10^{-06}mG/h which is less than the recommended value of Erica assessment tool that shows negligible effects of radioactivity for zooplanktons.

Comparison of total dose due to radionuclides to different fish spp. mussels and zooplanktons of Manora Channel is shown in figure 3.3.

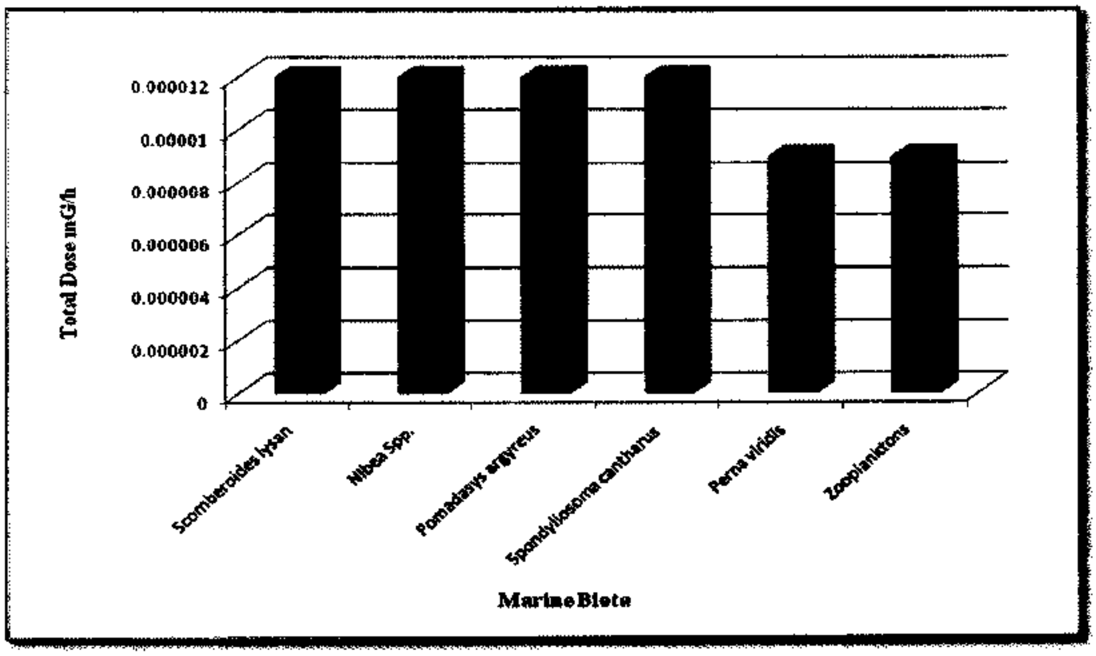

Figure 3.3 Dose rate to marine biota of Manora Channel

3.2 Radiological Risk Assessment by ERICA Tool

The ERICA Tool is used to calculate the dose rates of radionuclides to marine biota. ERICA is an integrated approach to scientific, managerial and societal issues concerned with the environmental effects of contaminants emitting ionizing radiation, with emphasis on biota. The risk quotient (RQ) method provides a simple means of assessing risk. Within the ERICA Integrated Approach, the risk quotient integrates exposure and effects data to determine ecological risk by calculating the quotient of estimated exposure and benchmark dose rate. The benchmark dose rate is the dose rate which is assumed to be environmentally 'safe'. Erica tool generates graphs of internal dose rate, external dose rate, total dose rate and risk quotient. Typical graphs are shown in Anexure A.

3.2.1 Radiological Risk Assessment for Fish at South East Coast

1. **Silver Pomfret –*Pampusargenteus* (Pelagic Fish)**

Total gamma dose to Silver Pomfret *(Pampusargenteus)* as calculated through ERICA tool at Tier-II due to ^{137}Cs, ^{40}K, ^{226}Ra and ^{228}Ra is 2.13 x 10^{-05}, 0.0337, 1.0941 and 0.0017 μGy h^{-1} respectively (Table 3.9). Total Dose rate due to all these radionuclide is 1.129 μGy h^{-1}or 0.001129 mGy h^{-1} which is well below the guideline value of US EPA. The results were calculated using Tier II assessments which are based on media concentration and use pre-calculated environmental media concentration limits (EMCLs) to estimate risk quotients. According Erica tool assessment, If sum of the risk quotients is <1, then it is guaranteed that there is a very less possibility that the assessment dose rate to any organism exceeds the incremental screening dose rate and therefore the risk to marine biota is considered insignificant. Risk Quotient to Pampusargenteus in this study is 0.113 which is less than 1 indicating no evidence of deleterious effect of radioactivity for this fish.

2. **Indian Mackerel - *Rastreliger kanagurta* (Pelagic Fish)**

Total gamma dose to Indian Mackerel (*Rastreliger kanagurta)*as calculated through Erica tool at Tier-II due to ^{137}Cs, ^{40}K, ^{226}Ra and ^{228}Ra is 2.13 x 10^{-05}, 0.0285, 1.0941 and 0.0017µGy h^{-1} respectively presented in Table 3.9. Total Dose rate due to all these radionuclide is 1.1242 µGy h^{-1} or 0.00112 mGy h^{-1}. Risk Quotient to Rastreliger kanagurta is 0.1124 which is less than the recommended value signifying no indication of injurious effects of radioactivity for Rastreliger kanagurta.

Table 3.9 Radiological Risk Assessment for Pelagic Fish of South East Coast

Radio-Nuclide	**External Dose Rate [µGy h^{-1}]**	**Internal Dose Rate [µGy h^{-1}]**	**Total Dose Rate [µGy h^{-1}]**	**Total Dose Rate [µGy h^{-1}]**	**Risk Quotient**
Pampusargenteus					
Cs-137	8.7 x 10^{-06}	1.26 x 10^{-05}	2.13 x 10^{-05}	1.129	0.113
K-40	0.0014	0.0324	0.0337		
Ra-226	0.0004	1.0937	1.0941		
Ra-228	0.0003	0.0014	0.0017		
Rastreliger kanagurta					
Cs-137	8.7 x 10^{-06}	1.26 x 10^{-05}	2.13 x 10^{-05}	1.1242	0.1124
K-40	0.0014	0.0271	0.0285		
Ra-226	0.0004	1.0937	1.0941		
Ra-228	0.0003	0.0014	0.0017		
Eleutheronema tetradactylum					
Cs-137	8.7 x 10^{-06}	1.26 x 10^{-05}	2.13 x 10^{-05}	1.1168	0.1117
K-40	0.0014	0.0196	0.0210		
Ra-226	0.0004	1.0937	1.0941		
Ra-228	0.0007	0.0014	0.0016		

3. **Salmon - *Eleutheronema tetradactylum* (Pelagic Fish)**

Total gamma dose to Salmon *(Eleutheronema tetradactylum)*as calculated through Erica tool at Tier-II due to ^{137}Cs, ^{40}K, ^{226}Ra and ^{228}Ra is 2.13 x 10^{-05}, 0.0210, 1.0941 and 0.0016μGy h^{-1} respectively (Table 3.9). Total Dose rate due to all these radionuclide is 1.1168 μGy h^{-1} or 0.0011168 mGy h^{-1}. Risk Quotient to *Eleutheronema tetradactylum* is 0.1117 which is below 1 revealing that there is no sign of poisonous effects of radioactivity for this fish.

4. **Grouper - *Epinephelus morio* (BenthicFish)**

Total gamma dose to Grouper *(Epinephelus morio)* as calculated through Erica tool at Tier-II due to ^{137}Cs, ^{40}K, ^{226}Ra and ^{228}Ra is 0.0002, 0.0650, 1.1147 and 0.0069μGy h^{-1} respectively as presented in Table 3.10. Total Dose rate due to all these radionuclide is 1.1867 μGy h^{-1}or 0.0011867 mGy h^{-1}. Risk Quotient to *Epinephelus morio* is 0.1187 which is less than the recommended value shows no indication of harmful effects of radioactivity for this fish.

Table 3.10 Radiological Risk Assessment for Benthic Fish of South East Coast

Radio-nuclides	External Dose Rate [μGy h^{-1}]	Internal Dose Rate [μGy h^{-1}]	Total Dose Rate [μGy h^{-1}]	Total Dose Rate [μGy h^{-1}]	Risk Quotient
Epinephelus morio					
Cs-137	0.0002	1.19 x 10^{-05}	0.0002	1.1867	0.1187
K-40	0.0336	0.0314	0.0650		
Ra-226	0.0107	1.1034	1.1147		
Ra-228	0.0055	0.0014	0.0069		
Carcharhinus Spp.					
Cs-137	0.0002	1.19 x 10^{-05}	0.0002	1.1780	0.1178
K-40	0.0336	0.0227	0.0563		
Ra-226	0.0107	1.1039	1.1147		
Ra-228	0.0055	0.0014	0.0069		
Arius halassinus					
Cs-137	0.0002	1.19 x 10^{-05}	0.0002	1.1802	0.1180
K-40	0.0243	0.0320	0.0564		
Ra-226	0.0118	1.1040	1.1158		
Ra-228	0.0064	0.0014	0.0080		

5. **Sand Tiger Shark - *Carcharhinus Spp.* (Benthic Fish)**

Dose rate assessments to *Carcharhinus Spp.* are given in Table 3.10.Total gamma dose to Sand Tiger Shark *(Carcharhinus Spp.)* as calculated through Erica tool at Tier-II due to ^{137}Cs, ^{40}K, ^{226}Ra and ^{228}Ra is 0.0002, 0.0563, 1.1147 and 0.0069μGy h^{-1} respectively. Total Dose rate due to all these radionuclide is 1.1780μGy h^{-1}or 0.001178 mGy h^{-1}. Risk Quotient to *Carcharhinus Spp.* is 0.1178 which below 1 indicating no verification of toxic effects of radioactivity for this fish.

6. **Cat fish- *Arius halassinus* (Benthic Fish)**

Total gamma dose to Cat fish *(Arius halassinus)* as calculated through Erica tool at Tier-II due to ^{137}Cs, ^{40}K, ^{226}Ra and ^{228}Ra come out to be 0.0002, 0.0564, 1.1158 and 0.0080μGy h^{-1} respectively(Table 3.10). Total Dose rate due to all these radionuclide is 1.1802 μGy h^{-1}or 0.0011802 mGy h^{-1} which is well below the guideline value of US EPA. Risk Quotient to *Arius halassinus* in Erica tool is 0.1180 which is less than 1 indicates that there is negligible effect of radioactivity for this fish.

3.2.2 Radiological Risk Assessment for *Metapeniaus affinis* at South East Coast

Total gamma dose to Shrimp *(Metapeniaus affinis)* as calculated through Erica tool at Tier-II due to ^{137}Cs, ^{40}K, ^{226}Ra and ^{228}Ra come out to be 0.000432, 0.035812, 1.183009 and 0.007629 respectively (Table 3.11). Total Dose rate due to all these radionuclide is 1.226 μGy h^{-1} or 0.001226 mGy h^{-1}. Risk Quotient to *Metapeniaus affinis* calculated in Erica tool is 0.1226 which is lower than 1 that indicates insignificant effect of radioactivity for crab.

Table 3.11 Radiological Risk Assessment for *Metapeniaus affinis*

Radio-nuclides	External Dose Rate[μGy h^{-1}]	Internal Dose Rate[μGy h^{-1}]	Total Dose Rate[μGy h^{-1}]	Total Dose Rate [μGy h^{-1}]	Risk Quotient
Cs-137	0.000193	0.000239	0.000432	1.22683	0.122688
K-40	0.022392	0.01342	0.035812		
Ra-226	0.011224	1.171785	1.183009		
Ra-228	0.00619	0.001439	0.007629		

Comparison of risk quotients due to radionuclides to different fish spp. and shrimp of South East Coast is shown in figure 3.4.

