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Global marine radioactivity database (GLOMARD)

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FOREWORD

In response to the request of Member States and under the IAEA's mandate, the IAEA Marine Environment Laboratory (MEL) in Monaco has developed and maintains a Global Marine Radioactivity Database (GLOMARD).

The GLOMARD stores all available data on marine radioactivity in seawater, suspended matter, sediments and biota. The database provides critical input to the evaluation of the environmental radionuclide levels in regional seas and the world's oceans. It can be used as a basis for the assessment of the radiation doses to local, regional and global human populations and to marine biota. It also provides information on temporal trends of radionuclide levels in the marine environment and identifies gaps in available information.

The database contains information on the sources of the data; the laboratories performing radionuclide analysis; the type of samples (seawater, sediment, biota) and associated details (such as volume and weight); the sample treatment, analytical methods, and measuring instruments; and the analysed results (such as radionuclide concentrations, uncertainties, temperature, salinity, etc.).

The current version of the GLOMARD allows the input, maintenance and extraction of data for the production of various kinds of maps using external computer programs. Extracted data are processed by these programs to produce contour maps representing radionuclide distributions in studied areas.

To date, development work has concentrated on the Barents and Kara Seas in the Arctic and the Sea of Japan in the northwest Pacific Ocean, in connection with the investigation of radioactive waste dumping sites, as well as on marine radioactivity assessment of the Mururoa and Fangataufa nuclear weapons tests sites in French Polynesia. Further data inputs and evaluations are being carried out for the Black and Mediterranean Seas. In the framework of the project on Worldwide Marine Radioactivity Studies, background levels of ^{3}H, ^{90}Sr, ^{137}Cs and $^{239,240}Pu$ in water, sediment and biota of the world's oceans and seas will be established.

By publishing this report, the IAEA would like to encourage Member States in the development of national databases of a similar structure which in the future could be inserted into the Global Marine Radioactivity Database.

The IAEA would like to express its gratitude to the numerous Member States laboratories which provided radionuclide data for the Global Marine Radioactivity Database. The officer responsible was P.P. Povinec of the IAEA's Marine Environment Laboratory in Monaco.

EDITORIAL NOTE

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SUMMARY

The creation and maintenance of a database on marine radioactivity has been undertaken by the Marine Environment Laboratory of the IAEA in response to requests from Member States and in line with its mandate. The Global Marine Radioactivity Database (GLOMARD) is a vast project compiling radionuclide measurements taken in the marine environment. It consists of systematic input of all radionuclide concentration data available for seawater, sediment, biota and suspended matter.

GLOMARD will provide Member States with data on radionuclide concentrations and inventories in the marine environment. This information will help them in radiological assessments related to radioactive waste dumping and nuclear testing, and in emergency response to radiological accidents at sea.

GLOMARD is therefore a powerful tool for researchers as it integrates the results of analyses in most of the areas of the marine environment which have been investigated.

The database serves the following important functions:

- Provides a snap-shot of activities at any time, which may be used as a baseline for any impact assessment studies,
- Provides immediate and up-to-date information on the levels of radionuclides in the world's seas in different environmental matrices,
- Permits investigation of temporal trends in environmental levels of radionuclides and identifies gaps in available information.

These data are analysed and used for the production of graphs representing mainly the concentration of radionuclides in the water column and in sediment or for the production of maps showing the distribution of radionuclides in seawater, sediment and biota of different regions of the world's seas.

The report describes in detail the logical structure of the database, its implementation and current status. As an example, marine radioactivity assessments of the Barents and Kara Seas in the Arctic and the Sea of Japan in the northwest Pacific Ocean in connection with the investigation of radioactive waste dumping sites and their impact on the marine environment are discussed.

1. INTRODUCTION

A growing number of sources of radioactivity from human activities are found in the marine environment. They are known to include global nuclear fallout following atmospheric weapons tests, the Chernobyl accident, discharges of radionuclides from nuclear installations, past dumping of radioactive wastes, nuclear submarine accidents, contributions from nuclear testing sites, loss of radioactive sources, and the burnup of satellites using radioisotopes as power sources.

Overall, the world's marine environment contains radionuclides that differ from one region to another. Differences are due to dynamic marine environmental processes and the particular source of radionuclides in a region. Scientific assessments of marine radioactivity, therefore, require knowledge of both the source terms and oceanic processes.

Radioactivity is deposited unevenly over the world's oceans. Global fallout is known to be mainly due to nuclear weapons tests carried out in the 1960s. On the other hand, discharges from nuclear fuel reprocessing plants or past dumping of liquid and solid radioactive wastes generally are confined to more localised areas. Even so, soluble radionuclides have been transported over long distances by prevailing ocean currents.

To estimate radionuclide inputs from local sources, scientists need to better understand the distribution of radionuclides throughout the world's oceans and seas. The understanding is important for analysing the results from scientific investigations of localised areas, such as past dumping sites, which then can be reviewed more thoroughly.

As a contribution to fuller understanding of the marine environment, the IAEA's Marine Environment Laboratory (MEL) in Monaco has been carrying out a project on the development of a marine radioactivity database. The project is helping to gather data on marine radioactivity in the world's ocean and regional seas and it will help to develop a better understanding of the present radionuclide distribution. Data sets obtained in national and international radioactivity surveys thus can be reviewed comparatively. The project contributes to scientific knowledge of the processes affecting radionuclide distribution and the sources that have introduced radioactivity to the open ocean.

The development of a database system for marine radioactivity and its computerisation involves consideration of a number of subjects related to the type and quantity of data, its format and the proposed uses for such information. Design of the database system is constrained by the decisions made concerning what data is required, how it should be referenced, how the system is to be interrogated, how the data can be validated and how the data can be evaluated and presented. The system and its implementation may be complex due to the different data requirements for the different environmental matrices in which the measurements have been made and the differing data types which must be accommodated within the database.

The value of such a database system is dependent on the quality of primary data, the organisation and reliability of the data entry and verification systems, and the accessibility of data (including analysis and presentational capacities). This document describes the various stages in the creation of the database including the design of the system to meet the data requirements, implementation of the chosen design in the database language, development of data management software and finally quality assurance procedures involving data evaluation and validation.

The IAEA Global Marine Radioactivity Database (GLOMARD) has been created to serve the following important functions:

(a) Provide a snap-shot of activities at any time, which may be used as a baseline for any impact assessment studies,
(b) Provide immediate and up-to-date information on the levels of radionuclides in the world's seas in different environmental matrices,
(c) Permit investigation of temporal trends in environmental levels of radionuclides and identify gaps in available information.

To satisfy these aims, the final system should be flexible and extendible and should be able to be interrogated by region/sea, by time period, by nuclide and by environmental matrix.

2. ORGANISATION OF DATA

2.1. PROGRAMMING LANGUAGE

Because of the desire to ensure widespread access to the database and to make the data entry and transfer between different systems as straightforward as possible, it was decided to use PCs for the database. The choice of a database language was also made based on the criteria of widespread availability, access on many different platforms and extendibility. This resulted in the system being implemented in DBASE V (Ashton Tate). DBASE V is a database with many standard features, including a powerful programming language which will encourage the development of integrated programme modules for different data analysis needs. Other languages such as EXCEL and SURFER have also been used for data evaluation.

2.2. DATA TYPES AND REQUIREMENTS

The data requirements for recording marine radioactivity measurements are relatively complex and extensive but can be functionally divided into two categories:

(a) Definition of the environmental sample and its processing
(b) Radioanalytical procedures undertaken and their results.

A complete data profile provides sufficiently detailed information to ensure that data verification and evaluation can be carried out. Such detail strengthens the data interpretation and analysis and forms the basis of data validation. The division into these two distinct data categories is reflected in the database structure which has two primary data files. A further reason for this structure is that frequently a single sample will give results on several radionuclides. The mapping from environmental data to radionuclide information is thus "one too many".

2.2.1. Definition of environmental sample data requirements

Four broad classes of sample type were defined, namely water, suspended matter, sediment and biota. These are the main marine environmental media considered. Associated with each are a number of further data fields which together provide a complete sample profile. A complete profile incorporates the sample description (including volume, oxygen content, pH, as appropriate), sampling location and pre-treatment (ashing, drying, etc.).

2.2.2. Radioanalytical procedures and results

This second category defines the data profile for the radionuclide information and includes method of analysis as well as results. The main considerations in the design of the data requirements were the different ways of reporting results, the difficulties in dealing with the limits of detection, the possibility of decay corrected results and the various uncertainties which could be quoted.

2.3. SOURCES OF INFORMATION

The information incorporated in the database is both current as well as retrospective. It reflects current research and environmental priorities as well as those of the past. Retrospective data acquisition (data archaeology) is a demanding task and/as there are a variety of sources of the necessary data, providing varying degrees of detail concerning the samples and results. This of necessity means that the system design, since it reflects an ideal list for data requirements and is intended for current data acquisition, may not be optimal for archaeological purposes. In the initial development of the database, it was decided to undertake a retrospective search for data making use of published literature and research reports. Particular areas of the world's oceans and seas were targeted and an intensive data search begun. This activity is centred at IAEA-MEL with nominated members of staff having responsibility for particular regions. Currently, the database holds a great deal of historical data from a number of technical reports and papers.

Laboratories and centres have been asked to provide data directly to the database. Therefore, consideration has been given to prospective data entry, through electronic transfer of data from the source laboratory to the central database. Various data transfer protocols and programmes have been developed to facilitate the exchange of data. The general organisation of the database is shown in Figs 1 and 2.

3. DATA ENTRY REQUIREMENTS

The above discussion has outlined the broad strategy of the database development. In this and later sections, the specific details of the database are described. The precise data requirements to provide a complete sample profile are described in more detail below.

3.1. ENVIRONMENTAL DATA REQUIREMENTS

The data requirements have been broadly classified into seven key areas. These areas were agreed on after extensive consultation with the scientific staff of the laboratory. It was felt that these seven areas reflected an achievable objective and would provide sufficient detail to ensure the usefulness of the data recorded. Each area and a brief description are given below:

3.1.1. Sample type

Four sample types were identified; water, suspended matter, sediment and biota corresponding to the environmental media most commonly used. The biota data entries are accompanied by further information which details the species and general classification of

organisms. An internal coding scheme has been developed by IAEA-MEL staff and forms the basis of the organism classification (Figs 1 and 2). Such a design allows broad interrogation of the database, but also will permit very specific queries since sample type is one of the key fields. For biological samples, the hierarchical description of the sample allows user choice in the specificity of the query.

3.1.2. Laboratory information

As the primary data source, laboratory information provides the necessary background information. Only the very basic laboratory details are required, but a key entry concerns the laboratory's participation in IAEA AQCS programmes. Information concerning participation in the AQCS programme is used as part of the data verification process. Specific entries link directly to the AQCS programme which is also maintained by MEL. AQCS participation is used as a broad indicator of good laboratory practice and may be used in individual cases to assess the validity of observations.

3.1.3. Sampling period

The date of sample collection or period of sampling (for suspended matter), defined by two limiting dates is required. Since temporal features will be an important analysis product from the database, these fields are essential and form the basis for temporal interrogation.

3.1.4. Sample location

All the data entered in the database are geographically registered. The degree of spatial registration recorded will, of course, be varied, ranging from precise (i.e. latitude and longitude) to less specific information (e.g. a specific sea). Provision has been made for this information to be entered in a variety of forms following a hierarchical structure.

Level 1: information on the region in which the sample was collected is sought. Following the International Hydrographic Bureau convention, there are nine main regions which are detailed in Table I. In addition, direction may also be specified, encouraging more detailed descriptions.

Level 2: at this level, the area within the region is defined again using the conventions of the IHB. A total of 129 areas are specified and detailed in Table I.

Level 3: the primary data is the exact location given by the latitude and longitude of the sampling location.

The name of the sampling station may also be entered but will not be used in data searching /under normal circumstances / except under special circumstances.

3.1.5. Sampling method

Information on the specific sampling method used to collect the sample is requested. Although not considered as a central data requirement, availability of such information may be used in the data evaluation and description stages.

