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Chapter 14

BIOLOGICAL SAMPLING FOR MARINE RADIOACTIVITY MONITORING

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Abstract

Strategies and methodologies for using marine organisms to monitor radioactivity in marine waters are presented. When the criteria for monitoring radioactivity is to determine routes of radionuclide transfer to man, the "critical pathway" approach is often applied. Alternatively, where information on ambient radionuclide levels and distributions is sought, the approach of selecting marine organisms as "bioindicators" of radioactivity is generally used. Whichever approach is applied, a great deal of knowledge is required about the physiology and ecology of the specific organism chosen. In addition, several criteria for qualifying as a bioindicator species are discussed; e.g., it must be a sedentary species which reflects the ambient radionuclide concentration at a given site, sufficiently long-lived to allow long-term temporal sampling, widely distributed to allow spatial comparisons, able to bioconcentrate the radionuclide to a relatively high degree, while showing a simple correlation between radionuclide content in its tissues with that in the surrounding waters. Useful hints on the appropriate species to use and the best way to collect and prepare organisms for radioanalysis are also given. It is concluded that benthic algae and bivalve molluscs generally offer the greatest potential for use as a "bioindicator" species in radionuclide biomonitoring programmes. Where knowledge on contribution to radiological dose is required, specific edible marine species should be the organisms of choice; however, both purposes can be served when the edible species chosen through critical pathway analysis is also an excellent bioaccumulator of the radionuclide of interest.

14.1. INTRODUCTION

There are two principal rationales for undertaking a biological monitoring programme in and around nuclear facilities located in the coastal environment. The first and perhaps most important concerns health safety and is meant to ensure that edible marine species consumed by the local population do not contain levels of artificial radionuclides that surpass the prescribed safe limits. The second involves the use of certain organisms as indicators of existant radionuclide levels in their surrounding environment. Both rationales, while quite different in their overall aim, call for a sound knowledge of the physiology and the ecology of the species concerned. In any biological monitoring programme, perhaps the most important task of all is to be able to gauge contaminant-induced variations of radionuclide levels in a population of organisms against radionuclide fluctuations brought on by natural causes - an extremely difficult task at present [1].

In the sections that follow, a brief discussion of the strategies for biological monitoring will be presented along with some suggestions for sampling key species that are most often used in contaminant monitoring studies.

14.2. CRITICAL PATHWAY APPROACH

If the criteria for monitoring radioactivity in marine organisms is to ensure the health and safety of the local population which consumes seafood, then the principal routes of radionuclide transfer to the consumer must be identified. This approach has been termed "critical pathway", and it takes into account only those species which form the principal diet of the seafood-eating population. In this case, organisms which readily accumulate radionuclides and are excellent bioindicators are not necessarily considered; only those species which contribute the major dose to the population are monitored. Once the key species has been identified, generally through a site survey of eating habits, the organisms are sampled and prepared as would be a bio-indicator organism as discussed below. A thorough discussion of the critical pathway approach and case studies can be found in the radioecology literature [see e.g., 2-5].

14.3. BIO-INDICATOR APPROACH

Alternatively, marine organisms can be used as environmental matrices to give information on levels of radioactivity, or changes in radionuclide levels in the surrounding environment. This method is called "biological monitoring" and makes use of the contaminant bioaccumulation potential of a given species. Organisms which have been used to quantify the bio-available level of contaminants like radionuclides in marine waters are commonly called "bio-indicator" or "sentinal" species. The pros and cons for the use of bio-indicator species for monitoring a wide variety of contaminants including artificial radionuclides have been addressed in numerous publications [6-11].

14.3.1. Use of bioindicators

Organisms accumulate radionuclides from both food and water, and resultant concentrations in their tissues provide, in theory, a time-integrated measure of radionuclide bioavailability. Thus, the principal justification for their use has been that they can bioconcentrate radionuclides existing at extremely low concentrations in ambient sea water to relatively high levels which are readily measurable. This overcomes the frequent difficulty of directly measuring radionuclides in sea water. Another obvious advantage of bio-indicators is that they accumulate the bio-available fraction of a radionuclide rather than give a measure of total radionuclide abundance, thus eliminating the need for time-consuming studies of the chemical speciation of radionuclides. A final major justification for their use is that they give a time-integrated picture of bio-available radionuclide concentrations provided certain criteria are met, in contrast to "snapshot" concentrations of radionuclides which may vary greatly over short time scales. Nevertheless, a good awareness of some of the drawbacks in their use is essential if bio-indicator monitoring programmes are going to succeed with their objectives.