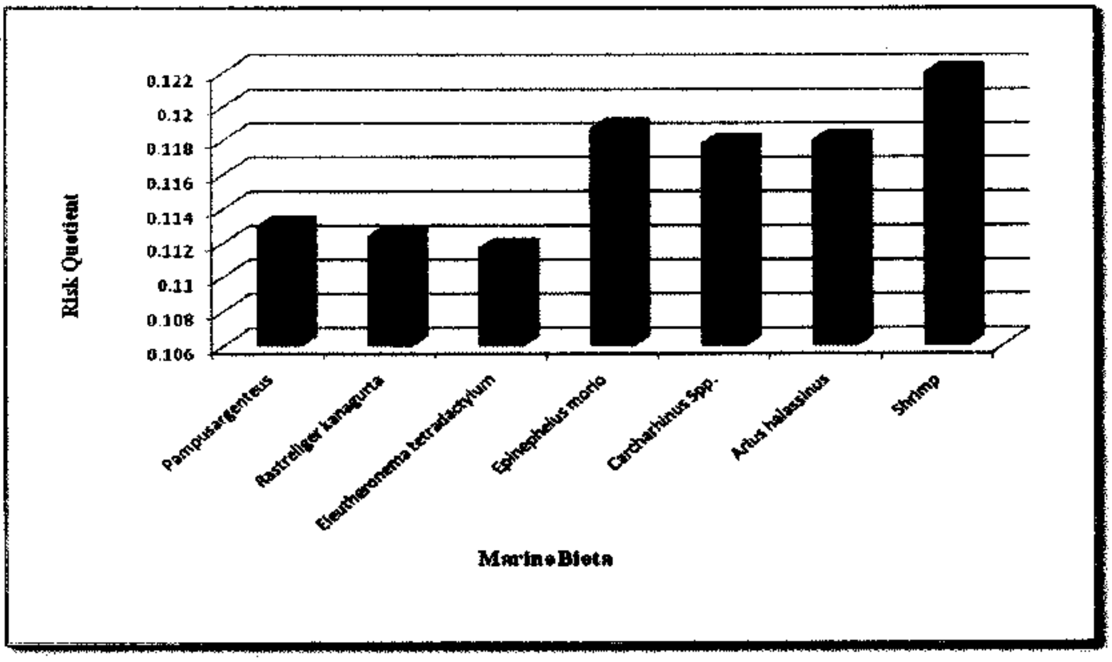

Figure 3.4 Risk quotient to marine biota of South East Coast

3.2.3 Radiological Risk Assessment for Fish at North West Coast

1. **Ribbon Fish – *Trachipteridae* (Pelagic Fish)**

Total gamma dose to Ribbon Fish *(Trachipteridae)* as calculated through Erica tool at Tier-II due to ^{137}Cs, ^{40}K, ^{226}Ra and ^{228}Ra come out to be 2.13 x 10^{-05}, 0.0310, 1.0942 and 0.0017 μGy h^{-1} respectively (Table 3.12). Total Dose rate due to all these radionuclide is 1.1269 μGy h^{-1} or 0.0011269 mGy h^{-1}. Risk Quotient to *Trachipteridae* by Erica tool assessment is 0.1126 which is less than 1 showing no indication of harmful effect of radioactivity for this fish.

2. **Sole - *Cynoghlossus Spp.* (Pelagic Fish)**

Total gamma dose to Sole *(Cynoghlossus Spp.)* as calculated through Erica tool at Tier-II due to ^{137}Cs, ^{40}K, ^{226}Ra and ^{228}Ra is 2.13 x 10^{-05}, 0.0247, 1.0942 and 0.0017 μGy h^{-1} respectively. Total Dose rate due to all these radionuclide is 1.1206 μGy h^{-1}or 0.0011206 mGy h^{-1}as given in Table 3.12. Risk Quotient to *Cynoghlossus*

Spp. in this study is 0.1121 which is below 1 that shows no significance effects of radioactivity for this fish.

Table 3.12 Radiological Risk Assessment for Pelagic Fish of North West Coast

Radio-Nuclides	External Dose Rate [μGy h^{-1}]	Internal Dose Rate [μGy h^{-1}]	Total Dose Rate [μGy h^{-1}]	Total Dose Rate [μGy h^{-1}]	Risk Quotient
Trachipteridae					
Cs-137	0.0002	1.26 x 10^{-05}	2.13 x 10^{-05}	1.1269	0.1126
K-40	0.0014	0.0296	0.0310		
Ra-226	0.0006	1.0937	1.0942		
Ra-228	0.0003	0.0014	0.0017		
Cynoghlossus Spp.					
Cs-137	8.7 x 10^{-06}	1.26 x 10^{-05}	2.13 x 10^{-05}	1.1206	0.1121
K-40	0.0014	0.0233	0.0247		
Ra-226	0.0006	1.0937	1.0942		
Ra-228	0.0003	0.0014	0.0017		

3. Cat fish - *Arius halassinus* (Benthic Fish)

Dose rate assessments to *Arius halassinus* are given in Table 3.13. Total gamma dose to Cat fish (*Arius halassinus*) as calculated through Erica tool at Tier-II due to ^{137}Cs, ^{40}K, ^{226}Ra and ^{228}Ra come out to be 0.0002, 0.0454, 1.1148 and 0.0073μGy h^{-1} respectively. Total Dose rate due to all these radionuclide is 1.1777 μGy h^{-1}or 0.0011777 mGy h^{-1}. Risk Quotient to *Arius halassinus* is 0.1178 that is less than 1 showing no deleterious effect of radioactivity for this fish.

4. Eel Fish -*Mastacembelus armatus* (Benthic Fish)

Total gamma dose to Eel Fish *(Mastacembelus armatus)*as calculated through Erica tool at Tier-II due to ^{137}Cs, ^{40}K, ^{226}Ra and ^{228}Ra is 0.0002, 0.0472, 1.1148 and 0.0073μGy h^{-1} respectively (Table 3.13). Total Dose rate due to all these radionuclide is 1.1695 μGy h^{-1} or 0.0011695 mGy h^{-1}. Risk Quotient to *Mastacembelus armatus* calculated through Erica Tool is 0.1170 that is less than 1 indicating negligible effects of radioactivity for this fish.

Cmparison of risk quotients due to radionuclides to different fish spp. of North West Coast is shown in figure 3.5.

Table 3.13 Radiological Risk Assessment for Benthic Fish of North West Coast

Radio-Nuclides	External Dose Rate [µGy h^{-1}]	Internal Dose Rate [µGy h^{-1}]	Total Dose Rate [µGy h^{-1}]	Total Dose Rate [µGy h^{-1}]	Risk Quotient
Arius halassinus					
Cs-137	0.0002	1.19×10^{-05}	0.0002	1.1777	0.1178
K-40	0.0221	0.0233	0.0454		
Ra-226	0.0108	1.1040	1.1148		
Ra-228	0.0060	0.0014	0.0073		
Mastacembelus armatus					
Cs-137	0.0002	1.19×10^{-05}	0.0002	1.1695	0.1170
K-40	0.0221	0.0251	0.0472		
Ra-226	0.0108	1.1040	1.1148		
Ra-228	0.0060	0.0014	0.0073		

3.2.4 Radiological Risk Assessment for Fish at Manora Channel

1. Black Sea Bream - *Spondyliosoma cantharus* (Pelagic Fish)

Total gamma dose to Black Sea Bream *(Spondyliosoma cantharus)* as calculated through Erica tool at Tier-II due to ^{137}Cs, ^{40}K, ^{226}Ra and ^{228}Ra is 2.13×10^{-05}, 0.0251, 1.0941 and 0.0017 µGy h^{-1} respectively. Total Dose rate due to all these radionuclide is 1.1208 µGy h^{-1} or 0.0011208 mGy h^{-1} presented in Table 3.14. Risk Quotient to *Spondyliosoma cantharus* is 0.1121 i.e. below 1 signifying no harmful effects of radioactivity for this fish.

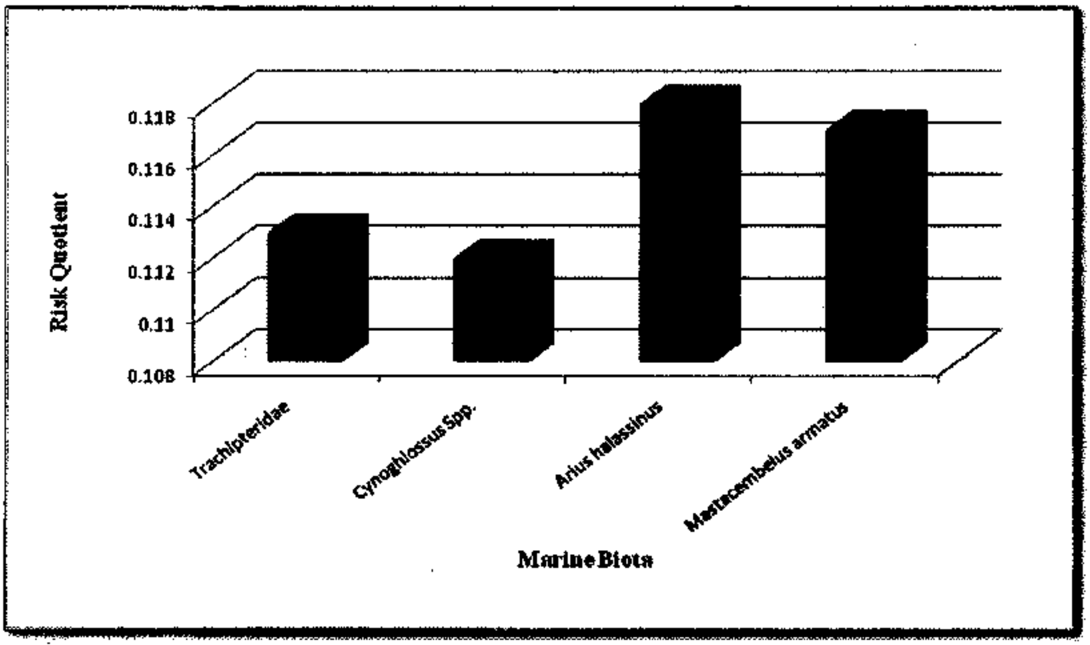

Figure 3.5 Risk quotient to marine biota of North West Coast

2. **Queen Fish – *Scomberoides lysan* (Pelagic Fish)**

Total gamma dose to Queen Fish *(Scomberoides lysan)* as calculated through Erica tool at Tier-II due to ^{137}Cs, ^{40}K, ^{226}Ra and ^{228}Ra is 2.13 x 10^{-05}, 0.0267, 1.0941 and 0.0017 μGy h^{-1} respectively (Table 3.14). Total Dose rate due to all these radionuclide is 1.1225 μGy h^{-1}or 0.0011225 mGy h^{-1}. Risk Quotient to *Scomberoides lysan* calculated through Erica tool is 0.1122 which is below 1 that shows there is no deleterious effect of radioactivity for this fish.

3. **Silvery Grunter - *Pomadasys argyreus* (Pelagic Fish)**

Total gamma dose to Silvery Grunter *(Pomadasys argyreus)* as calculated through Erica tool at Tier-II due to ^{137}Cs, ^{40}K, ^{226}Ra and ^{228}Ra come out to be 2.13 x 10^{-05}, 0.0300, 1.0941 and 0.0017 μGy h^{-1} respectively (Table 3.14). Total Dose rate due to all these radionuclide is 1.1257 μGy h^{-1}or 0.0011257 mGy h^{-1}. Risk Quotient to *Pomadasys argyreus* is 0.1126 which is far below 1 which reveals that there is no evidence of deleterious effect of radioactivity for this fish.