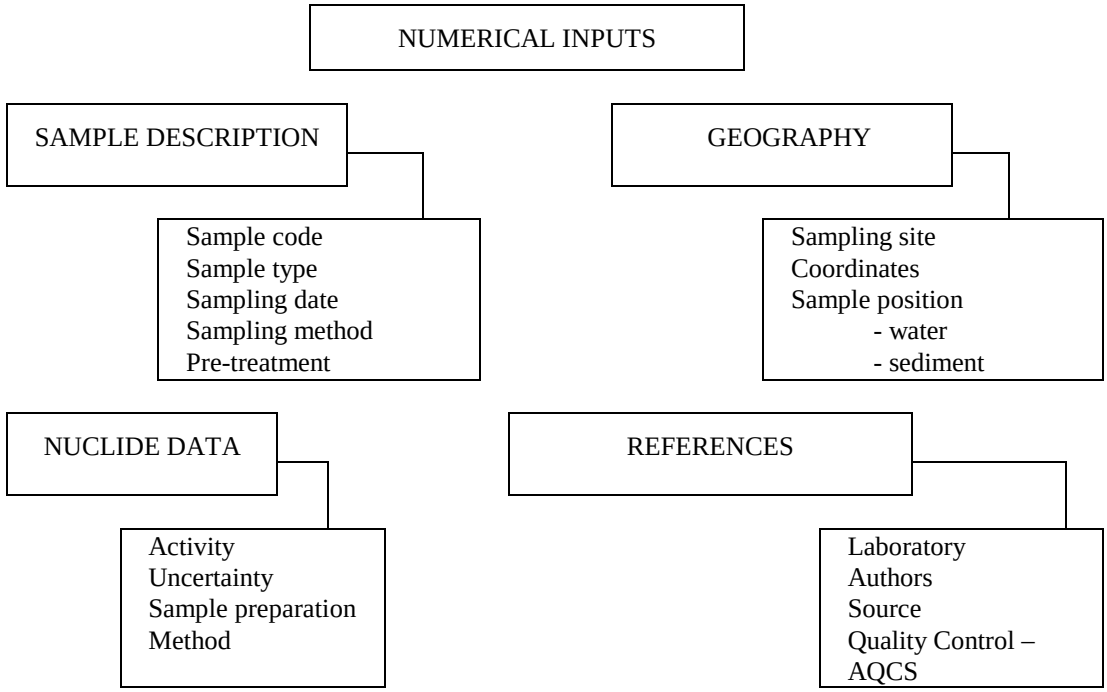

FIG. 1. General organisation of the database (inputs).

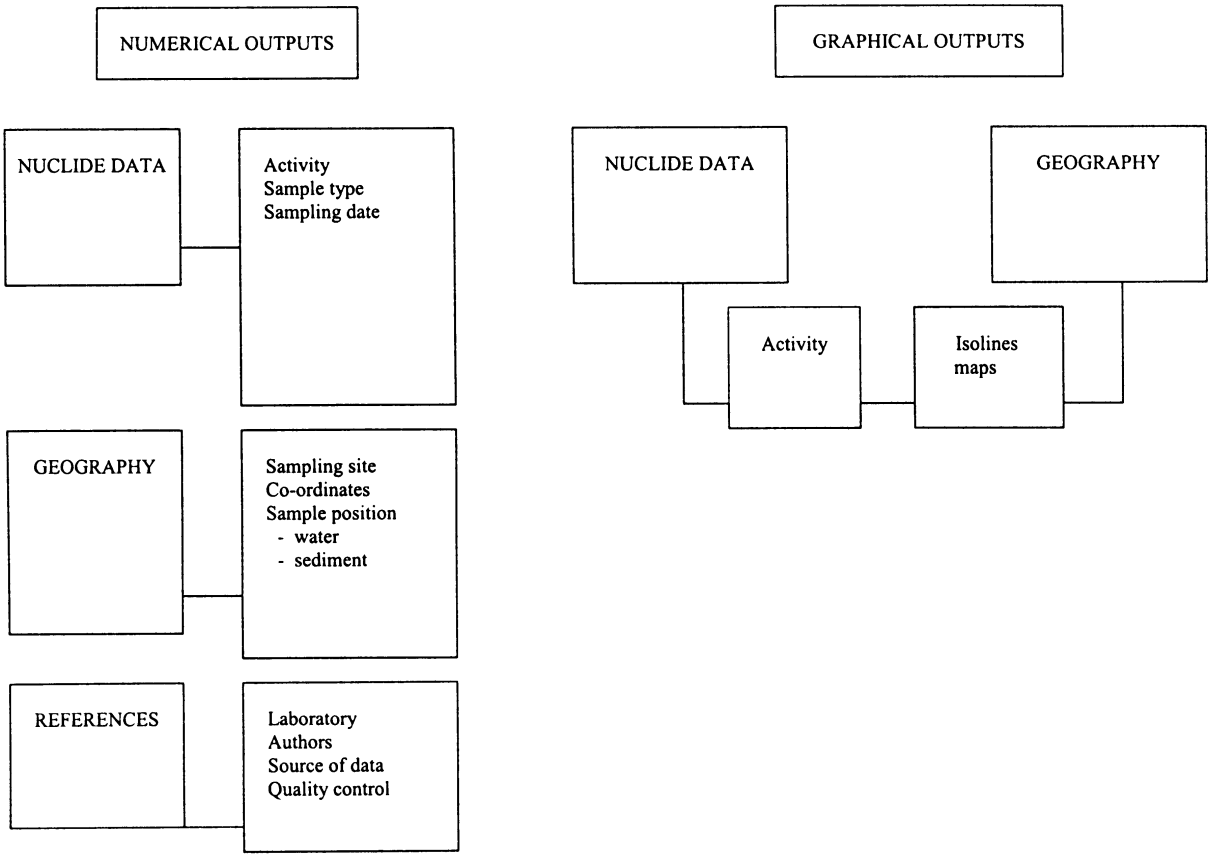

FIG. 2. General organisation of the database (outputs).

3.1.6. Data source and reference

Given a primary database function as a data archive and repository, it is important that the source of any data be fully referenced, thus part of the database system includes a full reference to the primary source, be it a published paper or internal laboratory report. Although within the main database, only a limited entry is made, a further third database file contains the full bibliographic reference with key words.

3.1.7. Laboratory treatment

A number of physical and chemical treatments may be applied to the sample prior to radionuclide analysis. General information on the processes to which the sample has been subjected is required as part of the profile. As for the sampling method, the primary function of this data is for data verification and in certain circumstances, e.g. in the identification of outliers it may be used in the validation process. Again, in the situation where results from different laboratories are being combined, such information may be used to ensure the comparability of results ant to explain any observed discrepancies.

3.1.8. Specific data requirements for distinct sample types

Clearly each distinct sample type has different properties which will be reflected in the different information requirements. As a result, in addition to the above general data, further specific information is sought.

3.1.8.1. Water

Information on sample volume, salinity, temperature and dissolved oxygen content is included.

3.1.8.2. Sediment

The area sampled and subsampled, the water content and if a slice has been taken from a larger core, the position within that core are requested. The type of sediment and its organic content are also part of the information required.

3.1.8.3. Biota

As indicated earlier, the species and general class of organism are input.

3.1.8.4. Suspended matter

The data fields for water and sediment in combination provide sufficient data coverage for suspended matter.

The above information specifies the general environmental data requirements. This information is stored in the first of the primary data files.

TABLE I. WORLD OCEAN REGIONS

AREA	REGION
BAFFIN BAY	ARCTIC OCEAN
BARENTS SEA	ARCTIC OCEAN
BEAUFORT SEA	ARCTIC OCEAN
BERING SEA	ARCTIC OCEAN
CHUKCHI SEA	ARCTIC OCEAN
DAVIS STRAIT	ARCTIC OCEAN
EAST SIBERIAN SEA	ARCTIC OCEAN
GREENLAND SEA	ARCTIC OCEAN
HUDSON BAY	ARCTIC OCEAN
HUDSON STRAIT	ARCTIC OCEAN
KARA SEA	ARCTIC OCEAN
LAPTEV SEA	ARCTIC OCEAN
LINCOLN SEA	ARCTIC OCEAN
NORTH GREENLAND SEA	ARCTIC OCEAN
NORTHWEST PASSAGE	ARCTIC OCEAN
NORWEGIAN SEA	ARCTIC OCEAN
WHITE SEA	ARCTIC OCEAN
BAY OF BISCAY	ATLANTIC OCEAN
BAY OF FUNDY	ATLANTIC OCEAN
BRISTOL CHANNEL	ATLANTIC OCEAN
CARIBBEAN SEA	ATLANTIC OCEAN
CELTIC SEA	ATLANTIC OCEAN
ENGLISH CHANNEL	ATLANTIC OCEAN
GULF OF GUINEA	ATLANTIC OCEAN
GULF OF MEXICO	ATLANTIC OCEAN
GULF OF ST. LAWRENCE	ATLANTIC OCEAN
IRISH SEA	ATLANTIC OCEAN
LABRADOR SEA	ATLANTIC OCEAN
NORTH CHANNEL	ATLANTIC OCEAN
NORTH EAST ATLANTIC OCEAN	ATLANTIC OCEAN
NORTH SEA	ATLANTIC OCEAN
NORTH WEST ATLANTIC OCEAN	ATLANTIC OCEAN
SKAGERRAK CHANNEL	ATLANTIC OCEAN
SOUTH EAST ATLANTIC OCEAN	ATLANTIC OCEAN
SOUTH WEST ATLANTIC OCEAN	ATLANTIC OCEAN
ST. GEORGES CHANNEL	ATLANTIC OCEAN
GULF OF BOTHNIA	BALTIC SEA
GULF OF FINLAND	BALTIC SEA
GULF OF RIGA	BALTIC SEA
KATTEGAT CHANNEL	BALTIC SEA
ARAFURA SEA	CHINA SEA
BALI SEA	CHINA SEA
BANDA SEA	CHINA SEA
CELEBES SEA	CHINA SEA
EAST CHINA SEA	CHINA SEA
FLORES SEA	CHINA SEA
GULF OF CARPENTARIA	CHINA SEA
GULF OF THAILAND	CHINA SEA
GULF OF TOMINI	CHINA SEA
GULF OF TONKING	CHINA SEA
HALMAHERA SEA	CHINA SEA
JAVA SEA	CHINA SEA
JOSEPH BONAPARTE GULF	CHINA SEA
MACLUER GULF	CHINA SEA
MAKASSAR STRAIT	CHINA SEA
SAWU SEA	CHINA SEA

TABLE I. (cont.)