When establishing a monitoring scheme using bio-indicators, three primary objectives must be considered:

(1) Identification of spatial variations in radionuclide abundance and bio-availability;
(2) Identification of temporal variations in radionuclide abundance and bio-availability;
(3) Identification of specific radionuclides.

Each basic objective can be achieved using specific bio-indicators but the design of the monitoring programme will differ in each case. For example, studies designed to follow spatial variability can not be confounded by temporal influences, and *vice versa*. These criteria have not always been met as Phillips and Segar [12] have so aptly shown in the case of the U.S. National Mussel Watch Programme [7,8,10]. Once the conceptual design for the overall monitoring programme is worked out, the choice of bio-indicator organism(s) becomes an easier task. Nevertheless, in the case of the bio-indicator itself, several criteria must be considered.

14.3.2. Selection of species

Implicit in the use of bio-indicators is that they adequately reflect contaminant concentrations in the ambient waters. This means that metabolic regulation of certain elements or radionuclides should not mask or interfere with spatial and temporal variations that occur in the environment. Not all organisms meet this requirement and in fact many teleosts, bivalve molluscs, crustaceans and mammals regulate the incorporation of certain elements [9]. Even passive accumulators like marine macro-algae which are excellent candidates for sessile bio-indicators [13] often display a non-linear uptake relationship with the concentration of certain metals and radionuclides in sea water. Obviously prior knowledge about which radionuclides are, or are not, metabolically regulated by a given species is essential before selecting the proper bio-indicator. In this respect, some of the best heterotrophic candidates may be very small species in which surface adsorption plays an important role in the contaminant uptake process.

14.3.3. Contaminant interactions

The occurrence of contaminant interactions on the uptake of a given element or radionuclide can not be overlooked. Indeed, if the bio-availability of a radionuclide of interest is affected by the presence of other contaminants, the use of a valid bio-indicator is compromised. Cases of pollutant interactions have been well-documented [9,12] and there is a definite need for laboratory and field studies to work out these relationships in the uptake process.

14.3.4. Temporal integration of radionuclides

The time-integration ability of an organism can vary according to the radionuclides under study. For example, the biological half-lives of many radionuclides in bivalves and crustaceans are on the order of months or more whereas half-lives for other nuclides may be quite short (i.e. a few days). Thus, depending upon the radionuclide, levels in a given species may reflect accumulation over the previous year or, on the other hand, over the previous few days. Prior knowledge of the radionuclide uptake kinetics will thus dictate the frequency with which the organisms are sampled. This aspect is often overlooked in bio-indicator surveys, thus greatly limiting the usefulness of the resultant information and cost-effectiveness of the survey.

14.3.5. Spatial integration of radionuclides

To identify spatial variations in radionuclide bio-availability, the bio-indicator should be sessile, sedentary or, in the case of open waters, associated with at least a given water mass. In this respect, filter-feeding bivalves, sponges and algae are excellent choices because they are often fixed to the substrate. Large pelagic fish are not ideal because of their great mobility, however, demersal or highly territorial fish have been used successfully for temporal and spatial assessments of radionuclide contamination [14]. In more open waters, zooplankton and micronekton species which can be identified with a given water mass are about the only possible candidates, even though factors such as mixed species composition (e.g., micro-zooplankton), molting and vertical migration behaviour limit their usefulness [15].

In order to maximize the information obtained for each analysis as well as overall cost-effectiveness of the bio-indicator programme, "space-bulking" of samples [12] can be undertaken. This involves pooling bio-indicator samples from several relatively closely-spaced locations for a single analysis. Space-bulking therefore smooths out short-term variations at a given site and is especially useful for examining long-term variations in contaminant bio-availability.

14.3.6. Transplanted organisms

In certain areas that are intended to be monitored but where no adquate bio-indicator can be found, transplantation of appropriate species has been attempted using cage or buoy systems [16]. One advantage is the use of cultured populations (e.g., mussels) which show lower age variability than in wild populations. In addition, besides measuring radionuclide levels at equilibrium after transplantation, time course measurements will furnish information on the kinetics of uptake or loss.