Table 3.14 Radiological Risk Assessment for Pelagic Fish of Manora Channel

Radio-Nuclides	External Dose Rate [μGy h^{-1}]	Internal Dose Rate [μGy h^{-1}]	Total Dose Rate [μGy h^{-1}]	Total Dose Rate [μGy h^{-1}]	Risk Quotient
Spondyliosoma cantharus					
Cs-137	8.7 x 10^{-06}	1.26 x 10^{-05}	2.13 x 10^{-05}	1.1208	0.1121
K-40	0.0013	0.0238	0.0251		
Ra-226	0.0004	1.0937	1.0941		
Ra-228	0.0003	0.0014	0.0017		
Scomberoides lysan					
Cs-137	8.7 x 10^{-06}	1.26 x 10^{-05}	2.13 x 10^{-05}	1.1225	0.1122
K-40	0.0013	0.0254	0.0267		
Ra-226	0.0004	1.0937	1.0941		
Ra-228	0,0003	0.0014	0.0017		
Pomadasys argyreus					
Cs-137	8.7 x 10^{-06}	1.26 x 10^{-05}	2.13 x 10^{-05}	1.1257	0.1126
K-40	0.0013	0.0287	0.0300		
Ra-226	0.0004	1.0937	1.0941		
Ra-228	0.0003	0.0014	0.0017		

4. **Croaker - *Nibea Spp.* (Benthic Fish)**

Total gamma dose to Croaker *(Nibea Spp.)* as calculated through Erica tool at Tier-II presented in Table 3.15due to ^{137}Cs, ^{40}K, ^{226}Ra and ^{228}Ra come out to be 0.0002, 0.0582, 1.1158 and 0.0070μGy h^{-1} respectively. Total Dose rate due to all these radionuclide is 1.1811μGy h^{-1}or 0.0011811 mGy h^{-1}. Risk Quotient to *Nibea Spp.* is 0.1181 that is less than the recommended value 1 showing no poisonous effects of radioactivity for this fish.

Table 3.15 Radiological Risk Assessment to Benthic Fish of Manora Channel

Radio-Nuclides	External Dose Rate [μGy h^{-1}]	Internal Dose Rate [μGy h^{-1}]	Total Dose Rate [μGy h^{-1}]	Total Dose Rate [μGy h^{-1}]	Risk Quotient
Cs-137	0.0002	1.19 x 10^{-05}	0.0002	1.1811	0.1181
K-40	0.0264	0.0318	0.0582		
Ra-226	0.0118	1.1040	1.1158		
Ra-228	0.0056	0.0014	0.0070		

3.2.5 Radiological Risk Assessment for Zooplanktons at Manora Channel

Total gamma dose to zooplanktons as calculated through Erica tool at Tier-II due to ^{137}Cs, ^{40}K, ^{226}Ra and ^{228}Ra come out to be 0.000427, 0.035594, 1.183004 and 0.006869 respectively (Table 3.16). Total Dose rate due to all these radionuclide is 1.226 μGy h^{-1} or 0.001226 mGy h^{-1}. Risk Quotient to zooplanktons calculated in Erica tool is 0.1226 which is lesser than 1 that indicates insignificant effect of radioactivity for zooplanktons.

Table3.16 Radiological Risk Assessment for zooplanktons

Radio-Nuclides	External Dose Rate[μGy h^{-1}]	Internal Dose Rate[μGy h^{-1}]	Total Dose Rate[μGy h^{-1}]	Total Dose Rate [μGy h^{-1}]	Risk Quotient
Cs-137	0.000193	0.000239	0.000427	1.225895	0.122589
K-40	0.024341	0.011253	0.035594		
Ra-226	0.011219	1.171785	1.183004		
Ra-228	0.00543	0.001439	0.006869		

Comparison of risk quotients due to radionuclides to different fish spp. and zooplanktons of Manora Channel is shown in figure 3.6.

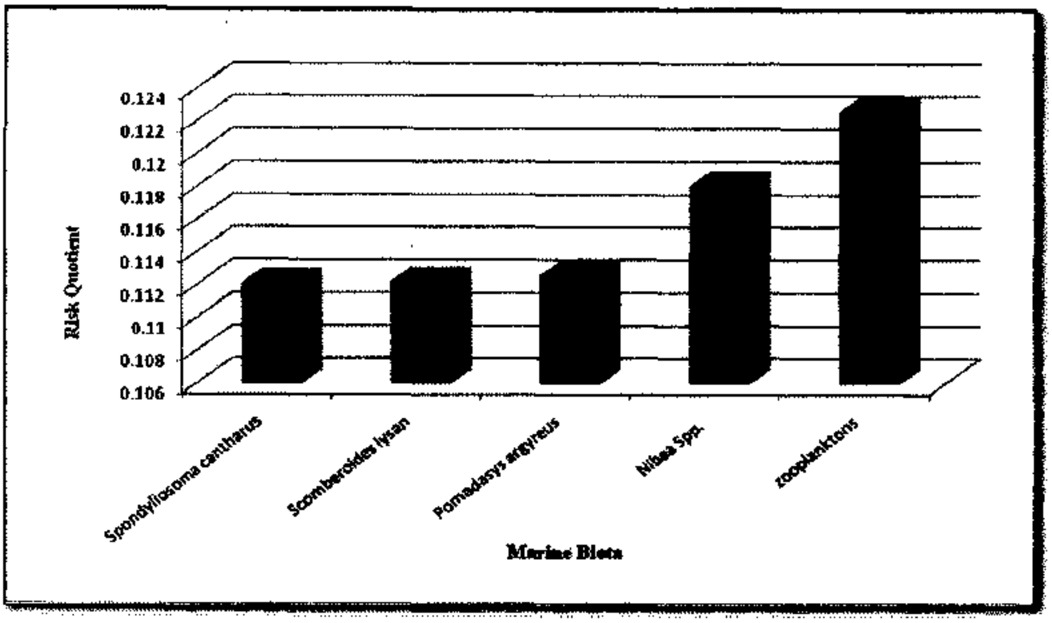

Figure 3.6 Risk quotient to marine biota of Manora Channel

3.3 Comparison between Total dose rates calculated by Point source distribution and Erica Tool

Total dose rates calculated by Point Source Distribution and ERICA Tool for different fish spp. along Karachi Coast is given in Table 3.17. Comparison shows difference between total dose rates from both approaches, values from Point Source Distribution are lower than the values resulting from Erica tool. The results from both calculations are lower than the DOE's suggested level of 0.4 mGy h^{-1} that shows no damaging effects from radiation exposure i.e., there is no quantifiable risk to the biota at Karachi coast.

Table 3.17 Comparison between Total Dose Rate (mG/h) calculated by Point Source distribution and Erica Tool

Radionuclide	Point Source Distribution	Erica Tool
South East Coast		
Pampusargenteus	1.81×10^{-05}	1.13×10^{-03}
Carcharhinus Spp.	1.81×10^{-05}	1.18×10^{-03}
Epinephelus morio	1.81×10^{-05}	1.19×10^{-03}
Rastreliger kanagurta	1.36×10^{-05}	1.12×10^{-03}
Eleutheronema tetradactylum	1.36×10^{-05}	1.12×10^{-03}
Arius halassinus	1.36×10^{-05}	1.18×10^{-03}
North West Coast		
Arius halassinus	1.24×10^{-05}	1.17×10^{-03}
Mastacembelus armatus	1.24×10^{-05}	1.17×10^{-03}
Cynoghlossus Spp.	1.24×10^{-05}	1.12×10^{-03}
Trachipteridae	1.24×10^{-05}	1.13×10^{-03}
Manora Channel		
Scomberoides lysan	1.45×10^{-05}	1.12×10^{-03}
Nibea Spp.	1.45×10^{-05}	1.18×10^{-03}
Pomadasys argyreus	1.45×10^{-05}	1.13×10^{-03}
Spondyliosoma cantharus	1.45×10^{-05}	1.12×10^{-03}

CONCLUSION

&

RECOMMENDATIONS

Conclusion

Radioactivity levels of radionuclides ^{137}Cs, ^{226}Ra, ^{228}Ra and ^{40}K in seawater, sediments and marine biota (fish, mussels and crab) were used to calculate radiological risk assessment and dose rates for marine fauna in different zones of Karachi coast. Assessment was carried out by two different approaches i.e., point source distribution and Erica Tool software. Following conclusions can be drawn from the study:

- Total dose rate calculated by point source distribution to fish eggs due to ^{40}K, ^{226}Ra, ^{228}Ra and ^{137}Cs at all coasts of Karachi was 3.47 x 10^{-06} mG/h. Dose rate for Benthic Fish species *Pampusargenteus, Carcharhinus Spp.* and *Epinephelus morio* is 1.81x 10^{-05} mG/h, while for *Rastrelliger kanagurta, Eleutheronema tetradactylum* and *Arius halassinus* is 1.36 x 10^{-05} mG/h and for *Metapenaeus affinis* total dose rate was 1.36 x 10^{-05} mG/h at South East Coast.
- Total dose rate to benthic and pelagic fish species, *Arius halassinus, Trachipteridae, Cynoghlossus Spp.* and *Mastacembelus armatus* due to ^{40}K, ^{226}Ra, ^{228}Ra and ^{137}Cs at North West Coast was 1.24 x 10^{-05} mG/h.
- Dose rate at Manora channel due to respective radionuclides for benthic and pelagic fish species, *Scomberoides lysan, Nibea Spp., Pomadasys argyreus* and *Spondyliosoma cantharus* was 1.45 x 10^{-05} mG/h while for *Perna viridis* and zooplanktons total radiation dose rate was 9 x 10^{-06} mG/h.
- Total dose rate in terms of risk quotient as calculated through Erica tool at Tier-II due to ^{137}Cs, ^{40}K, ^{226}Ra and ^{228}Ra at South East Coast for pelagic fish *Pampusargenteus, Rastreliger kanagurta* and *Eleutheronema tetradactylum* was 0.113, 0.1124 and 0.1117 respectively, while for benthic fish *Epinephelus morio, Carcharhinus Spp.* and *Arius halassinus* risk quotient was 0.1187, 0.1178 and 0.1180. Risk quotient to *Matuta Planipes* was 0.1226.
- Risk quotient calculated for pelagic fish *Trachipteridae* and *Cynoghlossus Spp.* was 0.1126 and 0.1121 at North West Coast and for

benthic fish *Arius halassinus* and *Mastacembelus armatus* it was 0.1178 and 0.1170 respectively.

- At Manora Channel risk quotient to pelagic fish *Spondyliosoma cantharus, Scomberoides lysan* and *Pomadasys argyreus* was 0.1121, 0.1122 and 0.1126 while for benthic fish *Nibea Spp.* it was 0.1181.
- Comparison of both approaches showed difference between total dose rates from these methodologies while values from Point Source Distribution were lower than the values resulting from Erica Tool.

Recommendations

- The present study was focused on baseline data for radiological risks assessment and calculation of total dose to marine biota along Karachi coast.

- Since this first of its kind systematic study of coastal areas of Pakistan, it appears appropriate to extend such work to measure the radiological risk assessment of radionuclides to marine biota of entire coastal zone of Pakistan in order to assess the suitability of the resources for use by human being.