AREA	REGION
SERAM SEA	CHINA SEA
SOUTH CHINA SEA	CHINA SEA
STRAIT OF FORMOSA	CHINA SEA
STRAIT OF SINGAPORE	CHINA SEA
SULU SEA	CHINA SEA
SUMBA STRAIT	CHINA SEA
TIMOR SEA	CHINA SEA
ARABIAN SEA	INDIAN OCEAN
BAY OF BENGAL	INDIAN OCEAN
GREAT AUSTRALIAN BIGHT	INDIAN OCEAN
GULF OF ADEN	INDIAN OCEAN
GULF OF AQABA	INDIAN OCEAN
GULF OF MANNAR	INDIAN OCEAN
GULF OF MARTABAN	INDIAN OCEAN
GULF OF OMAN	INDIAN OCEAN
GULF OF SUEZ	INDIAN OCEAN
MOZAMBIQUE CHANNEL	INDIAN OCEAN
NORTH INDIAN OCEAN	INDIAN OCEAN
PERSIAN GULF	INDIAN OCEAN
RED SEA	INDIAN OCEAN
SOUTH INDIAN OCEAN	INDIAN OCEAN
STRAIT OF MALACCA	INDIAN OCEAN
ADRIATIC SEA	MEDITERRANEAN SEA
AEGEAN SEA	MEDITERRANEAN SEA
BLACK SEA	MEDITERRANEAN SEA
IONIAN SEA	MEDITERRANEAN SEA
LIGURIAN SEA	MEDITERRANEAN SEA
NORTH MEDITERRANEAN SEA	MEDITERRANEAN SEA
SOUTH MEDITERRANEAN SEA	MEDITERRANEAN SEA
SEA OF MARMARA	MEDITERRANEAN SEA
SEA OF AZOV	MEDITERRANEAN SEA
STRAIT OF GIBRALTAR	MEDITERRANEAN SEA
STRAIT OF SIRYCY	MEDITERRANEAN SEA
TYRRHENIAN SEA	MEDITERRANEAN SEA
ANADYRSKIY GULF	PACIFIC OCEAN
BASS STRAIT	PACIFIC OCEAN
BERING SEA	PACIFIC OCEAN
BISMARCK SEA	PACIFIC OCEAN
CORAL SEA	PACIFIC OCEAN
EAST CHINA SEA	PACIFIC OCEAN
GREAT BARRIER REEF	PACIFIC OCEAN
GULF OF ALASKA	PACIFIC OCEAN
GULF OF CALIFORNIA	PACIFIC OCEAN
GULF OF LIAOTUNG	PACIFIC OCEAN
GULF OF PANAMA	PACIFIC OCEAN
GULF OF TARTARY	PACIFIC OCEAN
NORTH PACIFIC OCEAN	PACIFIC OCEAN
PHILIPPINE SEA	PACIFIC OCEAN
SEA OF JAPAN	PACIFIC OCEAN
SEA OF OKHOTSK	PACIFIC OCEAN
SOLOMON SEA	PACIFIC OCEAN
SOUTH PACIFIC OCEAN	PACIFIC OCEAN
TAIWAN STRAIT	PACIFIC OCEAN
TASMAN SEA	PACIFIC OCEAN
TORRES STRAIT	PACIFIC OCEAN
YELLOW SEA	PACIFIC OCEAN

3.2. ANALYTICAL INFORMATION

In principle, the information requested here is less complex than for the environmental description of the sample. It does, however, have a number of features which must be accommodated within the primary data file. Key issues which had to be resolved included the different uncertainty structures, data recorded at the limit of detection, below detection or not detected and the information concerning the different counting methods.

3.2.1. Data requirements

3.2.1.1. The nuclide

The nuclide is identified by standard convention using scientific notation. A convention places the atomic number first.

3.2.1.2. Units of measurement

Although an international convention on units does exist, it is noticeable and to be expected in data archaeology, that results are presented in a variety of units. The primary database file holds the information on radionuclide activities in the original units. Later, the data management system converts the data to a standard form for further manipulation and analysis.

3.2.1.3. Uncertainty and limit of detection

Uncertainties in both absolute and percentage form are accommodated (at 1σ level). Measurements made at the limit of detection or recorded as below detection or not detected are flagged in an additional character field.

3.2.1.4. Method of measurement

The particular analytical method of sample analysis is also incorporated.

In addition to these four basic pieces of information, the analytical data file also includes the sampling date (a secondary link to the environmental data file), date of measurement, whether a decay correction has been made and to which date.

A further series of data fields is used to accommodate a further data format, namely summary data.

3.2.2. Data summarisation

By SUMMARY data, is meant a single numerical summary of a set of results e.g. a summary of ^{137}Cs in Black Sea fish for 1986 might be the maximum activity level observed. Thus the summarisation may be over both space and time. Although this would not be the preferred format for data, it is, nevertheless, a form which occurs regularly, particularly in retrospective data. Necessary information includes the number of measurements being summarised, the time period over which the summary applies and the type of summary variable.

Typical summary measures include:

(a) The average or mean: two pieces of information should be provided, namely the mean value and its standard deviation,

(b) The maximum (or minimum),

(c) The median (sometimes given as an alternative to the mean value),

(d) The range.

All summary measures should be accompanied by the number of observations on which the summary is based.

3.2.2.1. Entry of summary data

Summary data are identified in the first data file by using a character field. The period of time over which the data has been summarised is also indicated (month and year). Summarisation over space would be indicated through the region and area fields described earlier. In summary form, the same degree of detail is not generally available, so that the data structure described in the earlier sections is not generally applicable. However, those data fields which are relevant may still be used. The nuclide information is also entered into the radioanalytical file in a special form, including the form of the summary (e.g. maximum) and the number of observations on which the summary is based. It is possible that several summaries might be provided at the same time e.g. mean and median or mean and range, in which case a combination of fields would be completed.

3.2.2.2. Bibliographic references

The third basic information type gives details of the bibliographic information on the data source. It includes the authors/source of the data, if from a report, the full title and date of publication and a number of keywords.

3.2.2.3. Administrative details

In addition to the scientific data requirements, a number of administrative details are also recorded providing the history of the data entry procedure. These include the member of staff entering the data, when the data entry was completed and when the data had undergone preliminary checking.

3.2.2.4. Linking variables

The various data files are linked by a number of fields. The primary variable linking the environmental sample information to the radionuclide information is the sample code, a unique identifier assigned to each sample. The entries are also linked by sample date. The data source file is linked to the environmental data by the author of the report and the area to which the data relates.

4. THE DATABASE STRUCTURE

The preceding sections have described in general terms, the variables which are used within the data structure. This section now deals with the implementation of these data requirements within the database management system.

The two main database files contain the sample information and the associated radionuclide information linked together by a unique sample code. The third linked database file contains bibliographic information..

There are a number of fields which are particularly important in both linking and data management procedures. These are dealt with in a special way in the data entry (i.e. they link to other databases or have specific coding schemes for entry) and these are described in more detail below. The coding system for the character fields used will also be described. Throughout, suggestions for the uses of the field for data verification will be made.

4.1. LABORATORY INFORMATION

The information on the source laboratory is entered using fields LABCODE, LABNAME and COUNTRY. Since these fields link to IAEA-MEL's AQCS database, these fields are in common and a common coding system has been designed. Data entry is made from a select screen showing the various entries sorted alphabetically on COUNTRY. A laboratory which is not already on the list can be added and assigned a code and name, the two databases are then updated simultaneously. Whether a laboratory has taken part in any AQCS programme is also indicated, but no further details connecting their results on specific intercomparisons are entered. Clearly, if a laboratory has taken part in any IAEA-MEL programme, its primary results can be accessed if necessary for any data verification purposes. Participation in an AQCS programme and reported results provide a general quality measure for that laboratory.

4.2. POSITIONAL INFORMATION

The sampling location at regional and area level is again made by selecting an entry from a help screen which also shows the coding scheme adopted. The International Hydrographic Bureau conventions are observed (Table I).

4.3. BIOLOGICAL TYPE

A dictionary of the main biological species and their broad classification has been created at MEL and forms the basis of the species and class coding. This list is continually being updated as species are added. The coding scheme adopted is simple and is based on a maximum five letter system.

4.4. NUCLIDE

The nuclide entry may also be made from a dictionary, this is perhaps less necessary than for other fields, but does ensure that the entry follows a defined convention. At the same time, a linked counting method list is also available.

4.5. AUTHOR

The author of the primary source is entered providing a connection to a references database and thus ensuring that the full source of the data is available. In addition, this database contains administrative information on the location of the data within the main database, when it was entered and by whom. These details are discussed more fully in the data evaluation section.

4.6. MISSING DATA

One potential drawback of designing a database system with an extensive field list is that often some of the fields will not be available, thus a separate coding system to deal with missing data is necessary, particularly for the numerical fields. In general, the missing data code is a value which cannot occur in practice and for most of the numerical fields, this value is taken to be -9.

5. DATA ENTRY SYSTEMS

The data entry system is built around a number of specifically designed forms (Figs 3 and 4), and the equivalent data entry screen, with select screens for those fields with specialised coding. The actual data entry screen is automatically selected according to the sample type and reflects the differences in the information requirements already covered in earlier sections. The coding system is described in Tables II–VIII.

For numerical data, a missing data code of -9 is automatically entered and is only overwritten when the data is available. For character fields, the initial entry is blank.

Data is entered independently on satellite databases and then undergoes a number of checks before finally being appended to the master file held on a central machine.

6. DATA VERIFICATION AND VALIDATION

As discussed earlier, the value of the database is directly related to the quality of the data. Thus, in the development of the system, considerable resources must be allocated to the quality assurance procedures.

The quality assurance procedures which are built as part of the database system have a crucial role to play. The main goal of the assurance procedures is an automated system which:

(a) Verifies that the entries are correct, or at least lie within defined ranges,

(b) Highlights and detects anomalous values,

(c) Confirms that entries are logically consistent within the coding system,

(d) Ensures that the primary data is traceable.

It is clear that there are a number of procedures involved in the quality assurance steps necessary for a database and data management system. There are two main headings - data verification, where the main concerns are the correct coding and entry of data within the system, relating to (a), (c) and (d) above; and data validation, where the main concerns relate to the quality of the data i.e. primarily (b) and partly (a). Data validation is particularly critical when dealing with multi-laboratory input since it deals with the key question of comparability of data and hence the interpretability of the synthesised data. The quality assurance and quality control procedures therefore play an important role in data validation procedures. The system is implemented at three distinct levels.

At level 1 each entry is checked against defined ranges, logical checks and coded values. At level 2 anomalous or outlying data values are identified. Such values are identified through simple numerical rules and through graphical procedures. Outlying values are flagged for further inspection. Finally, at level 3 flagged values are further investigated manually and the investigation may involve an assessment of laboratory data (including AQCS results).

6.1. DATA VERIFICATION

Level 1 of the IAEA-MEL system involves data verification. Each field is considered in turn, the approach to verification differs depending on whether the field is numerical or character.

TABLE II. CODES FOR SEDIMENT TYPE

CODE	SEDIMENT TYPE
GRAVE	GRAVEL
SAND	SAND
SANDF	FINE SAND
SILT	SILT
CLAY	CLAY
MUD	MUD
SIGR	SILT and GRAVEL
SICL	SILT and CLAY

Text cont. on page 23.

TABLE III. CODES FOR SPECIES

CODE	SPECIES
MA	**MAMMALS**
MACET	CETACEA (whales, dolphins, porpoises)
MAPIN	PINNIPEDIA (seals, sea lions, walruses)
BIR	BIRDS (marine birds)
TUR	SEA-TURTLES
FI	**FISHES**
FIBO	BONY FISHES
FICA	CARTILAGINOUS FISHES (shars, batoid fishes, hagfishes, lamphreys)
TUNI	TUNICATA (sea-squirts, salps, appendicularians)
ECHI	ECHINODERMS (sea-stars, sea-urchins, holothurians, brittle-stars)
CRU	**CRUSTACEANS**
CRUDEC	DECAPODA (crabs, lobsters, shrimps)
CRUOT	OTHER CRUSTACEANS
MO	**MOLLUSCS**
MOCEPH	CEPHALOPODS (squids, cuttle-fish, octopuses)
MOGAST	GASTROPODS (marine snails)
MOBIV	BIVALVES (mussels, clams, oysters)
MOLL	OTHER MOLLUSCS
CHAE	CHAETOGNATHS
POLY	POLYCHAETES (worms)
CNI	CNIDARIANS (medusae, siphonophores)
CTEN	CTENOPHORES
SPON	SPONGES
WEED	SEAWEEDS (marine algae)
GRA	SEAGRASS (posidonia, etc.)
PPK	PHYTOPLANKTON
ZPK	ZOOPLANKTON
PBE	PHYTOBENTHOS
ZBE	ZOO BENTHOS
NECT	NECTON
NEUS	NEUSTON

TABLE IV. CODES FOR TISSUE

CODE	TISSUE
BLO	BLOOD
BON	BONES
SOBH	BRONCHIAL HEART
ENT	ENTRAILS
EXOSKELETON	EXOS
FINS	FINS
FILL	FLESH FILLETS
FLEB	FLESH WITH BONES
GIL	GILLS
GON	GONAD
HEAD	HEAD
HEA	HEART
SOHP	HEPATOPANCREAS
INT	INTESTINE
KID	KIDNEY
LIV	LIVER
MOLT	MOLT
FMUS	MUSCLE
OV	OVARY
PYLC	PYLORIC CAECA
SCA	SCALES
SHEL	SHELLS
SKI	SKIN
SOFT	SOFT PARTS
STO	STOMACH
STIN	STOMACH AND INTESTINE
TES	TESTES
VISC	VISCERA
WHO	WHOLE ANIMAL
WHOHE	WHOLE ANIMAL WITHOUT HEAD AND ENTRAILS
WHORE	WHOLE ANIMAL RECONSTITUTED
WHOEV	WHOLE ANIMAL EVISCERATED
PLAR	PLANTS ROOTS
PLAL	PLANTS LOWER PART
PLAU	PLANTS UPPER PART
PLAW	PLANTS WHOLE
FCPT	FAECAL PELLET