14.3.7. Other biological and environmental factors

Phillips [9] has thoroughly reviewed the many factors that are considered to influence seasonal or temporal bio-availability and they will be only briefly discussed here. Short-term fluctuations may interfere with assessments of spatial and temporal variations in bio-availability. One cause can be highly variable contaminant input from episodic events or through increased rainfall during certain seasons. Another cause may be physiological changes related to the sexual cycle, e.g., fluctuations in lipid content with concomittant changes in lipophilic contaminant concentration. Obviously quantification of lipids would be of utmost importance when using bio-indicators for organically-bound radionuclides. Likewise, dry weight changes can effectively alter radionuclide concentrations that are derived on a weight basis (e.g., radionuclide activity per gram dry weight). If true radionuclide variations between sites are of the same order as those brought about by physiological changes within a given site, intersite comparisons will be difficult to make. Thus, it is necessary to have a good understanding of sources of variance within the populations used as bio-indicators.

Age and size are also variables affecting radionuclide concentrations. This problem can be overcome for the most part by understanding the relationship involved and sampling individuals within a given size range. Other parameters of usually lesser importance include location of individuals in the intertidal zone, substrate on which they live, and sex of the organism. Many of the above-mentioned effects of these parameters can be overcome by making pooled samples consisting of several individuals and analyzing replicates [17].

14.4. SAMPLING OF KEY SPECIES

Not overlooking many of the drawbacks in the use of bio-indicators mentioned above, these organisms have been instrumental in establishing spatial and temporal trends in radionuclide fluctuations in a variety of marine ecosystems [7-10, and many others]. Bivalve molluscs, sessile algae and fish have proven particularly useful in establishing temporal trends and hotspots in coastal waters throughout the world. With proper intercalibration of methodologies, studies with such coastal organisms could be linked into a far more widespread coastal network. Relatively unsophisticated analyses of radionuclides in these species are well within the grasp and budgets of many developing countries and results can be verified through stringent intercomparisons with standard reference materials [18,19]. In fact, considering all possible alternatives, these types of bio-indicators may offer the most realistic and economical method of monitoring changes in radionuclide bio-availability.

Outlined briefly below are strategies and guidelines for sampling benthic algae, bivalve molluscs, fish, plankton and crustaceans in the context of a marine radioactivity monitoring survey.

14.4.1. Macroalgae

For many reasons marine macroalgae are excellent organisms for use in monitoring programmes. Macroalgae are ubiquitous in both estuarine and coastal waters throughout the world. Algae are key links in benthic food webs and are of direct economic importance to man as well. Their size and sedentary nature facilitates rapid collection of large amounts of material. Because they act as time-integrators of many pollutants, macroalgae have been considered in many marine pollution monitoring programmes for use as bio-indicator species.

Phillips [20], reviewing the usefulness of biological indicator organisms in trace metal pollution studies, listed several criteria for an organism to qualify as a "bio-indicator" for these substances. The criteria, which generally hold for most pollutants including radionuclides, can be briefly summarized as follows:

The organism should:
- accumulate the pollutant without being killed by the levels encountered;
- be sedentary in order to show levels of pollutant representative of the area under study;
- be abundant in the region;
- be sufficiently long-lived to allow sampling of more than one year class;
- be of adequate size to furnish sufficient tissue for analysis;
- be easy to sample and hardy enough to survive laboratory testing of pollutant uptake;
- be able to tolerate brackish water;
- exhibit high pollutant concentration factors allowing direct analysis without pre-concentration;
- be able to show a simple correlation between the pollutant content in their tissues with that in the surrounding waters at all locations studied, under all conditions.

It is evident that in most cases, macroalgae could be classified as a biological indictor organism; however, as Phillips [20] points out, certain things must be known about them to correctly interpret the results from a monitoring study using these species. For example, macroalgae appear to concentrate only soluble trace elements; hence, for radionuclides of lead and iron,, which are mainly particulate in sea water, algae will not accurately reflect changes in the environment. Furthermore, some studies have shown competition between metals for binding sites in macroalgae [21]. Excluding certain soluble metals from binding can lead to spurious results concerning the relative abundance of available trace elements or radionuclides at any one location. This could be one of the greater problems to overcome in using macroalgae as a biological indicator for monitoring radionuclides.