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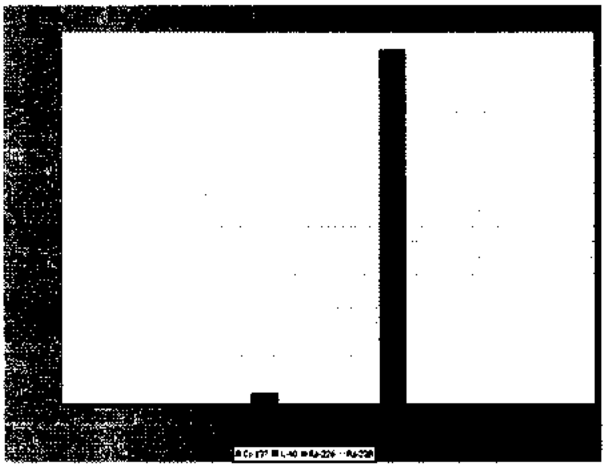
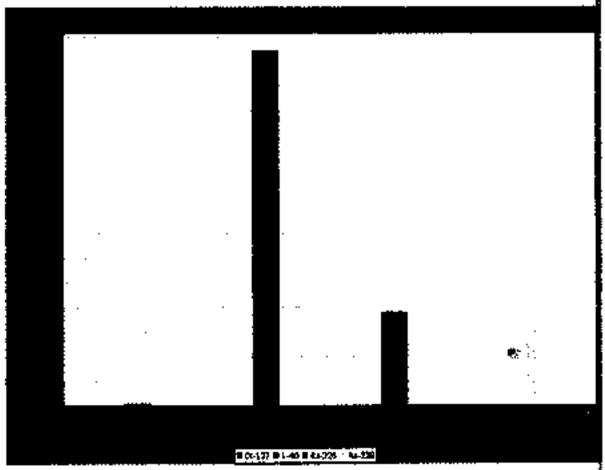
ANNEXURE