TABLE V. CODES FOR SAMPLING METHODS

MATRIX	CODE	METHOD
WATER		
	BOTTL	BOTTLE SAMPLING
	GRABW	GRAB SAMPLING
	PUMP	PUMPING
	PUMPP	PUMPING WITH PRE-CONCENTRATION
SEDIMENT		
	BOX	BOX CORER
	GRABS	GRAB SAMPLER
	GRAV	GRAVITY CORER
	GRAVP	GRAVITY CORER WITH PISTON
	OTH	OTHER TYPE OF SAMPLER - SPECIFY
SUSPENDED AND SEDIMENTING PARTICLES		
	BOTTL	BOTTLE SAMPLING
	PUMP	PUMPING
	PUMPP	PUMPING WITH PRE-CONCENTRATION
	SEDT	SEDIMENT TRAP
BIOTA		
	NET	NET
	DRE	DREDGES
	HAN	BY HAND
	SCO	SCOOP

TABLE VI. CODES FOR DRYING METHODS

CODE	METHOD
AIR	AIR DRYING
FRE	FREEZE DRYING
OVE	OVEN DRYING
SIL	SILICA GEL DRYING

TABLE VII. CODES FOR METHODS OF SAMPLE PREPARATION

CODE	METHOD
FIL	FILTERING
SPR	SPRAYING
EVA	EVAPORATION
EVAV	EVAPORATION IN VACUUM
ELD	ELECTRODEPOSITION
ELDV	ELECTRODEPOSITION IN VACUUM
MP	MOLECULAR PLATING
ELP	ELECTROPHORETIC
CS	CATHODIC SPUTTERING
EIS	ELECTROMAGNETIC ISOTOPE SEPARATION
OXID	DRY OXIDATION
OXIW	WET OXIDATION
SYN	SYNTHETIZATION

TABLE VIII. CODES FOR ANALYTICAL METHODS*

CODE	METHOD
ALPI	ALPHA IONIZATION CHAMBER SPECTROMETRY
ALPL	ALPHA LIQUID SCINTILLATION SPECROMETRY
ALPS	ALPHA SEMICONDUCTOR SPECTROMETRY
ALPT	ALPHA TOTAL (ZnS)
BETG	BETA GM COUNTING
BETL	BETA LIQUID SCINTILLATION SPECTROMETRY
BETP	BETA GAS PROPORTIONAL COUNTING
BETS	BETA SEMICONDUCTOR SPECTROMETRY
BETT	BETA TOTAL
GAMN	GAMMA SCINTILLATION SPECTROMETRY
GAMS	GAMMA SEMICONDUCTOR SPECTROMETRY
GAMI	GAMMA SPECTROMETRY IN SITU
XRAY	X-RAY SPECTROMETRY
EMA	EMANATION
FIS	FISSION TRACK COUNTING
NAA	NEUTRON ACTIVATION ANALYSIS
MS	MASS SPECTROMETRY
AMS	ACCELERATOR MASS SPECTROMETRY
ICP	INDUCTIVELY COUPLED PLASMA AES
ICPMS	INDUCTIVELY COUPLED PLASMA SOURCE MASS SPECTROMETRY
RIMS	RESONANCE IONIZATION MASS SPECTROMETRY
TIMS	THERMAL IONIZATION MASS SPECTROMETRY
AA	ATOMIC ABSORPTION
COL	COLORIMETRY
FLU	FLUORIMETRY

* If other, please specify

IDENTIFICATION

LABORATORY NAME AND ADDRESS : .....

.....

.....

.....

For IAEA use only:

- sample code _____

- laboratory code _____

Tel : ..... Fax : ..... e-mail: .....

AUTHOR(S) .....

.....

JOURNAL/BOOK/REPORT TITLE : .....

.....

..... Year : ..... No. : .....

BOOK PUBLISHER : ..... TOWN : .....

TITLE OF PAPER : .....

.....

..... Page Nos. .....

SAMPLE IDENTIFICATION CODE (Note 1) : .....

TYPE OF SAMPLE ANALYSED (Note 2) : .....

HAVE YOU PARTICIPATED IN THE IAEA-MEL AQCS PROGRAMME WITHIN THE LAST 5 YEARS? Y/N

SAMPLING DATE : ..... **OR SAMPLING PERIOD** : From : ..... to .....

LOCATION :

STATION (Note 3a) : ..... AREA (Note 3b) : .....

COORDINATES (Note 3c) – Latitude : ..... N/S Longitude : ..... E/W

TOTAL DEPTH OF WATER AT SAMPLING POINT (m) : .....

DEPTH AT WHICH SAMPLE WAS COLLECTED (Note 4) (m) : .....

FOR WATER SAMPLES :

TOTAL VOLUME SAMPLED : .....

SALINITY (‰) ..... TEMPERATURE (°C) ..... DISSOLVED O_2 .....

WAS THE WATER FILTERED? Y/N WAS THE WATER ACIDIFIED? Y/N

WAS THE WATER EVAPORATED? Y/N

RADIOCHEMICAL PROCESSING METHOD : .....

.....

FOR SEDIMENT SAMPLES

SEDIMENT TYPE (Note 5) : .....

WAS THE SEDIMENT SURFACE LAYER OXIC? Y/N

TOTAL SURFACE AREA SAMPLED (cm^2) : .....

IF FURTHER SUB-SAMPLED, WHAT AREA WAS TAKEN (cm^2) : .....

FOR A CORE SLICE, DEPTHS FROM SURFACE LAYER (Note 6) - UPPER (cm) : .....

- LOWER (cm) : .....

WATER CONTENT OF THE SEDIMENT (% weight) : .....

ORGANIC CONTENT OF THE SEDIMENT : .....

WAS THE SAMPLE SIEVED? Y/N MESH SIZE : .....

RADIOCHEMICAL PROCESSING METHOD : .....

.....

FOR BIOTA AND SUSPENDED PARTICLES

SPECIES (Note 7) : .....

TISSUE ANALYSED (Note 8) : .....

RADIOCHEMICAL PROCESSING METHOD : .....

.....

FOR ALL SAMPLE TYPES

SAMPLING METHOD (Note 9): .....

.....

FILTER PORE SIZE (μm) : ..... PLANKTON NET SIZE (μm) : .....

DRY WEIGHT (g) : ..... WET WEIGHT (g) : ..... % DRY/WET : .....

DRYING METHOD (Note 10): ..... DRYING TEMPERATURE (°C) : .....

WAS THE SAMPLE HOMOGENIZED ? Y/N

ASH WEIGHT (g) : ..... ASHING TEMPERATURE (°C) : .....

IGNITION LOSS (FROM DRY WEIGHT) (%) : .....

REMARKS :

FIG. 3. Reporting format — sample information form.

NUCLIDE INFORMATION (Note 11)

DATE MEASURED :

NUCLIDE	VALUE	UNITS	UNCERTAINTY ±σ		DECAY CORRECTED Y/N	METHOD OF SAMPLE PREPARATION	ANALYTICAL METHOD	SAMPLE WEIGHT OR VOLUME (g or l)
			ABS	%				

NOTES:

1. Identification code for sample within laboratory
2. Type of sample analysed: Select from the following:
   seawater
   sediment
   suspended particles
   biota
3. Location
   (a) Station: full name and code of the station where the sample was collected
   (b) Area: general location (e.g. Black Sea, Northwest Mediterranean Sea)
   (c) Co-ordinates: exact LATITUDE and LONGITUDE in degrees and decimal fractions of minutes, not seconds)
4. Depth at which sample was collected: depths are recorded to the nearest m. For surface samples use '0'.
5. Sediment type: see the list of codes for sediment types.
6. For a core: insert the upper and lower limits of the slice depth from the surface layer (in cm).
7. Species: see the list of codes for species.
8. Tissue analysed: see the list codes for tissues.
9. Sampling method: see the list of codes for sampling methods.
10. Drying method: see the list of codes for drying methods.
11. Nuclide information
    (a) VALUE; if the measurement is below the limit of detection, indicate by including "<'' in the value, e.g. <10.0.
    (b) UNITS: Give the units of measurement, e.g. Bq/m^3 or Bq/kg.
    (c) UNCERTAINTY: The uncertainty should be at 1σ level, either given in absloute or % terms.
    (d) METHODS OF SAMPLE PREPARATION: See the list of codes for sample preparation methods.
    (e) ANALYTICAL METHOD: See the list of codes for analytical methods.
    (f) REMARKS: Please give any information not covered in the form or make any comments.

FIG. 4. Reporting format —sample information sheet.

For each character field, there already exists a list of the acceptable entries in the form of the subsidiary coding databases used for the select screens. During verification, a "spelling check" is carried out for each entry. Any entry which does not match the coding thesaurus for the field is then flagged for further investigation. In addition, further checks are carried out on sets of related fields as listed below.

6.1.1. Region, area, latitude and longitude

A check is made that area is associated with the correct region and then that the latitude and longitude are correctly associated with the area. The latter check is only approximate, the limits defining each area (listed in the IHB classification scheme) are irregularly shaped and for the purposes of this check, they are roughly gridded.

6.1.2. Biota, species, organism

A secondary check is carried out to confirm that the species and organism coding correspond.

6.1.3. Country, labname, labcode

Internal checks that the labname and corresponding country are identified and that the labcode correctly corresponds to the laboratory which carried out the measurements.

6.1.4. Nuclide counting method

Although a direct one-to-one correspondence between nuclide and counting method is not possible, certain combinations could be eliminated. Thus the checks here deal with the correct conventions for nuclide identification and verify that the counting method is appropriate to the nuclide (isotope) in question.

The verification process for the numerical fields is more difficult and involves defining valid ranges within which the field entry should lie. The definition of valid ranges requires some prior knowledge concerning feasible values for the particular field. Clearly, the limits should not be too prescriptive, resulting in too many entries being flagged. Some suggested examples are given below:

For environmental data:

(a) The sampling date and the beginning and end date of the sampling period should not be in the future, and the end date should follow the beginning date,
(b) Latitude should lie between 0 and 90, while longitude should lie between 0 and 180 degrees,
(c) The total depth should be at least as great as sample depth,
(d) All variables recorded as percentages should be at most 100%,
(e) For sediment cores, the upper slice (in mm or cm) should be less than the lower slice,
(f) Wet weight should be greater than dry weight which should exceed ash weight.

For radioanalytical results:

(a) The value and uncertainty should be positive,

(b) The date measured should be after the sample collection date,
(c) If the data is in summary form, the mean or median should be bounded by the minimum and maximum.

Checks on the logical consistency of data entry are performed as part of data entry and where the entry fails, the record is flagged for further investigation. In addition to the logical consistency checks, the data is also verified against the primary source. A random selection of data entries is made and checked from original data sources through to records stored in the database. The selection of samples can be stratified by area or author (i.e. a fixed proportion of records from a single location or from each paper are selected) or by a number of other fields. In this way, the overall uncertainty rate for data entry can be estimated for the system and efforts and procedures designed to maintain it at an acceptable level.

6.2. DATA VALIDATION

In the implementation of Level 2, in addition to the process of logical checking under Level 1, the data held in the database are checked for numerical consistency as part of the wider data validation process. This level incorporates both graphical and numerical checks for anomalous observations and this is the first level where the data are considered in a scientific context. The checks are carried out on defined data groupings which may reflect space and/or time summarisation. It is assumed that the data subgroups created are "homogeneously" defined and thus, that comparison and summarisation of the data distribution are valid.