TABLE I. TYPICAL RADIONUCLIDE CONCENTRATION FACTORS FOR MACROALGAE AND MEAN CONCENTRATIONS OF RADIONUCLIDES MEASURED IN CONTAMINATED BROWN ALGAE *(FUCUS)* COLLECTED AROUND THE BRITISH ISLES AND ALONG THE WEST COAST OF SWEDEN

Radionuclide	Measured Concentration ($Bq\ kg^{-1}$ dry)		Typical Concentration Factor***
	U.K.*	Sweden**	
^{58}Co		45-73	$5.6\text{-}6.6 \times 10^{4}$
^{60}Co	70	78-111	$1.4\text{-}7.5 \times 10^{4}$
^{65}Zn	63		2×10^{4}
^{90}Sr	370		1×10^{1}
$^{95}Zr\text{-}Nb$	107		3×10^{3}
^{106}Ru			2×10^{3}
^{110m}Ag	56		2×10^{3}
^{134}Cs	373		$8.5\text{-}9 \times 10^{1}$
^{137}Cs	2775	7.4	$8\text{-}9.5 \times 10^{1}$
^{144}Ce	633		5×10^{3}
^{238}Pu	141		1.35×10^{4}
$^{239+240}Pu$	999	0.19	1.35×10^{4}
^{241}Am		0.053	1.8×10^{4}

*From 18,19
**From 23
***From 23,24

Several other aspects which pertain to variations in concentration of metals in macroalgae should be considered. Metal levels vary remarkably with species, therefore comparisons of tissue concentrations are best made between the same species. The position of the algae on the shoreline with respect to tide mark also can affect the metal concentration [22]. Several studies have shown that the distal (older parts of macroalgal lamina often contain higher metal concentrations than the faster-growing new tissue [22]. It was suggested that the older, slower-growing regions of the lamina with higher dry weight have more metal-binding sites. All the above could affect the measured concentrations of radionuclides in the species collected.

Table 1 gives some values for radionuclides measured in a common brown algae, *Fucus* from various areas along the U.K.and Swedish coasts which have received radioactive inputs from nuclear industry.

14.4.1.1. Selection

Choice of algae depends on the region being considered for monitoring. In the near-shore environment, in general, representatives of the *Phaeophyceae*, or brown algae, would appear to be the most suitable. This most familiar class of algae contains members throughout the world. The largest forms of macroalgae belong to this group and, as a whole, most species are readily obtainable because they grow in the intertidal zone. Within this group, members of the genus *Fucus* should be considered as a first choice principally because several of these species have already been used in radionuclide monitoring programmes [25]. Two other genera, *Laminaria* and *Ascophyllum*, have also been the subject of pollution surveys and could be considered as alternative species.

4.4.1.2. Collection, Preparation and Analysis

The best way to collect uncontaminated seaweed samples is by hand. This is easily done with species such as *Fucus* when the algae are exposed at low tide. Care should be taken to sample only the outer fronds (lamina) since the lower stipe and holdfast often contain sand and grit. After collection the lamina are rinsed in clean sea water to remove the adhering silt. Samples are best shipped to the laboratory in large, pre-cleaned glass (or glass-lined or plastic) containers. The algae is later rinsed in de-ionized double-distilled water to remove much of the adventitious salts. Wet algae with excess water removed with paper towels are weighed prior to drying so that dry weight/wet weight ratios can be determined for future reference. The possibility exists that certain radionuclides may be volatilized at temperatures normally used for oven drying; therefore, it is generally preferable to lophilize the tissues [26]. If preliminary tests indicate difficulty in powdering lophilized whole algae, the samples should be homogenized in a blender prior to freeze-drying. This pre-treatment usually results in obtaining a more homogeneous powder during the grinding process.

The dried product is broken by hand into small pieces (~5cm x 5cm) and then ground to a fine powder in a comminuting machine or porcelain ball mill. The resulting powder should be carefully sieved through stainless steel or nylon screens to remove both large refractory particles and ultra-fine sediment grains.

Homogenization is best carried out in some type of commercial feed mixer which automatically divides the sample, mixes and recombines the mixed product. At this stage, homogeneity can be tested for the radionuclide of choice with random aliquots taken from bulk tissue samples.

Non-destructive gamma-ray spectrometry is ideal for many gamma-emitting isotopes since the entire sample can be counted in a well-type scintillation crystal. Most beta and alpha-counting techniques require decomposition and separation of the radio-isotope from the matrix. Some species of macroalgae have high levels of calcium and phosphorus which may interfere in the separation of transuranium nuclides from these tissues. Similarly, caution should be observed in separating certain radionuclides from coralline algae which contain large amounts of calcium and magnesium. Standard radio-analytical methods and their applicability to the measurement of a variety of radionuclides in macroalgae are discussed in detail in two recent technical reports [27,28].