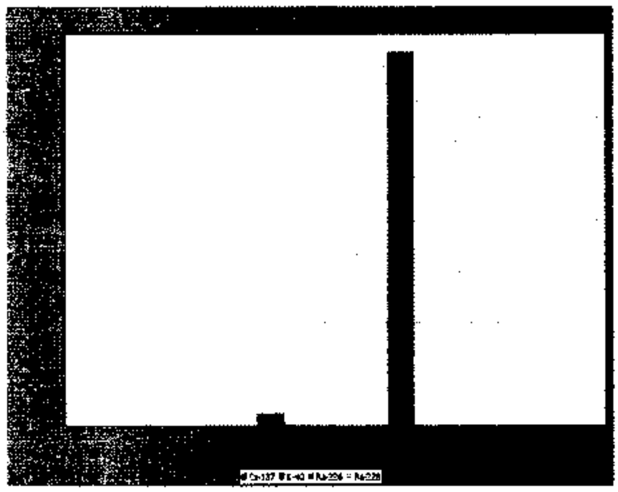
ERICA GRAPHS

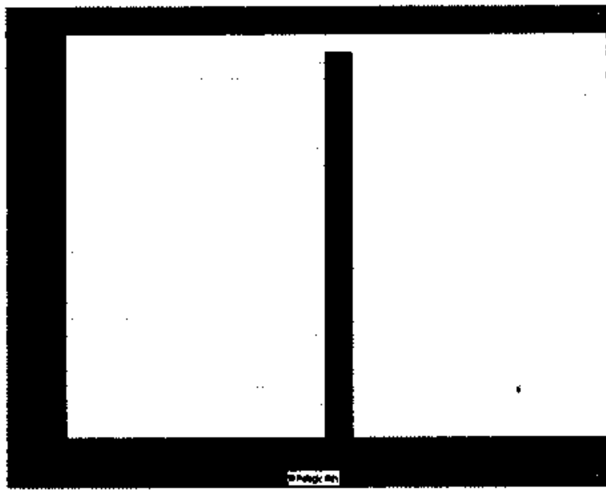
SOUTH EAST COAST

Silver Pomfret

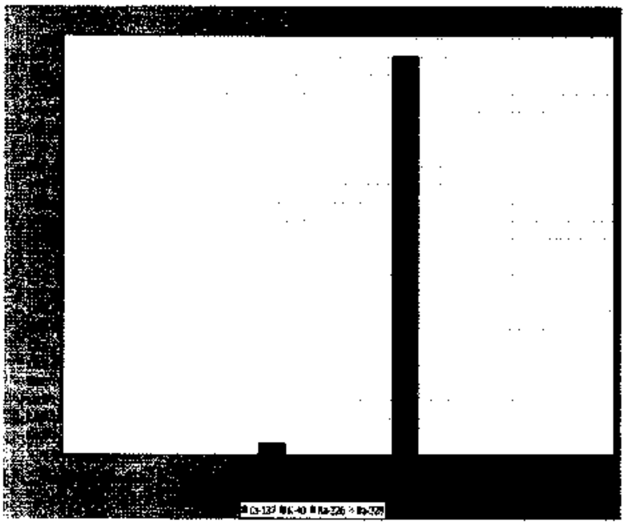


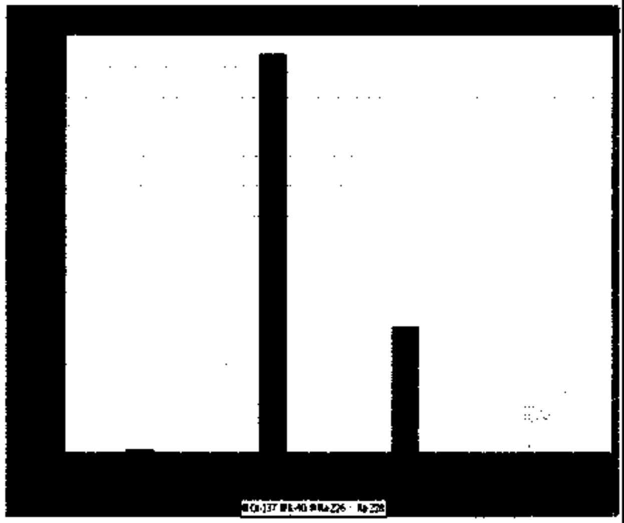


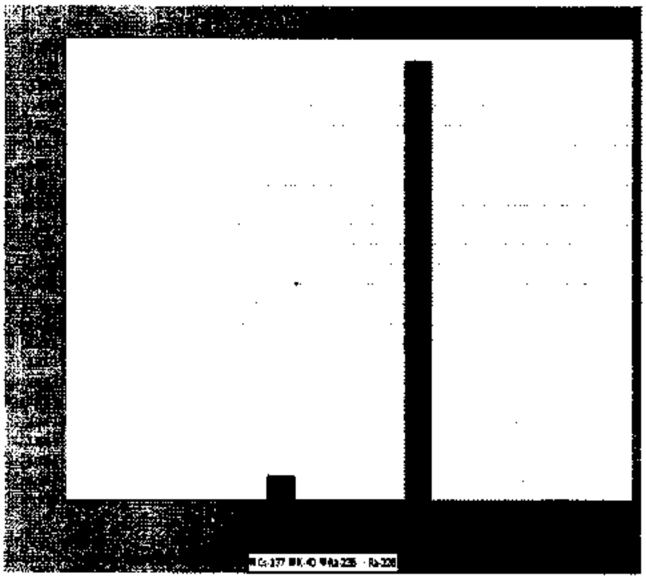


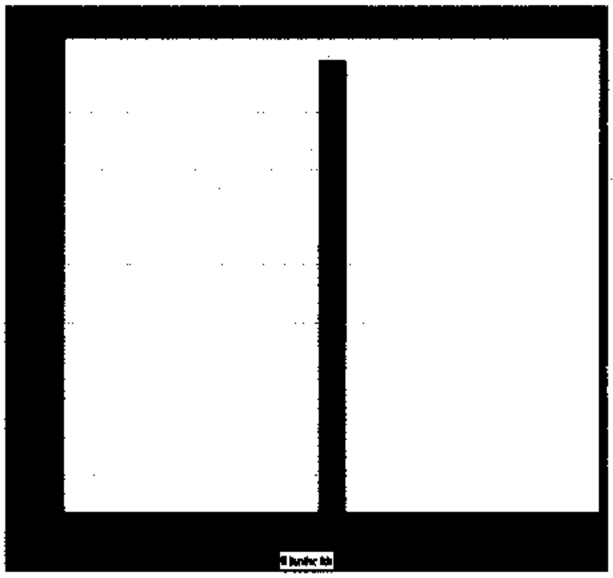


Malabour Grouper

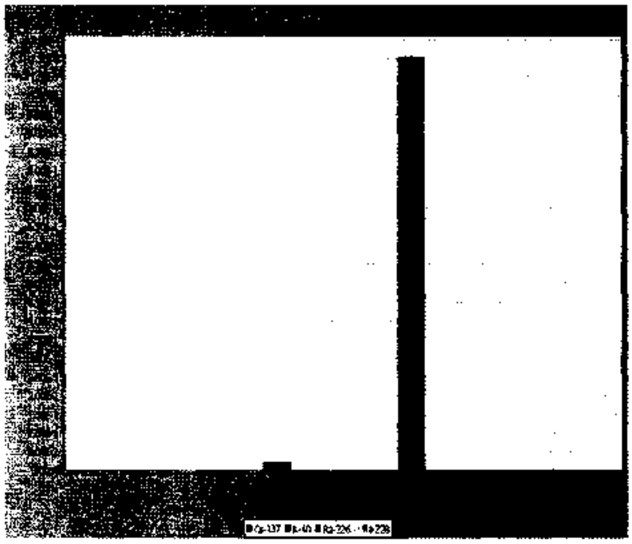


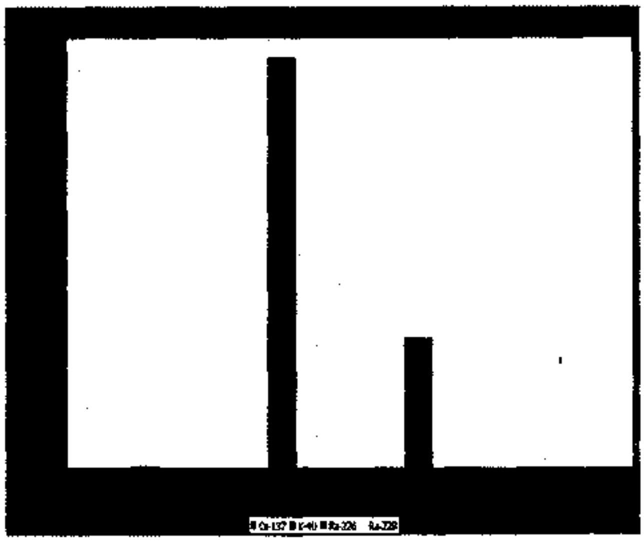


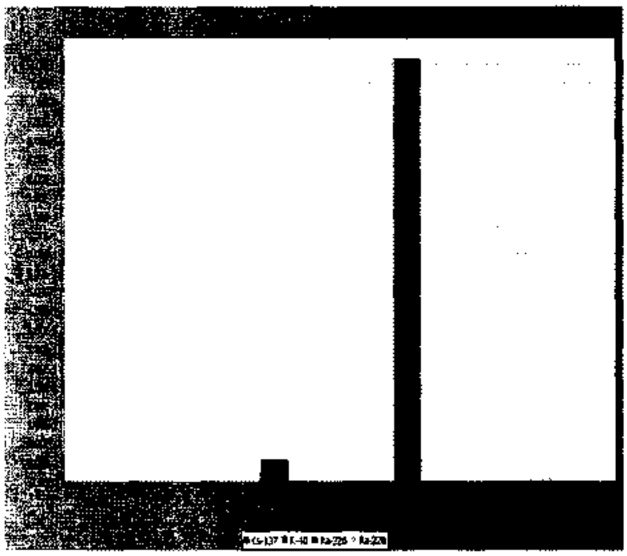


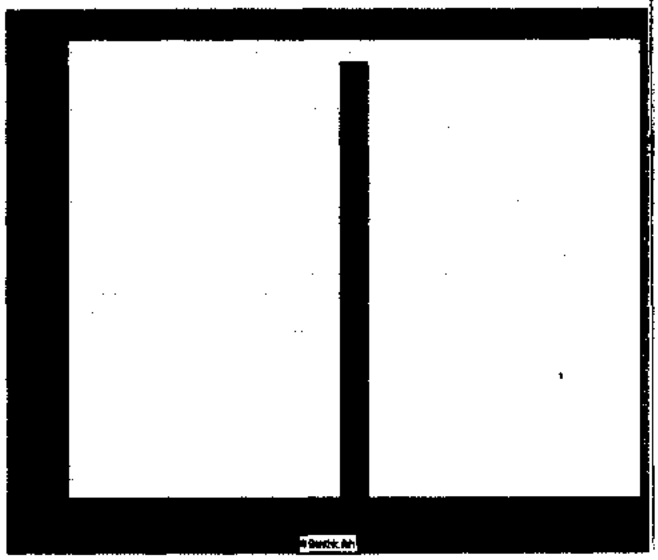


Sand Tiger Shark

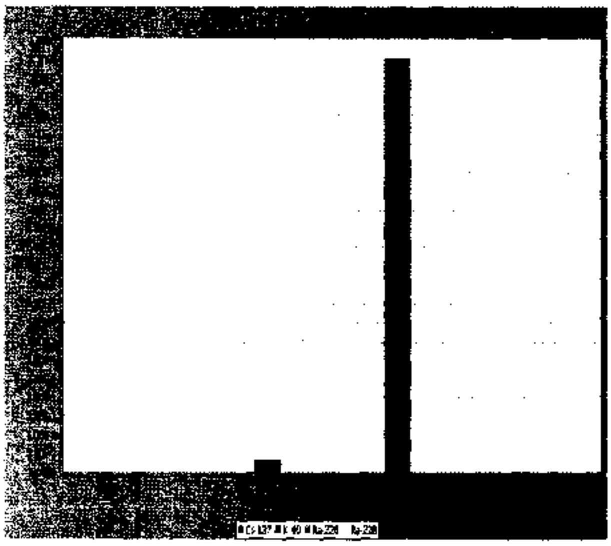


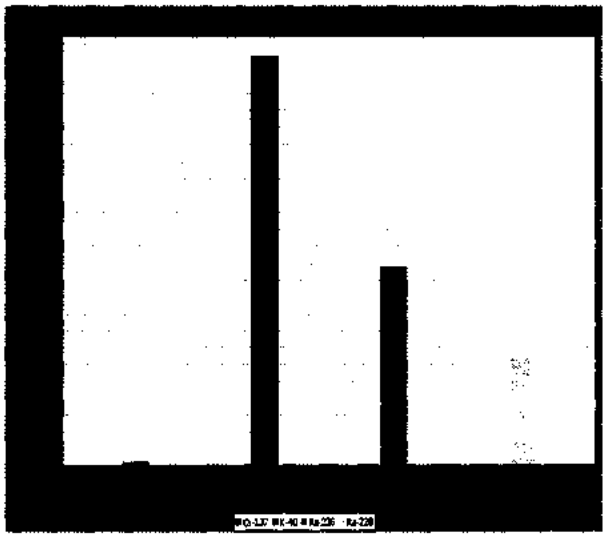


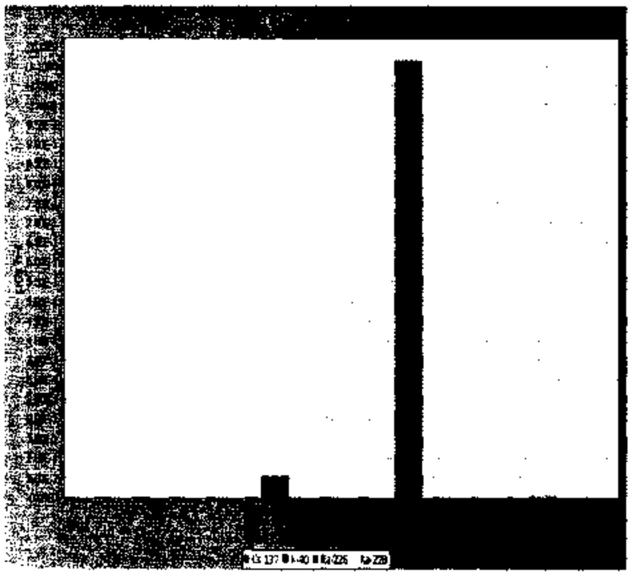


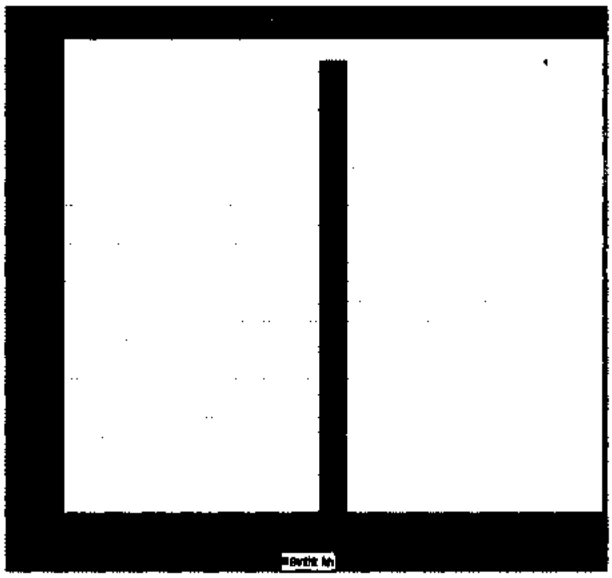


Cat Fish

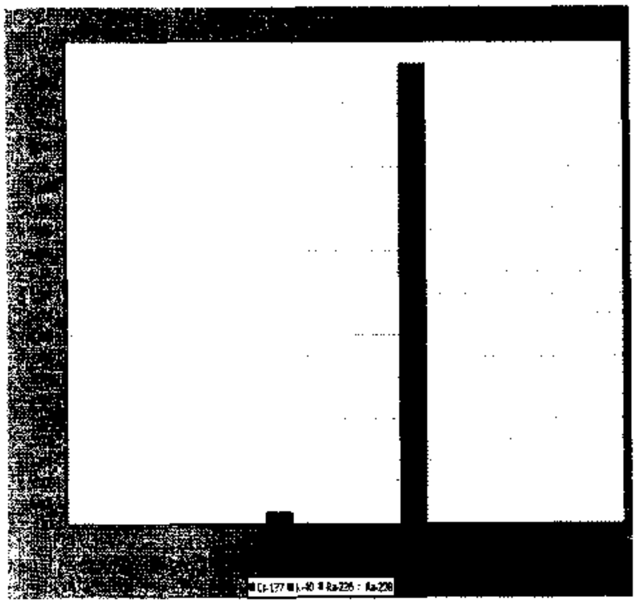