6.2.1. Numerical checks

Numerical checks implemented include a simple range calculation, evaluation of the coefficient of variation, and evaluation of the average (its robust alternative, the median), the standard deviation (and inter-quartile range). In a communal sense, a large coefficiency of variation or a large difference between mean and median can be indicative of a highly variable data set, one which may be skewed (to the right or left) or simply one which includes one or more extreme data values. As a first step in the search for anomalous observations, any data value lying beyond 3 standard deviation from the mean is flagged. These summaries can be evaluated for selected sub-groups of the data (by nuclide, area/region, by sample type and by time period). Such data summaries may ignore spatial or temporal nearness, so that a further level of checking requires a definition of "neighbourhood", in the spatial context, all samples within a specified distance (e.g. "d" units apart) would comprise a spatial grouping. Similarly, within the temporal context, measurements made sufficiently close in time might be analysed for the presence of extreme values. Both such analyses make use of the idea of a "smoother" (e.g. running weighted average) to highlight the underlying levels.

6.2.2. Graphical checks

To complement the numerical summaries, further checks are performed graphically. Diagrams include histograms, serial data plots and scatterplots (particularly appropriate for spatially registered data). Observations identified by either of these procedures are flagged for further manual investigation.

The scientific value and reliability of the data is an issue which goes beyond the discussion above. The procedures already discussed try to ensure that the data entry uncertainty rate is kept low and that anomalous observations are highlighted. The

interpretation of such anomalous values is made difficult by reason of the two possible causes of the value (the possibility of a simple typographical error has already been discounted). The scientific validity of the anomalous observation is dependent on the reliability of the measurement, an assessment based upon a combination of expert knowledge and the degree of detail concerning the actual measurement. The GLOMARD database, through its connections to the AQCS database, is designed to provide at minimum, an indication that the laboratory participated in inter-laboratory checks and their performance. In addition, the number of pieces of supporting information requested for each measurement is intended to assist users in making value judgements concerning the data. The anomalous observation, having undergone rigorous scrutiny, is intensely valuable and the above procedures have been developed to maximise its credibility.

6.3. DATA SECURITY AND BACKUP

As in all major database projects, important functions of the quality assurance procedures are the data backup and security systems.

6.3.1. Data security

Access to the master database file is restricted to a small number of staff. Data modifications and changes are approved and checked by two members of staff before being implemented. Full records of the modifications are made and can be directly referenced.

6.3.2. Data backup

Several backup copies of the database are made routinely after each update. Routine backups are made every week.

7. USES OF THE SYSTEM

A number of standard uses are already envisaged and as such, specific application modules have been developed. The number of uses for the system is limitless and includes use in model validation studies, mapping, impact assessment and investigation of the dynamics of the marine system. The specific application modules already existing or planned include:

(a) Conversion to standard units
(b) Preparation of standard reports
(c) Evaluation of time trends
(d) Inventory calculations.

The first application module is, of course, necessary for all the other applications. Underlying each application is the method of searching within the database, which is based on several key fields. Each search is undertaken under constraints of location, nuclide, sample type and time period. Users identify the location of interest, either through region, area or latitude and longitude; for the sample type, they must select one of four categories, if biota is selected, they may select class of organism or species. The time period is for most applications dealt with in terms of month and year (for specialised work, it is, of course, possible to define the day also).

The basic report module selects some of the possible database fields to provide an adequate (if undetailed) summary, the actual format is dependent on the type of sample which is being summarised.

The nuclide ratio module identifies those samples which have had the requisite measurements made, evaluates their ratio and uncertainty.

The time trend module produces results by nuclide through the period of interest. The inventory module nuclide inventories in predefined regions and areas in either sediment or water.

Data entry into the GLOMARD database has followed a well defined pattern. Specific areas in the world are selected and data from those areas sought from the various sources. Areas such as the Black Sea, the Arctic, the Mediterranean and the Sea of Japan provide good examples of the location specific data entry schedule. In this way the system can respond to identified needs within these locations. Clearly as progress is made, new areas will be selected. Historical data archives such as the GEOSECS and TTO surveys are also being added to the database. IAEA technical documents will be produced at regular intervals on selected areas.

The non-graphics reports from the GLOMARD should be very flexible and adjustable to future needs of any Member State potentially using the database. Generally, it should be possible to arrange any information stored in the GLOMARD in a tabelized (and graphical) form and to print it.

The reports should provide, e.g.:

Distribution of radionuclides in a given sea

Location Sampling time Radionuclides Levels ± uncertainties

Isotopic ratios
Location Sampling time Isotopes Levels ± uncertainties

Time trends
(similarly as for radionuclides and isotopic ratios)

Radionuclide profiles in the water column
LocationDepth Time Radionuclides Levels ± uncertainties

Radionuclide profiles in sediment
(similarly as for the water column)

Isotopic ratio profiles (in water, sediment)
(similarly as for radionuclides)

radionuclide profiles in the water column vs. salinity (temperature)
(as above)

etc. (there could be tens of examples).

Further work is being carried out to implement data in the Geographical Information System (GIS) using the relational database ORACLE. The new software in comparison with the software presently used (SURFER) will allow greater precision in the interpolation procedures, as well as to form 3D images. This is especially important when correlation studies are necessary, e.g. radionuclide concentrations vs. salinity and water depth.

8. RADIOACTIVITY OF THE BARENTS AND KARA SEAS

The first application of the Global Marine Radioactivity Database was under the International Arctic Seas Assessment Project (IASAP). The IAEA-MEL acted as a central facility for the collection, synthesis and interpretation of data on marine radioactivity in the Arctic Seas. About 50 MB of data on the Arctic Seas have already been entered, with initial emphasis on the extensive joint Norwegian-Russian data, IAEA-MEL's own measurements and data obtained from other institutions.

8.1. PRE-1992 RADIONUCLIDE CONCENTRATIONS

Results of radionuclide measurements in water, sediment and biota of the Arctic Seas are sparse, as can be seen from Fig. 5, where sampling stations of ^{137}Cs in surface water are shown. The density of data is so low that sophisticated methods of data analysis cannot be used for data evaluation. The evaluation of time trends may be carried out only for the Norwegian, Barents and Kara Seas.

8.1.1. Water

Figure 6 shows the evolution of average surface concentrations of ^{90}Sr and ^{137}Cs with time in Barents Sea surface water. The only well-documented record available is for ^{90}Sr [1] and partially also for ^{137}Cs [2, 3]. ^{90}Sr levels are gradually decreasing from the average 19 Bq m^{-3} in 1964 to the present value of about 4 Bq m^{-3}. A slight increase in concentrations at the end of the seventies and the beginning of the eighties may be associated with Sellafield peak releases in the mid-seventies. This is, however, much better documented by ^{137}Cs records, although there are also values missing for several of these years. Thus an approximate transit time from Sellafield to the Barents Sea can be estimated to be 4-5 years.

The data from GLOMARD show that there has been a decrease in the anthropogenic radioactivity of the Kara Sea in recent years. For example, the ^{137}Cs content of surface Kara Sea water decreased from (18-27) Bq m^{-3} in 1982 in the SW Kara Sea to (3-8) Bq m^{-3} at present. This trend may reflect a considerable decrease in local fallout and probably also the reduction in ^{137}Cs discharges from the Sellafield reprocessing plant. ^{90}Sr in surface waters shows similar trends, the levels having decreased from (7-21) Bq m^{-3} in 1982 to the present values of (3-11) Bq m^{-3}.

In the histogram shown in Fig. 6 for the Kara Sea, high ^{90}Sr concentrations (about 39 Bq m^{-3}) can be observed in the sixties which may be associated with local fallout; medium concentrations (below 15 Bq m^{-3}) in 1970, 1971 and 1982, and low concentrations (about 5 Bq m^{-3}) have been observed in recent years. The ^{137}Cs data are only available from 1982, and the value for that year (about 20 Bq m^{-3}) is consistent with mean ^{90}Sr values. Present concentrations are much smaller (about 6 Bq m^{-3}) and therefore one can speculate that the 1982 value may represent a Sellafield signal in the Kara Sea. The approximate transit time from Sellafield to the Kara Sea would then be 6-7 years. There are no pre-1992 data available for $^{239+240}$Pu concentrations in Kara Sea waters.

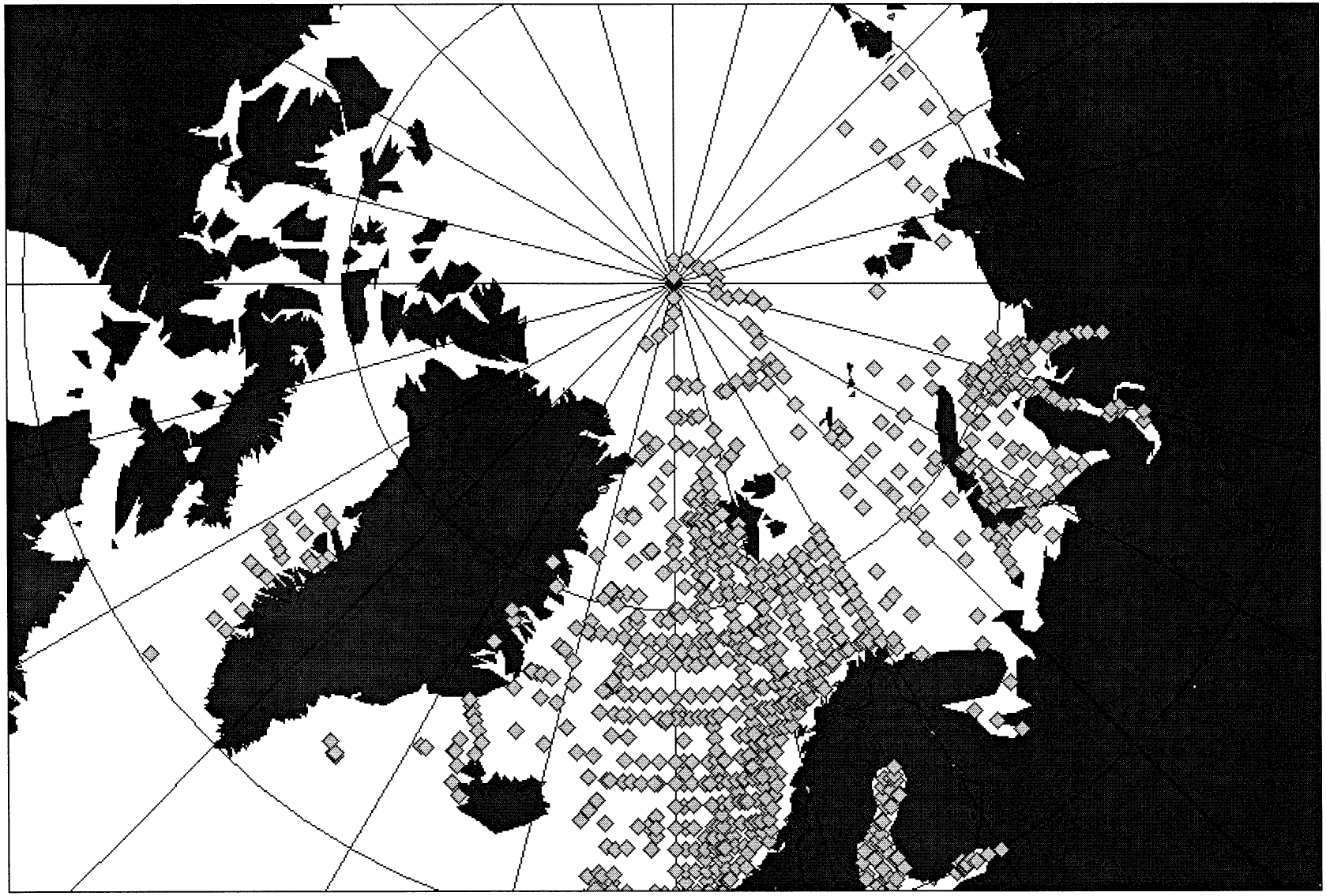

FIG. 5. Sampling stations in the Arctic Seas for Cs-137 in surface water (1965-1995).