14.4.2. Bivalves

From a brief scanning of the marine pollution literature, it is evident that bivalve molluscs have been the most commonly used bio-indicators to date. This is largely because bivalves conform well to the basic pre-requisites of an indicator species [9], are often consumed as seafood, and are ubiquitous in most coastal marine ecosystems. Mussels, oysters and clams are the species most frequently chosen, and their use has lead to "Mussel Watch"-type pollution monitoring programmes throughout the world [7-9,29]. Mussels of the genus *Mytilus* have usually been the bivalve of choice in temperate zones because of their widespread occurrence. In tropical regions where mussels are uncommon or non-existent, sessile species such as the rock oyster (*Saccostrea* sp.) have been used. In areas where neither type is found, intertidal clams have proven useful. While all three molluscs have been used for radionuclide monitoring, the choice inevitably depends on the overall availability of the organism at the study site.

Because of the small size of most bivalves, in order to avoid biasing the analysis, several individuals (generally 5-20) from a population are pooled to form a single sample. Each individual should be approximately the same size and its length and/or weight measured since size can affect radionuclide content [9]. Following collection, the individual bivalves are opened with a shucking knife and the soft parts removed for the sample. In some studies where more refined bioaccumulation information is needed, target tissues (e.g., hepatopancreas) can be dissected from the soft parts to form a sample. The methodologies for shucking the molluscs and preparing the soft tissues for radionuclide analyses generally follow those that have been internationally accepted for trace metals (e.g., see 17,30].

Oysters are sampled and prepared in generally the same way as the mussels. An exception is the rock oyster which has one of its valves cemented to the rock and is very difficult to open. Either the oysters must be broken off the rocks with hammer and chisel, and opened later, or the top shell removed by diving knife and the soft parts scraped directly into the collection bottle.

Many species of clams are generally found embedded in the bottom sediments and must be dug out by shovel. Such species often contain large amounts of fine sediments and analysis of the total soft parts containing contaminated sediments can lead to spurious results [31]. It is therefore recommended that, prior to dissection, the clams be held for several hours in filtered sea water from the site to depurate the residual sediments.

When the tissues are dissected, freeze-drying and homogenization of the dried material proceed as outlined for the algae. Examples of the use of bivalves in marine radioactivity monitoring studies can be found in numerous reports and scientific publications [7,8,16,32-35].

14.4.3. Fish

Because of their economic importance to man, fish have regularly been used in marine radioecology studies [14,20,36-42]. Nevertheless, as a measure of radionuclide levels in the marine environment, few fish species conform even to the basic requirements of an indicator species [9]. For example, many fish species are highly mobile or migratory and, at best, provide only a composite average of ambient radionuclide levels over a large area. To some extent, this problem can be overcome by using demersal fish or species that are highly territorial. Another problem is that uptake of certain stable elements of many common radionuclides are often regulated and, hence, the concentration of these radionuclides in fish tissue will not reflect changes of ambient levels in the environment. Therefore, if fish are chosen as a bio-indicator, both the fish species and the target radionuclide must be carefully considered.

Local conditions and knowledge of the fish species selected will dictate how the fish are collected (i.e. hand-line, benthic trawl, nets, etc.). Before dissection, one should determine the length, weight and sex of the individual fish since these parameters can affect radionuclide concentrations. Attempts should be made to standardize upon a given size of fish in order to reduce biological variation. If the fish species is large, individuals can be dissected for a single sample. For small fish, it is often necessary to pool tissue from several individuals to form a composite sample. In either case the skin, which contains mucus and can be easily contaminated with adsorbed radionuclide, must first be removed. Then a muscle filet is carefully cut away from the vertebral column taking care not to include bone. The amount of fish muscle sample will depend on the level of radionuclide that is detectable, therefore, some prior knowledge of the approximate radionuclide concentration is necessary. Samples are then placed in plastic bags and directly radioanalyzed or frozen for later analyses. The number of individual fish samples collected will depend on the nature of the monitoring programme and the desired level of statistical significance. Details on the sampling and preparation of fish tissues for pollutant analysis as well as suggestions for making composite samples can be found in Bernhard [17].

14.4.4. Plankton

Marine plankton are extremely important in terms of their total biomass, their key position in the food web and their ability to rapidly accumulate trace elements from the surrounding water mass; hence, they have also been used as indicators of ambient levels of contamination [43,44]. For this reason, a brief mention of their applicability to marine radioactivity studies is warranted.