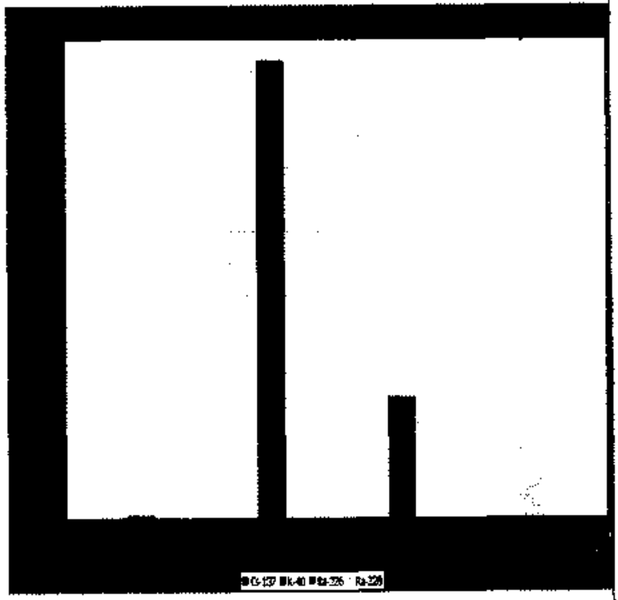


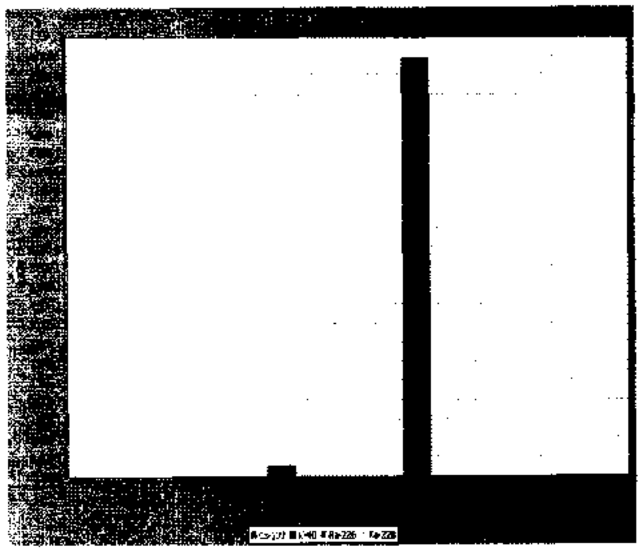


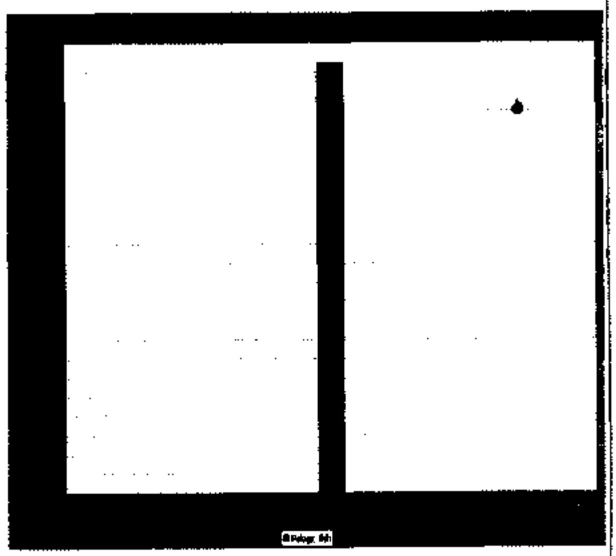


Indian Mackerel

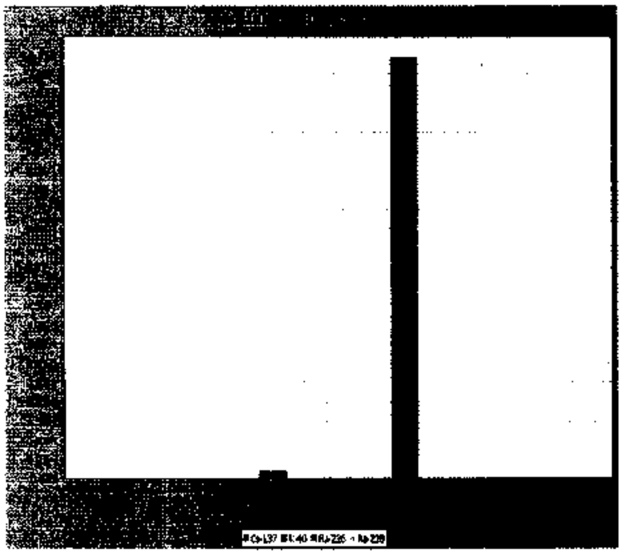


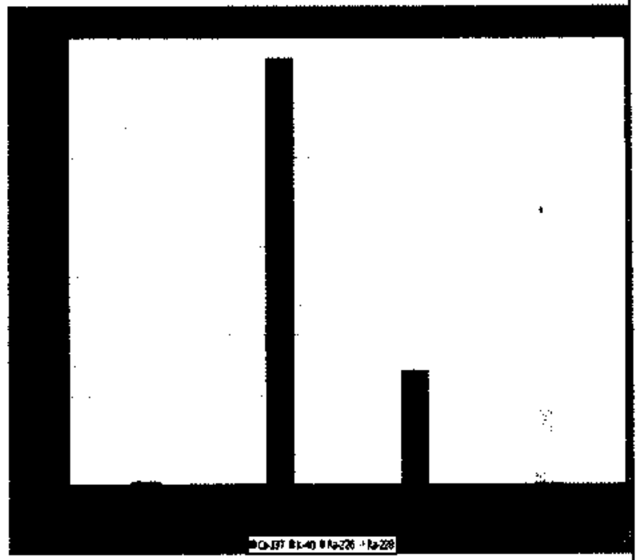


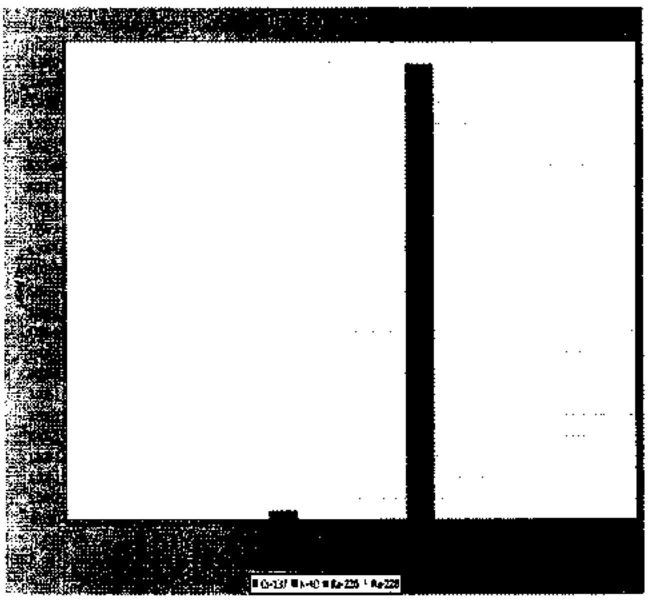


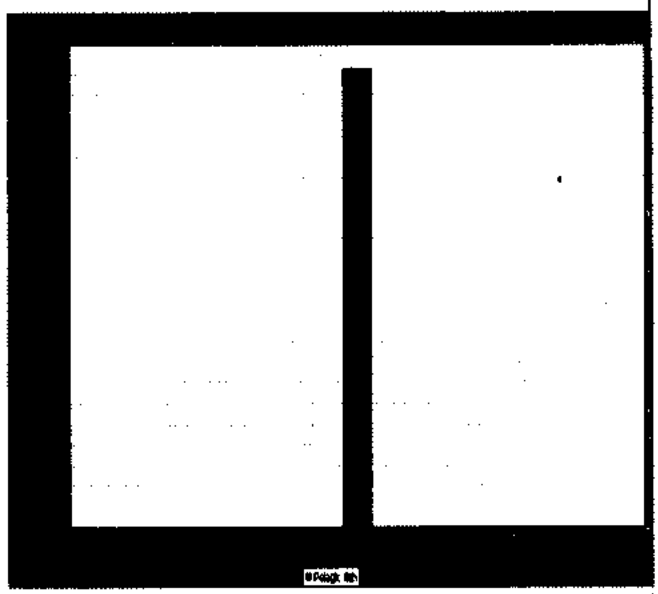


Salmon



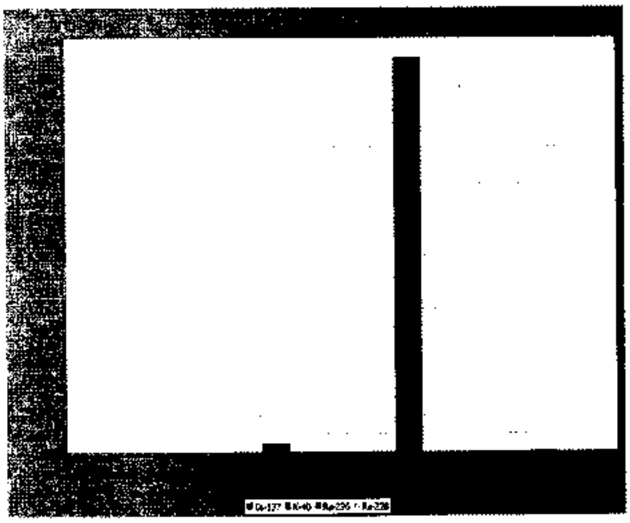


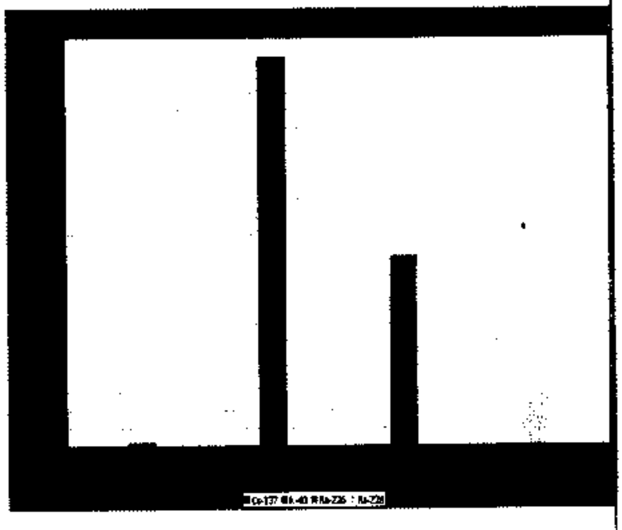


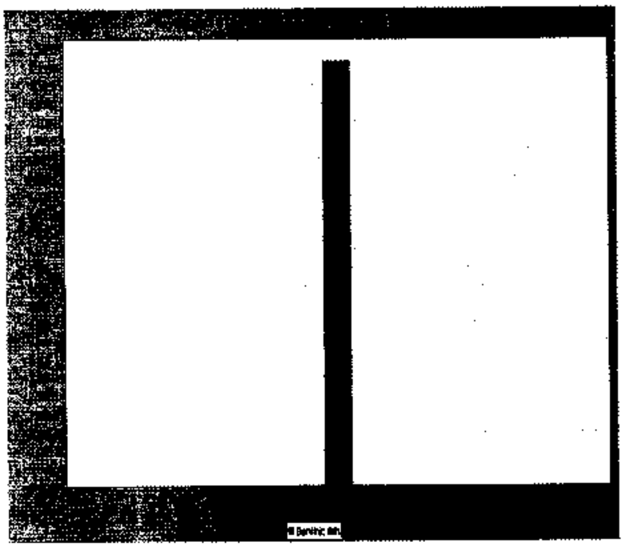


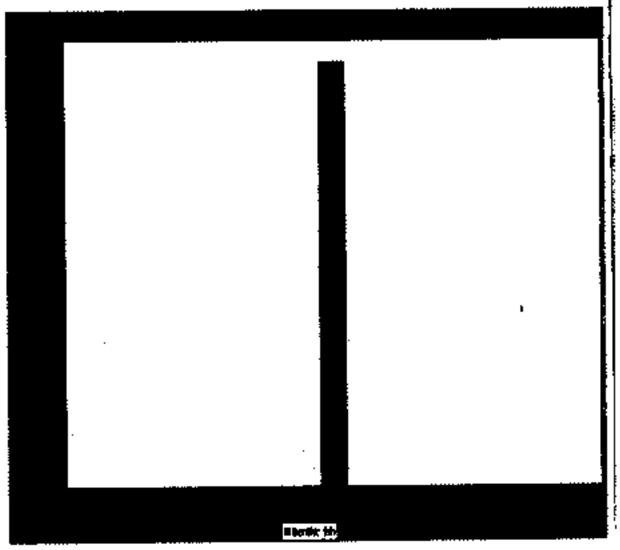
<u>**NORTH WEST COAST**</u>

<u>**CAT FISH**</u>

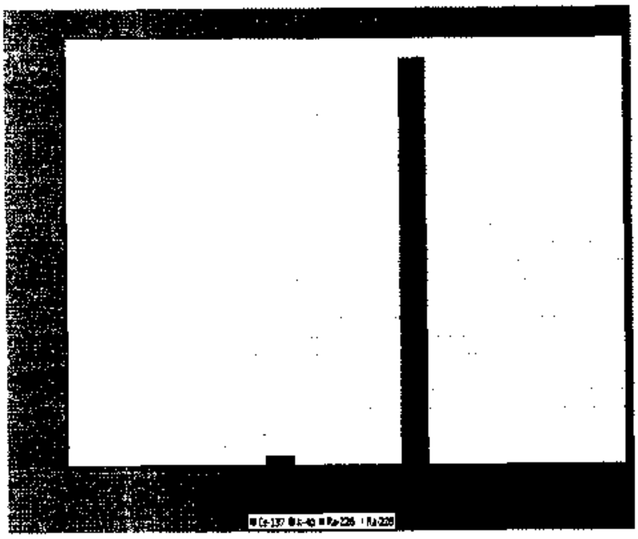


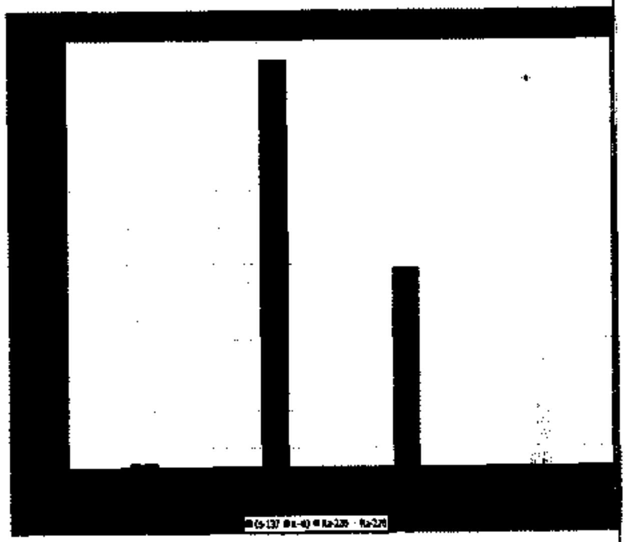


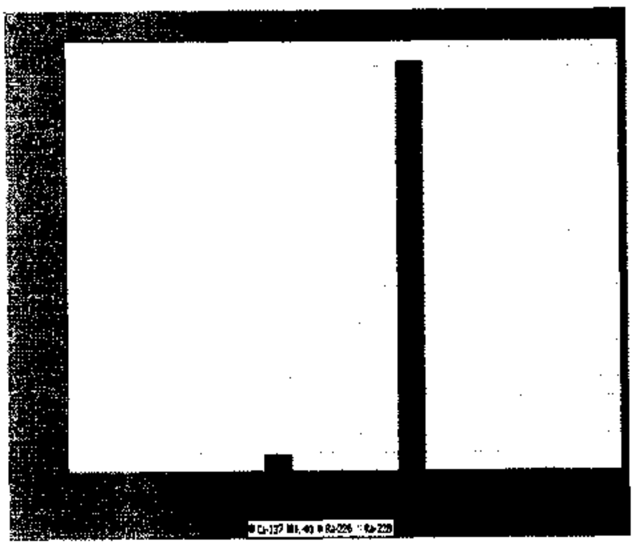


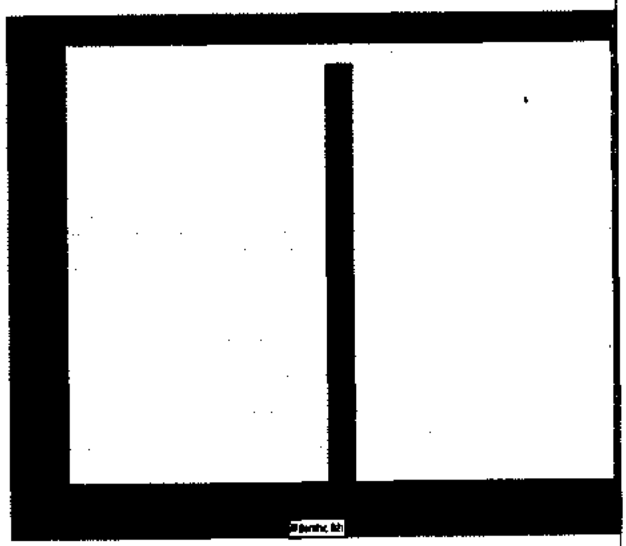


Eel fish

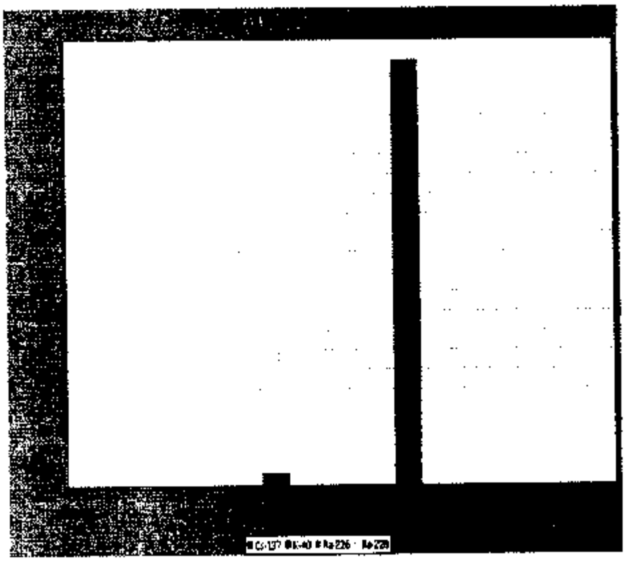