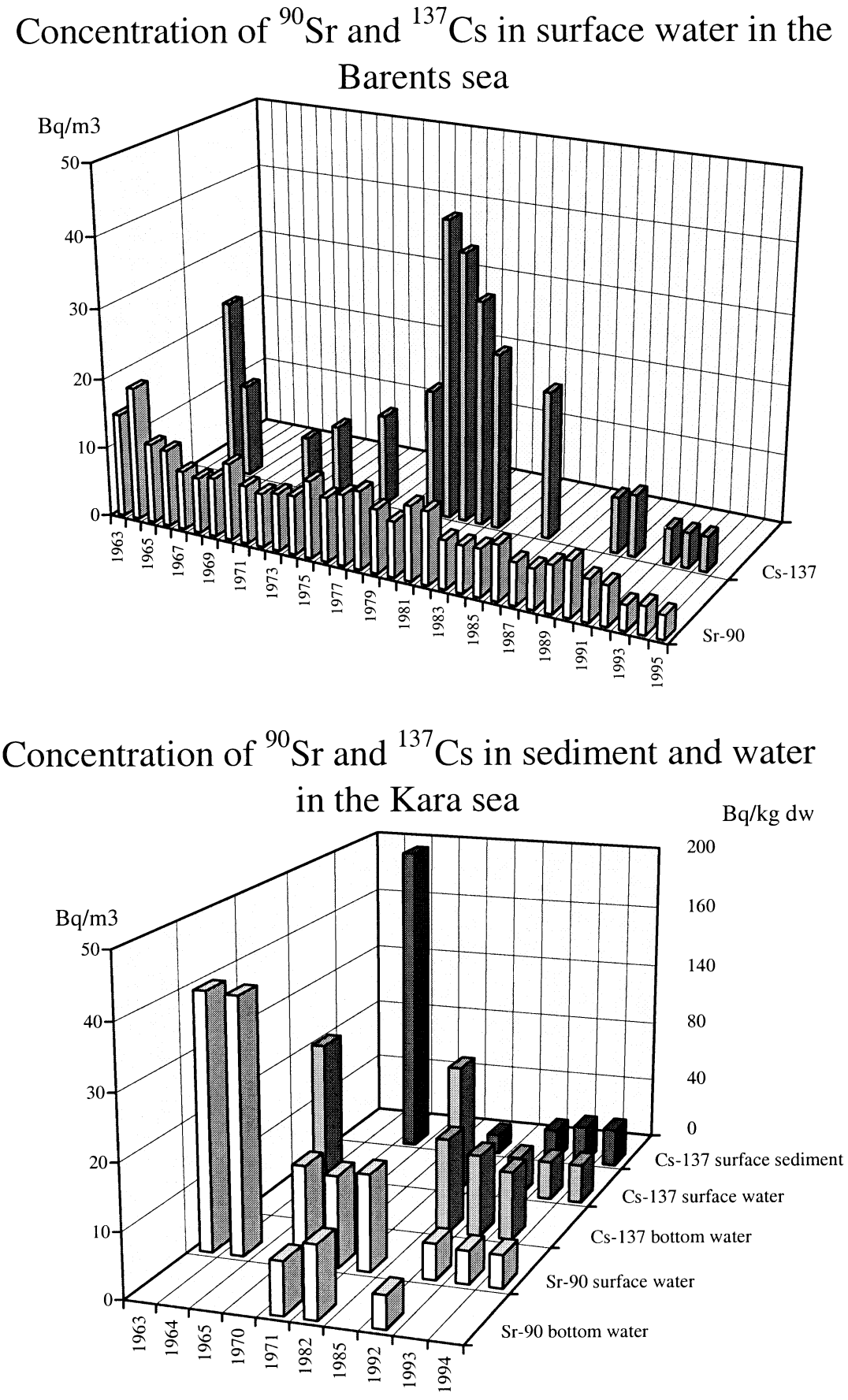

FIG. 6. Average concentrations of Sr-90 and CS-377 in surface water and sediment in the Barents and Kara Seas.

The spatial distribution of ^{137}Cs in the Barents and Kara Sea surface and bottom waters in three time intervals (1965–1970, 1971–1990 and 1991–1995) is shown in Figs 7 and 8. The effect of transport of Sellafield ^{137}Cs to the Barents Sea and a recent decrease in ^{137}Cs concentrations can be clearly seen. Because of the above temporal trends coupled with residence time and salinity effects, deeper waters (>50 m) in the Kara Sea show higher concentrations of ^{137}Cs and $^{239+240}$Pu than surface waters, by about a factor of 2–3.

The spatial distribution of ^{90}Sr in Barents and Kara Sea surface waters depicted in Fig. 9 also shows a considerable decrease of ^{90}Sr levels in the open Kara Sea. Remarkably higher ^{90}Sr concentrations have been observed in the central and eastern Kara Sea, which are due to discharges of radioactive wastes from the former Soviet Union's nuclear plants to the Ob and Yenisey rivers. This is well documented by ^{90}Sr/^{137}Cs activity ratios in surface water (Fig. 10).

8.1.2. Sediment

Pre-1992 radionuclide data for sediments in the Kara Sea are also very sparse. The highest ^{137}Cs levels (around 200 Bq kg^{-1} dw) were observed in the seventies in the central and eastern Kara Sea, probably due to discharges in the Ob and Yenisey rivers. Data from the eighties show (4–20) Bq kg^{-1} dry weight for ^{137}Cs in surface sediment [1] which can be compared with the present values (18–32) Bq kg^{-1} dw [4–7]. This is documented in a contour map (Fig. 11) showing the spatial distribution of ^{137}Cs in surface sediments. There are no pre-1992 data available for $^{239+240}$Pu concentrations in Kara Sea sediments.

8.2. PRESENT RADIONUCLIDE INVENTORIES IN THE KARA SEA

8.2.1. Dump sites

Radionuclide analyses of water, sediment and biota sampled at the major dump sites in Tsivolki, Stepovoy and Abrosimov Bays and the Novaya Zemlya Trough show that radionuclide concentrations are generally low, similar to those observed in the open Kara Sea. However, highly localised contamination has been observed from leakage of waste containers in Abrosimov and Stepovoy Bays.

Abrosimov Bay

A down core profile of ^{60}Co, ^{90}Sr, ^{137}Cs and Pu isotopes in sediment collected in 1994 at the containers dump site in Abrosimov Bay has shown that the concentrations of all detected radionuclides were higher by a factor of 10 to 1000 than those at uncontaminated sites.

Contamination by fission products (^{137}Cs up to 30 kBq kg^{-1} and ^{90}Sr up to a few kBq kg^{-1} dw), activation products (^{60}Co up to a few hundreds of Bq kg^{-1} dw) and actinides ($^{239+240}$Pu up to 18 Bq kg^{-1} dw) have been observed [8–13]. The ^{238}Pu/$^{239+240}$Pu activity ratio, a strong indicator of plutonium origin in the marine environment, ranges from 0.3 to 0.7 which differs significantly from the value for global fallout (0.03) and suggests a waste origin of plutonium in the sediment core. The sampling site where the highest contamination is observed does not contain reactor compartments, only low level wastes packed in containers. This observation implies that leakage probably occurred from dumped containers. However, the leakage has not led to a measurable increase of radioactivity in the outer part of the Bay. The highly localised character of the contamination suggests that leakage probably occurred in particulate form.

Text cont. on page 36.

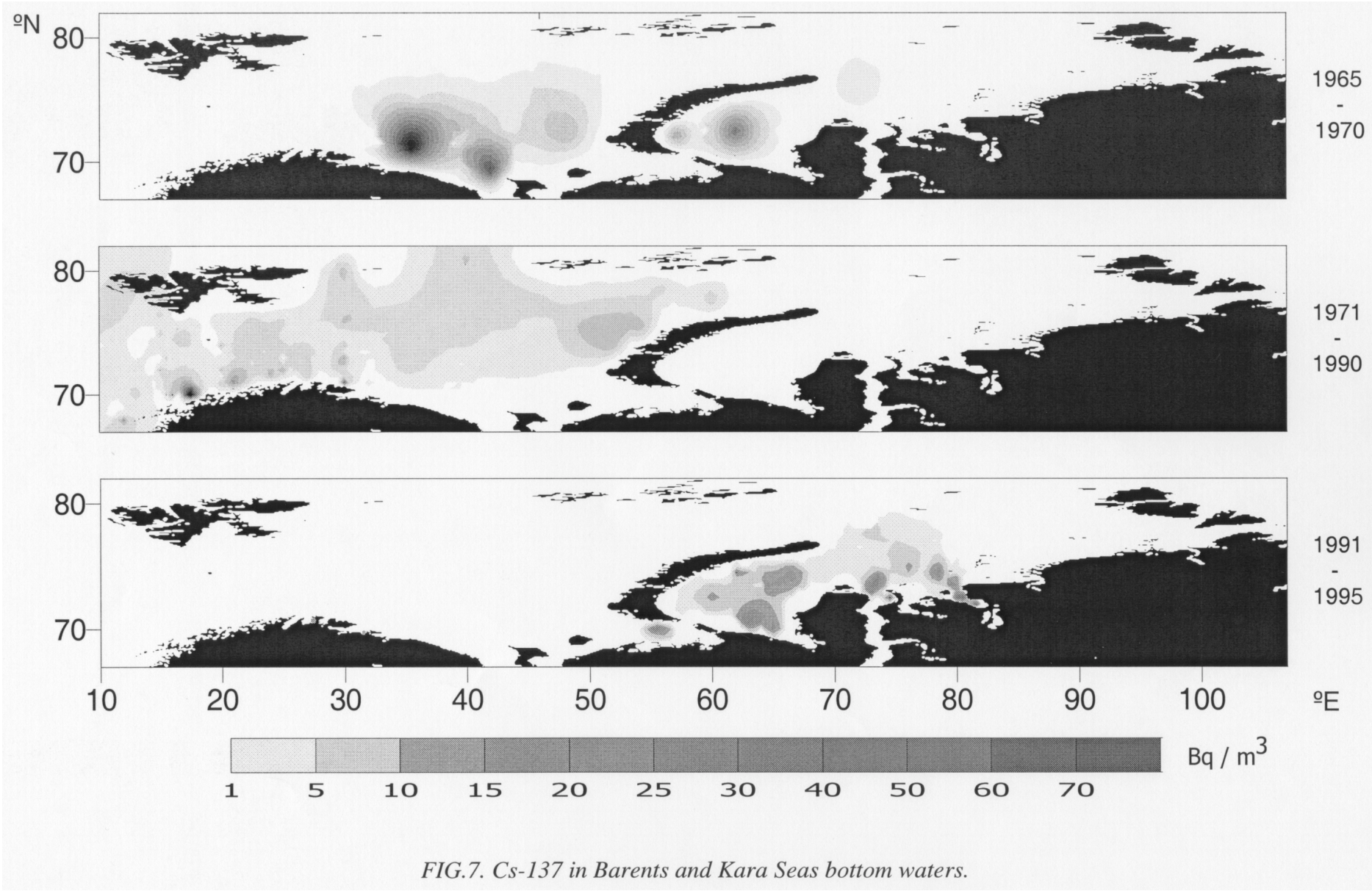

FIG.7. Cs-137 in Barents and Kara Seas bottom waters.