First, it is important to remember that the composition of plankton is extremely varied and most often comprised of many different organism types, both plant and animal. As the bioaccumulation response of each species for radionuclides will vary, changes in species composition can confound radionuclide comparisons from one sample to the next. Therefore, if possible, it is always best to select single genera or individuals of the larger species for the analyses. In this respect, the shrimp-like euphausiids (commonly called krill) have shown promise as bio-indicators in trace metal surveys [15]. Because zooplankton are rapid integrators of radioactivity and generally accumulate radionuclides to very high levels (Table 2), they have also proven useful in signalling the presence of radioactivity in the water column following accidents or deliberate releases of radionuclides [45,48,49].

A variety of plankton nets of various net mesh-sizes are used to filter plankton from the water. The mesh size of the netting is chosen depending upon the size fraction of the plankton or, in some cases, the individual organisms in the plankton that are desired. Since plankton usually

TABLE II. TYPICAL CONCENTRATION FACTORS FOR ARTIFICIAL RADIONUCLIDES AND ABSOLUTE RADIONUCLIDE CONCENTRATIONS WHICH HAVE BEEN MEASURED IN CONTAMINATED MIXED-ZOOPLANKTON FROM THE MEDITERRANEAN FOLLOWING THE CHERNOBYL ACCIDENT

Radionuclide	Measured Concentration* ($Bq\ kg^{-1}$ dry)	Typical Concentration Factor**
^{95}Nb	12	$2x10^{4}$
^{103}Ru	280	$3x10^{3}$
^{106}Ru	70	$3x10^{3}$
^{134}Cs	22	$3x10^{1}$
^{137}Cs	34	$3x10^{1}$
^{141}Ce	20	$3x10^{3}$
^{144}Ce	100	$1x10^{3}$
^{241}Am	0.004	$1x10^{3}$
^{239}Pu	0.016	$3x10^{3}$

*From 45,46
**From 24,47

congregate in the upper water column, collections can be made by simply towing a net through the upper few meters for several minutes. The contents in the collector are then screened for visible debris which might bias the analysis, and the pure plankton poured onto a fine mesh screen, briefly rinsed with distilled water to remove salts and concentrated into a sample. At this point, individual target species can also be picked out by forceps for the sample. The final samples are then placed in plastic vials or glass bottles for eventual analysis.

Prior to analyses, the frozen or fresh samples are usually either oven-dried at 60°C or freeze-dried, ground to a powder with mortar and pestle, weighed and analyzed by the appropriate radiometric method like other tissues.

Needless to say, lack of sound information on the species composition of the plankton and the changes that take place over time will severely limit the usefulness of these organisms as bio-indicators of ambient levels of radioactivity in the marine environment. Therefore, it is always wise to keep an aliquot of each sample preserved in formalin for later species identification.

14.4.5. Crustaceans

Various macro-crustaceans such as shrimp, lobster and crab have also been used in radionuclide monitoring programmes particularly in countries where they are considered important commercial species [50,51]. Nevertheless, as in the case of fish, crustaceans are not always a perfect bio-indicator species since they can regulate their uptake of certain radionuclides and often show great variation in radionuclide bioaccumulation during different phases of their intermoult cycle. Furthermore, many radionuclides are little accumulated in crustacean muscle which necessitates obtaining a very large sample in order to achieve good counting statistics. On the other hand, one notable advantage with crustaceans is their marked ability to concentrate radionuclides to a very high degree in hepatopancreas tissue [52]. This fact suggests the potential value of using crustacean hepatopancreas as a target tissue for measuring a variety of heavy metals and radionuclides.

14.5. CONCLUSIONS

Despite certain limitations, many marine organisms can be used to gain information on ambient radionuclide levels (spatial and temporal) in the marine environment. With respect to fulfilling the main criteria for a good bio-indicator species, benthic brown algae and bivalve molluscs appear to offer the best potential for use in radionuclide monitoring programmes in most marine areas. The main advantage of using bio-indicator species is that they bioconcentrate many radionuclides to a very high degree, and analyzing resultant radionuclide concentrations in their tissues is much easier and less costly than analyzing the relatively low levels of radionuclides present in the surrounding sea water.

In cases where information on potential radiation dose to the seafood-eating population is required, specific edible marine species in the area which are major contributors to the dose should be selected and their edible tissues analyzed. Both purposes are served when the species targeted through the critical pathway approach is also one that can be selected based on bio-indicator criteria.

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