Ribbon fish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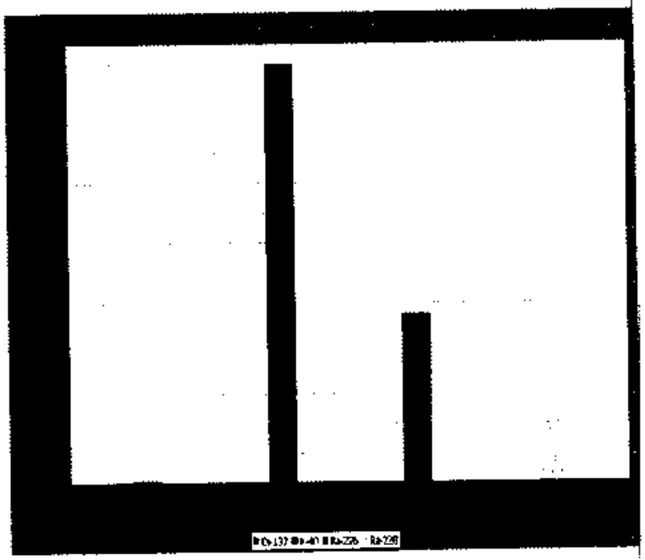
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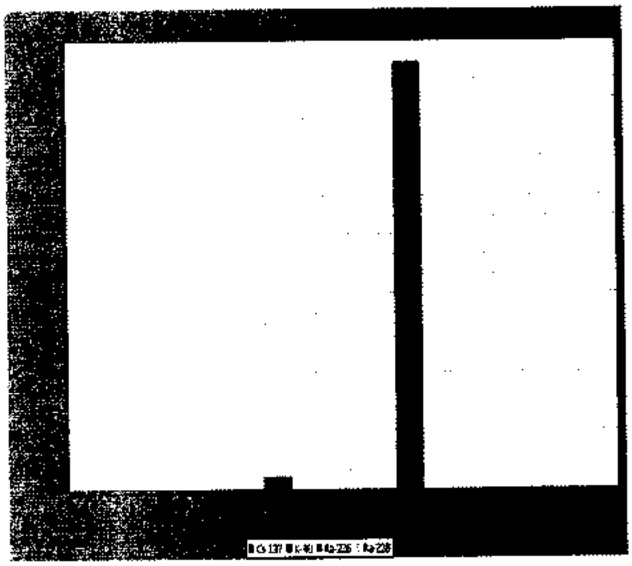
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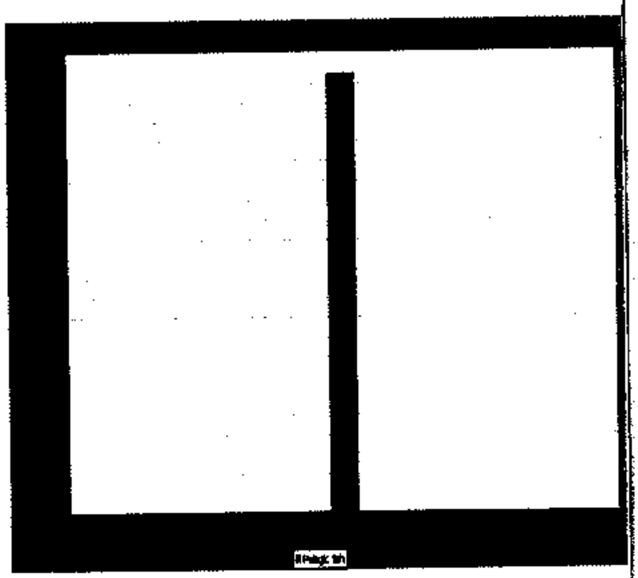
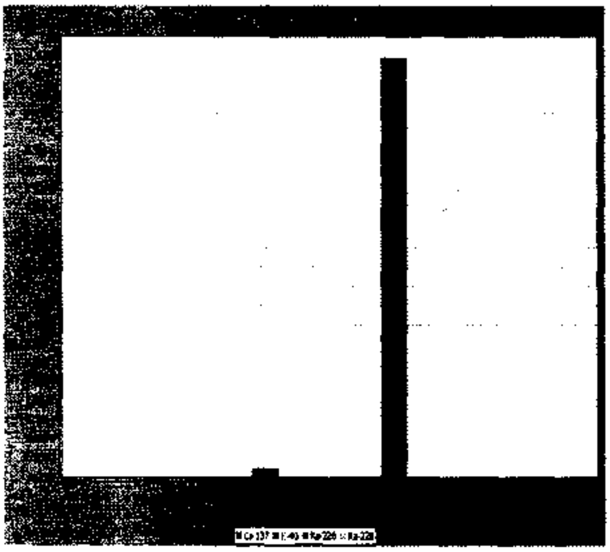


SOLE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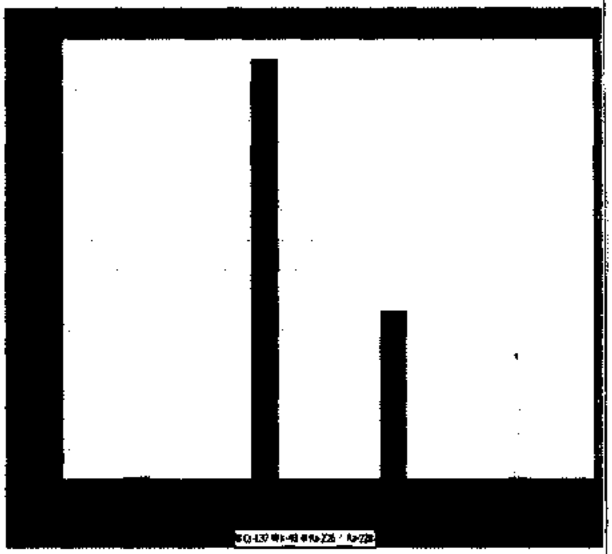
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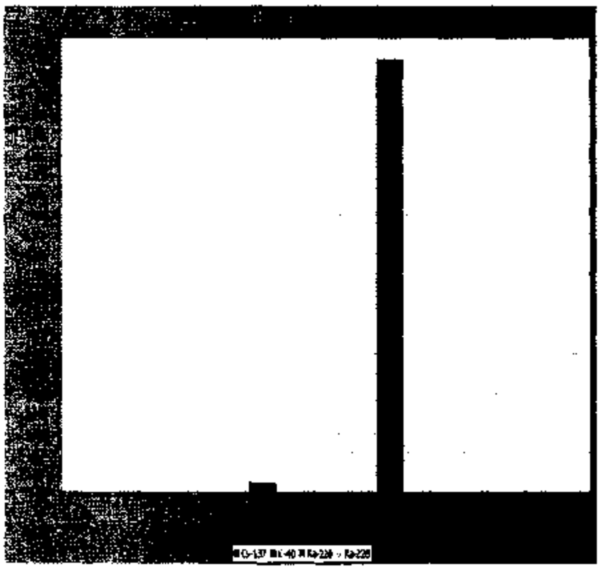
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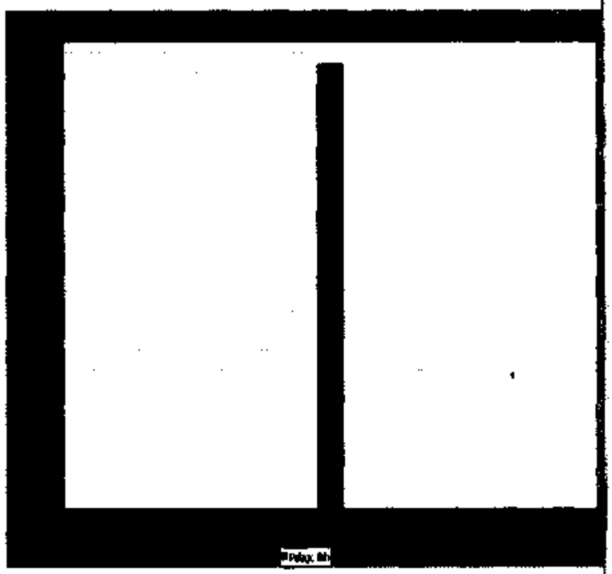
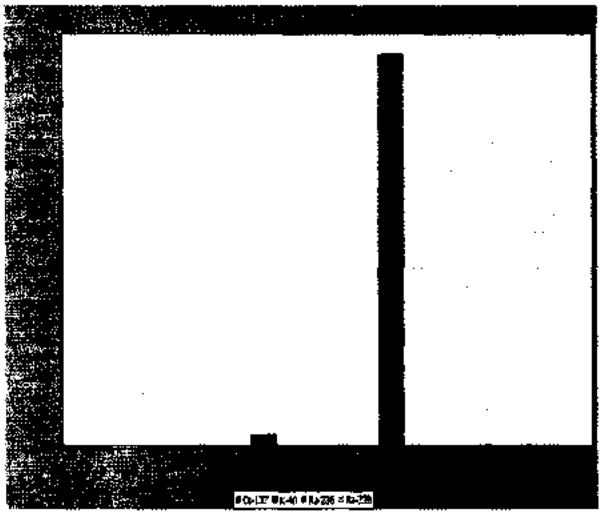
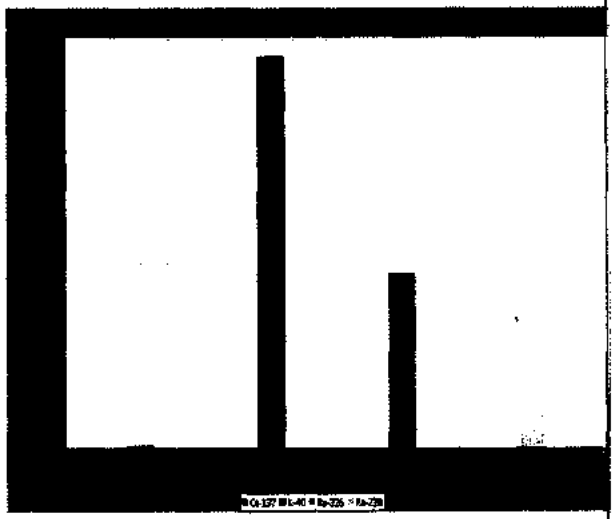
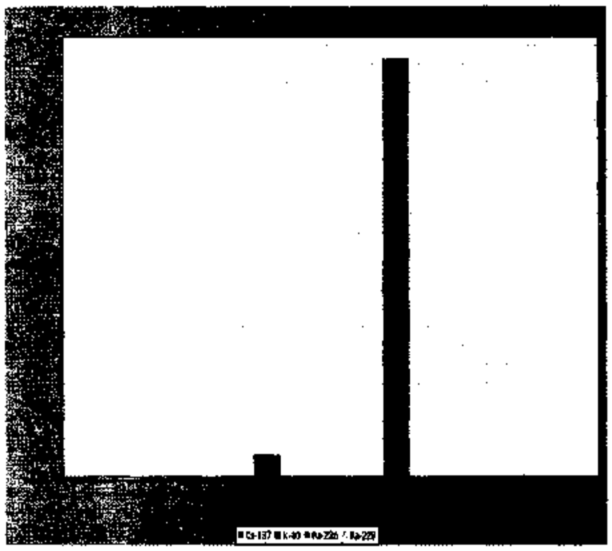