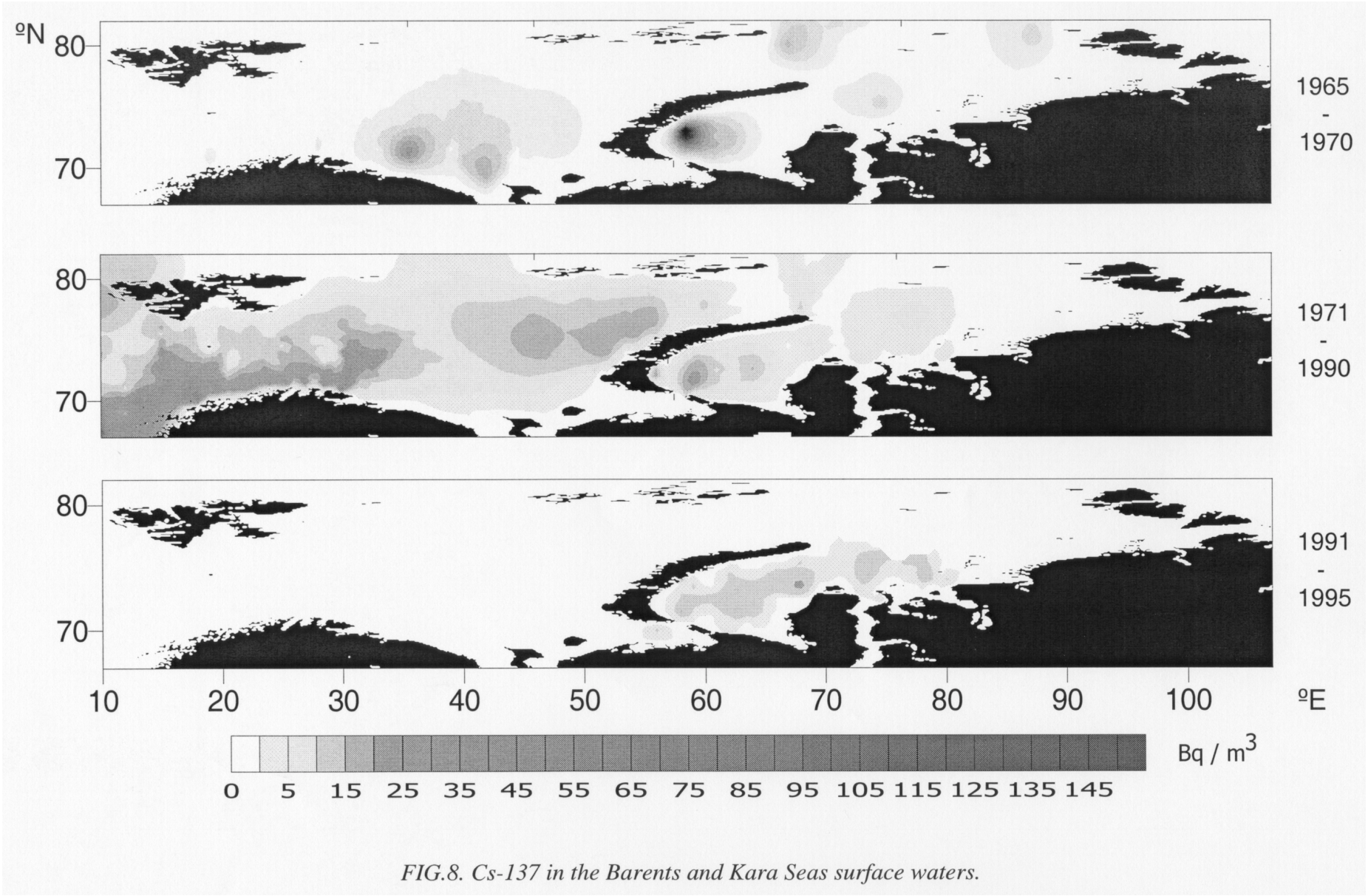

FIG.8. Cs-137 in the Barents and Kara Seas surface waters.

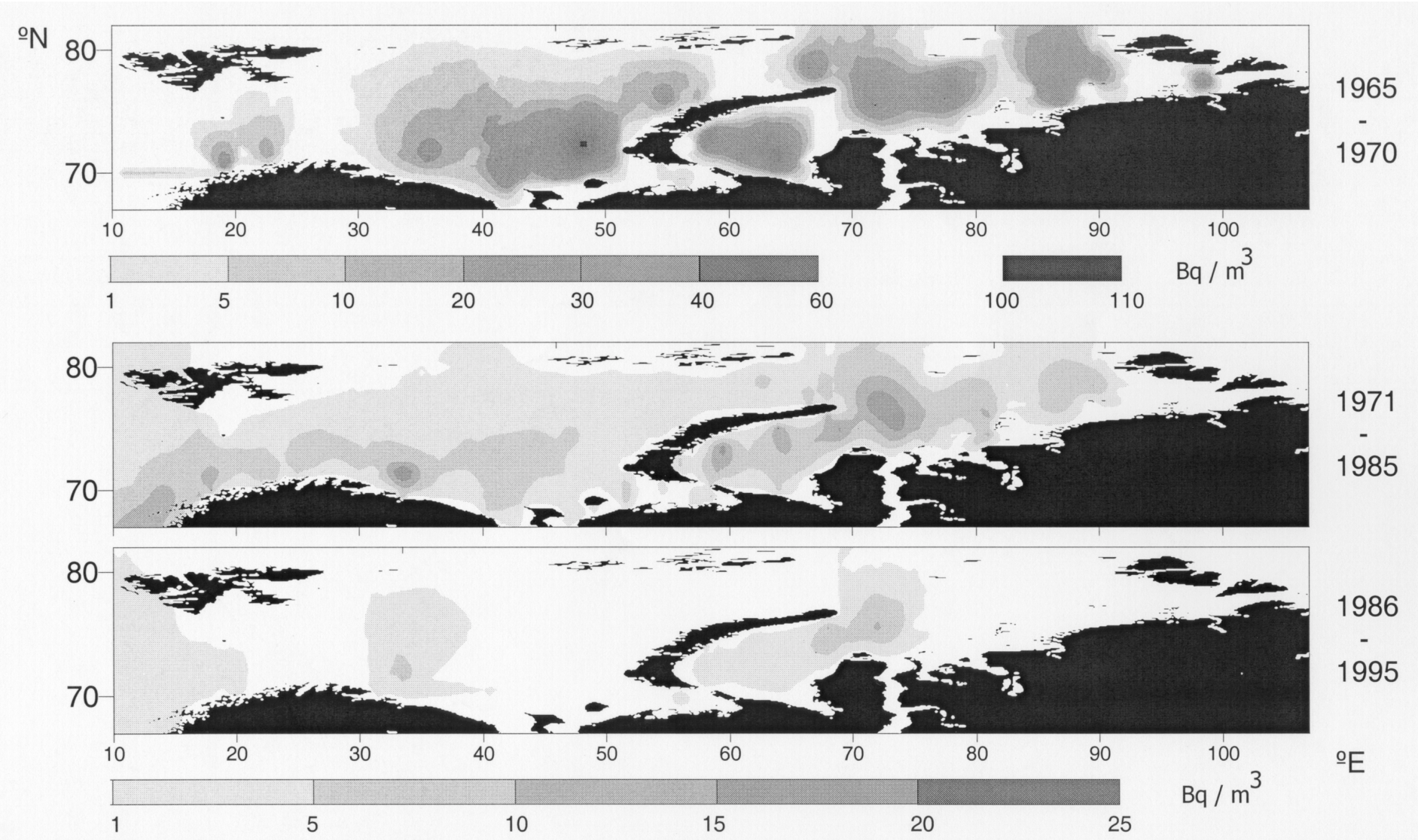

FIG. 9. Sr-90 in the Barents and Kara Seas surface waters.

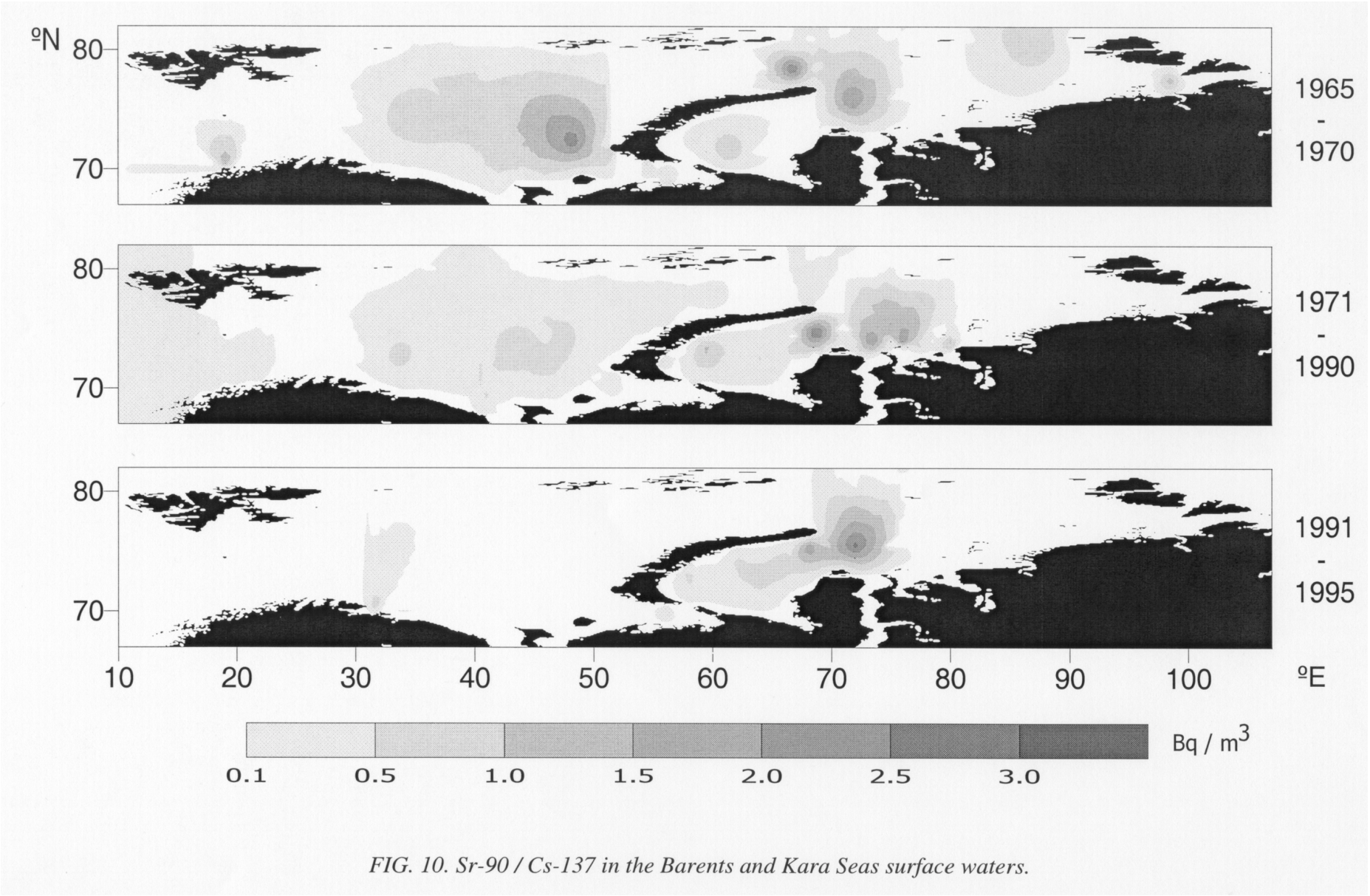

FIG. 10. Sr-90 / Cs-137 in the Barents and Kara Seas surface waters.