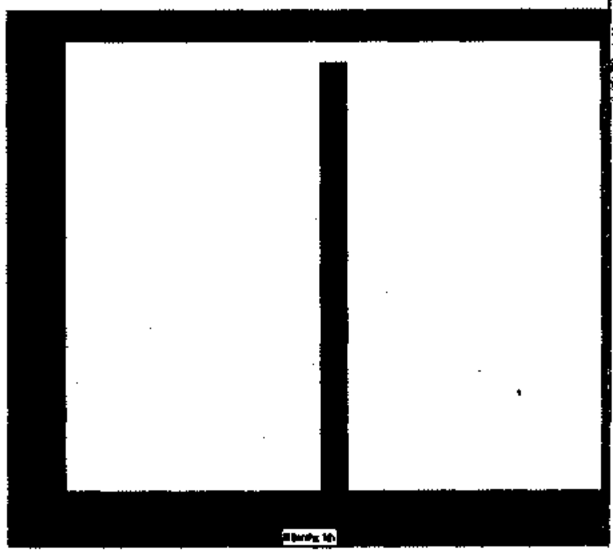
MANORA CHANNEL

CROAKER

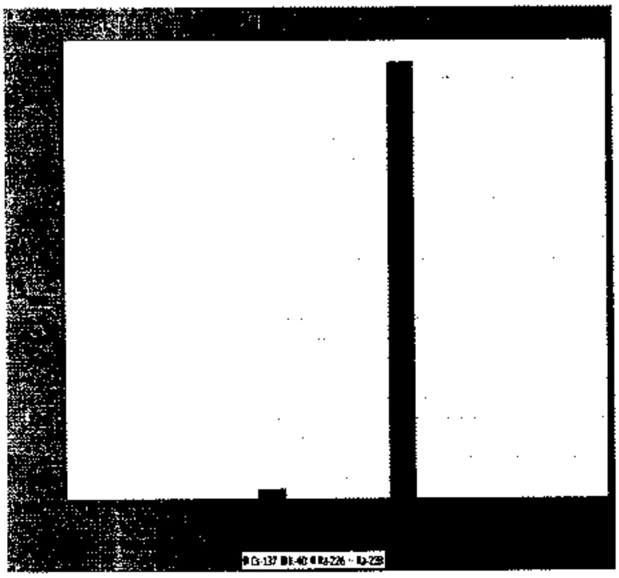


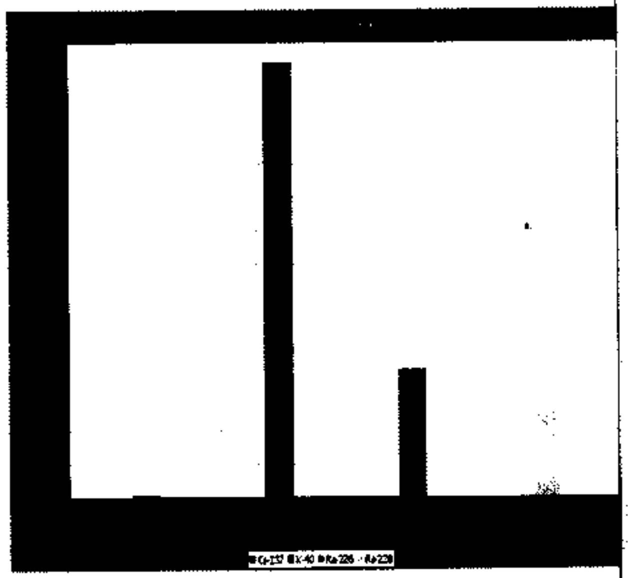


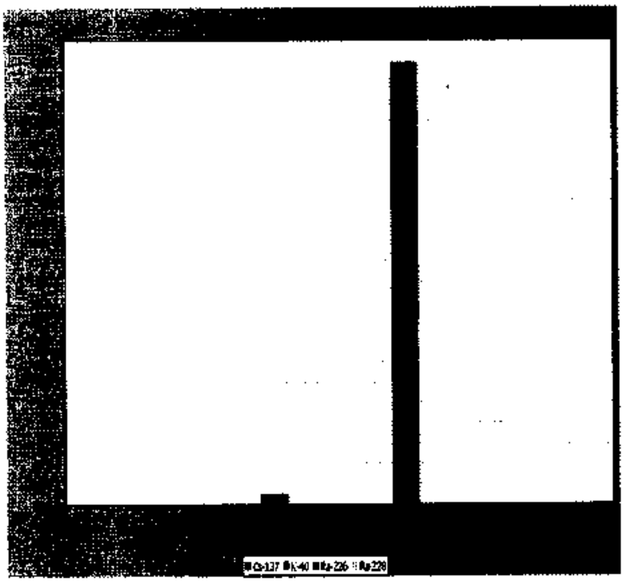


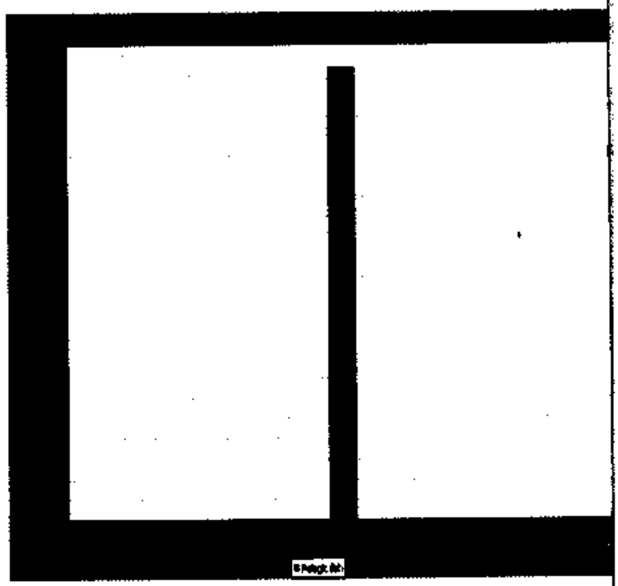


Black Sea Bream

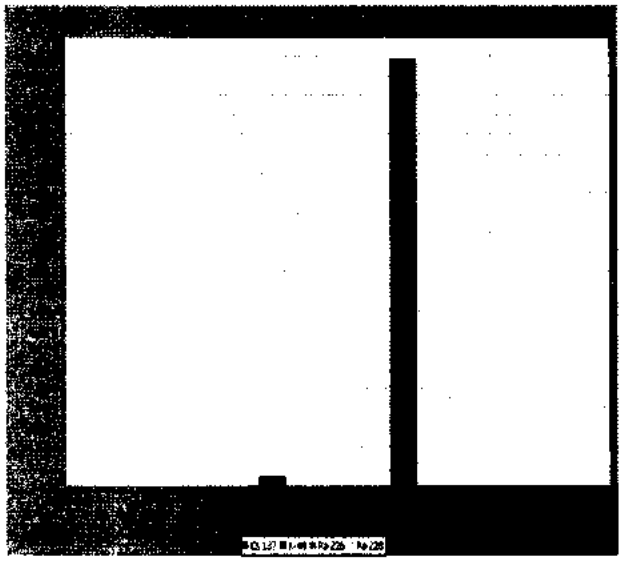


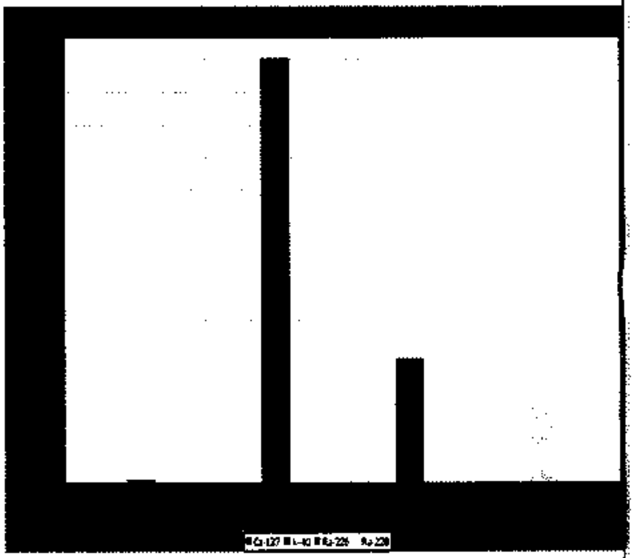


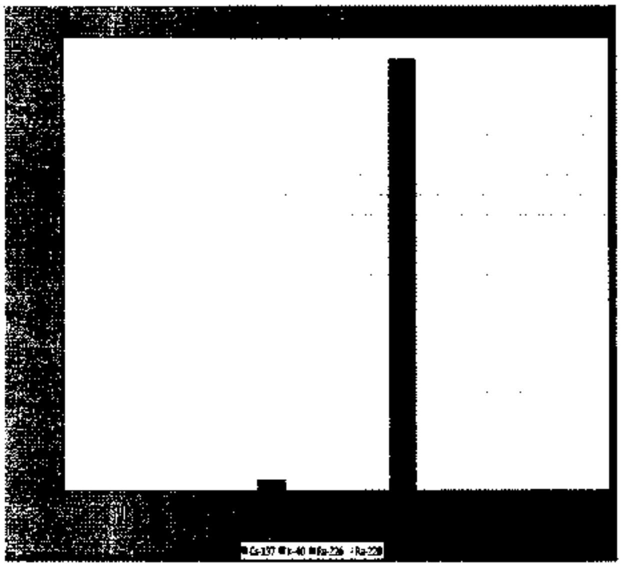


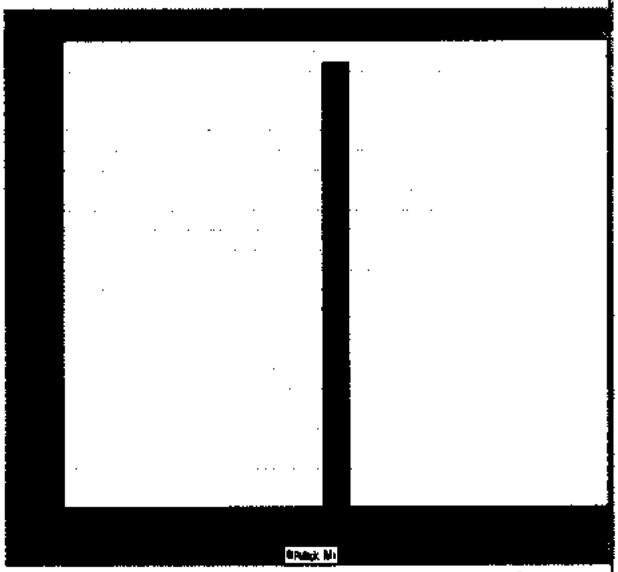


<u>**QUEEN FISH**</u>









Silvery Grunter