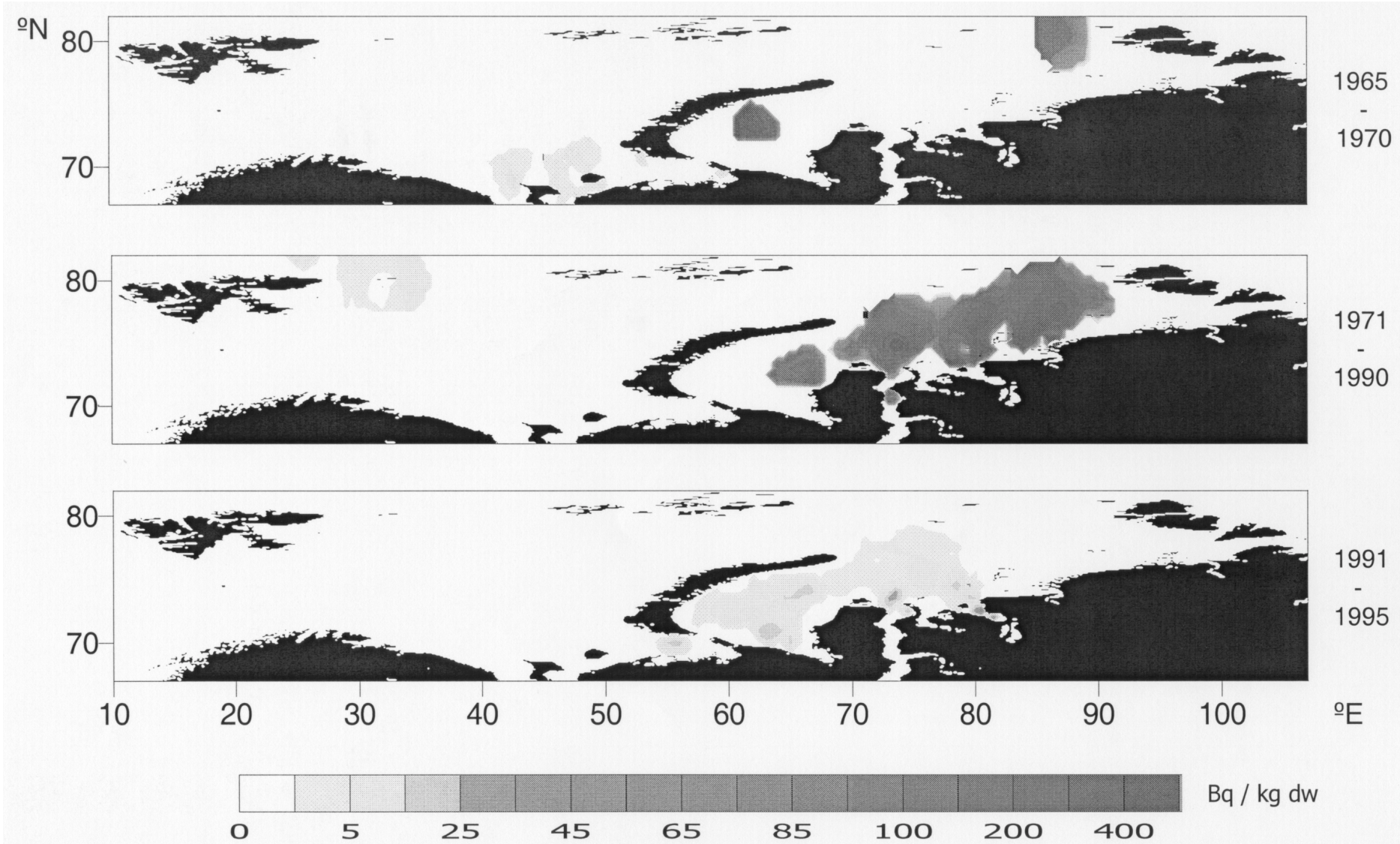

FIG. 11. Cs-137 in the Barents and Kara Seas surface sediments.

Figure 11 shows a map of Abrosimov Bay with localised dumped objects and elevated ^{137}Cs concentrations measured in surface sediments. A similar distribution has been observed for ^{60}Co, ^{90}Sr and $^{239+240}$Pu. However, ^{3}H, ^{90}Sr, ^{137}Cs and $^{239+240}$Pu levels observed in the water of the bay are within the typical range for the open Kara Sea. This would imply that leakage is not continuing at present and that the sediment contamination observed occurred in the past.

Radionuclide inventories in sediments vary for ^{137}Cs from 0.5 to 3000 kBq m^{-2} at locations where leakages have been observed. Similarly ^{60}Co and $^{239+240}$Pu inventories are up to about 3 and 0.2 kBq m^{-2}, respectively.

Stepovoy Bay

Higher concentrations of ^{137}Cs, ^{60}Co, ^{90}Sr and Pu isotopes (^{137}Cs up to 110 kBq kg^{-1}, ^{60}Co up to 3 kBq kg^{-1}, ^{90}Sr up to 0.3 kBq kg^{-1} and $^{239+240}$Pu up to 10 Bq kg^{-1}) have been measured only at very localised places around dumped containers. As in Abrosimov Bay, the leakage has not led to a measurable increase in the outer part of the Bay.

Measured concentrations of ^{90}Sr, ^{137}Cs and $^{239+240}$Pu in the outer part of the bay bottom water are by a factor of 3–5 higher than in the surface water, indicating a leakage from containers. In the outer part of the bay, the concentrations are typical of those in the open Kara Sea.

Radionuclide inventories in sediments may vary for ^{137}Cs from below 1 kBq m^{-2} in uncontaminated locations to 11 kBq m^{-2} where leakage has been observed. Similarly ^{60}Co and $^{239+240}$Pu inventories are up to 26 and 0.2 kBq m^{-2}, respectively.

Tsivolki Bay

Sediment cores analysed from Tsivolki Bay have shown ^{137}Cs and $^{239+240}$Pu concentrations comparable with those in open Kara Sea sediment. However, the presence of traces of ^{60}Co suggest a local source of contamination. The observed radionuclide profiles indicate a fast deposition of sedimentary material and effective mixing by physical or biological processes.

The spent nuclear fuel of the Lenin reactor has not been localised yet, therefore any possible leakage associated with this waste has not been reported. Radionuclide concentrations in water are typical of the open Kara Sea.

Radionuclide inventories in sediment range for ^{137}Cs from 0.3 to 3 kBq m^{-2}, for ^{60}Co and for $^{239+240}$Pu, up to about 0.3 and 0.02 kBq m^{-2}, respectively.

Novaya Zemlya Trough

No local contamination of sediment has been observed. However, the nuclear reactor dumped in the Novaya Zemlya Trough has not yet been properly localised.

As mentioned previously concentrations of ^{137}Cs and $^{239+240}$Pu are expected to be higher in deep waters. While ^{137}Cs concentration in surface water varies between 4 and 7 Bq m^{-3}, bottom water ^{137}Cs concentrations are 7–14 Bq m^{-3}.

^{137}Cs and $^{239+240}$Pu inventories in sediment are in the range 0.3–0.8 and up to about 0.02 kBq m^{-2}, respectively.

8.2.2. The open Kara Sea

The concentration of anthropogenic radionuclides in Kara Sea water, sediment and biota is generally very low. ^{137}Cs data show almost constant spatial distribution, however, ^{90}Sr data, especially ^{90}Sr/^{137}Cs activity ratio in seawater vary across the Kara Sea (Fig. 10). The ratio correlates with salinity and indicates the importance of the ^{90}Sr input from the Ob and Yenisey rivers.

The ^{137}Cs inventory in the water column ranges from 1 to 4 kBq m^{-2} and shows a relatively smooth and linear correlation with water depth. This implies that there are no point sources of radioactivity near the sampling stations.

The sediment column inventories, ranging from 0.5 to 0.9 kBq m^{-2}, show an inverse correlation with water depth, suggesting an enhanced rate of nuclide scavenging in the higher particle fluxes associated with shallower waters [6].

The total ^{137}Cs inventories in the open Kara Sea range from 1.5 to 4.5 kBq m^{-2}. In comparison with the amounts of radioactive fallout deposited in the northern hemisphere [14], we estimate that the contribution of global fallout to the ^{137}Cs inventory in the Kara Sea should be about 0.5 kBq m^{-2}. This value is lower than the average measured value weighted over the mean water depth in the Kara Sea (1.5 kBq m^{-2}), suggesting that the difference may reflect contributions from local fallout and from discharges from the Sellafield reprocessing plant. Indeed, in the Pechora Sea, the observed ^{137}Cs concentrations are much higher [15, 6, 16] which reflect its close proximity to the Guba Chernaya underwater nuclear test site.

The $^{239+240}$Pu inventory in sediments is between 0.01 and 0.03 Bq m^{-2}. The $^{239+240}$Pu/^{137}Cs inventory ratios are about 0.03, as would be expected from global fallout. ^{238}Pu/$^{239+240}$Pu ratios in sediments are between 0.02 and 0.05, suggesting a global fallout origin for the plutonium in sediment.

8.2.3. Ob and Yenisey estuaries

The Ob and Yenisey rivers are important suppliers of fresh water to the Kara Sea and possibly of contaminants (e.g. ^{90}Sr and ^{137}Cs) from land based sources. The data clearly show ^{137}Cs and $^{239+240}$Pu depletion from water at low salinity [13]. On the other hand, ^{90}Sr, which is less particle-reactive, shows less variation as a function of salinity. Therefore fast sedimentation and scavenging occur at locations of low salinity carrying relatively high sediment inventories of ^{137}Cs (1–5 kBq m^{-2}).

8.2.4. Biota

There are no data available on pre-1992 radionuclide concentrations in biota of the Kara Sea. From post-1992 data, we can conclude that typical concentrations of ^{137}Cs in the benthic fauna of the Kara Sea are around 1 Bq kg^{-1} dw. ^{137}Cs and $^{239+240}$Pu concentrations in gammarids were found around 1.5 and 0.01 Bq kg^{-1} dw, respectively. Brittle stars (*Ophiuridea*) showed $^{239+240}$Pu concentrations around 0.1 Bq kg^{-1} dw. Higher values of ^{137}Cs were observed for Polychaeta (*Spiochaetoperus*) between 6–17 Bq kg^{-1} in the tubes. For fish (Arctic cod) caught in the open Kara Sea and in Abrosimov Bay, ^{137}Cs concentrations were about 1 Bq kg^{-1} dw. Algae samples showed ^{137}Cs levels below 3 Bq kg^{-1} dw [17, 18, 12].

Generally, the concentrations of ^{137}Cs, ^{90}Sr and $^{239+240}$Pu in biota samples from the Kara Sea are very low (the latter two often below detection limits of 0.5 Bq kg^{-1} and 0.01 Bq

kg^{-1} dw, respectively). No systematic trend in the distribution of these radionuclides has been observed.

8.2.5. Conclusions on radionuclide inventories in the Kara Sea

On the basis of the extensive joint Norwegian–Russian data [17, 19, 12] and of IAEA-MEL and other results stored in the GLOMARD database, on measurement of concentrations of several radionuclides (^{3}H, ^{60}Co, ^{90}Sr, ^{99}Tc, ^{129}I, ^{137}Cs, ^{238}Pu $^{239+240}Pu$ and ^{241}Am) in water, sediment and biota sampled at the major dump sites in Abrosimov, Stepovoy and Tsivolki Bays and the Novaya Zemlya Trough as well as in the open Kara Sea and the Ob and Yenisey estuaries, it can be concluded that, with the exception of limited areas in Abrosimov and Stepovoy Bays, only minor contamination exists relative to background levels. *In situ* gamma-spectra recorded at the dump sites indicate that the contamination has a localised character and, at sites outside the disposal areas, no contribution from local sources can be observed [20, 21]. The most marked contamination of sediment appears to be associated with leakage from dumped containers.

The open Kara Sea is relatively uncontaminated, the main contributions being due to direct deposition and catchment run-off from global fallout caused by nuclear weapons tests, discharges from reprocessing plants in Western Europe and the former Soviet Union, local fallout from tests performed at Novaya Zemlya and Chernobyl fallout.

9. RADIOACTIVITY OF THE SEA OF JAPAN

In 1995 the IAEA's Marine Environment Laboratory began a project on World-wide Marine Radioactivity Studies (MARS) [22] thanks to the generous support of the Government of Japan (The Science and Technology Agency). The aim of the project is to provide new data on current marine radioactivity of the world's oceans and seas in order that the results from expeditions to dumping sites and nuclear weapons testing sites can be reviewed objectively, comparatively and comprehensively.

As part of this project, IAEA-MEL is collecting data on marine radioactivity for the GLOMARD database. During the first phase of the project, the work has concentrated on the North West Pacific Ocean and its marginal seas.

In this document, we report the first set of data obtained for marine radioactivity around Japan, as an illustration of GLOMARD's possibilities.

The data cover radionuclide concentrations in seawater, sediment and biota from 1980 to the present. The main sources of data were:

(i) the Japan Chemical Analysis Center (JCAC),
(ii) the National Institute of Radiological Sciences (NIRS),
(iii) the Marine Safety Agency (MSA),
(iv) the Fisheries Agency (FA),
(v) research institutes and literature survey.

Only data on radionuclide concentrations outside territorial waters have been included in the GLOMARD. Altogether about 25 000 data inputs have been made for the NW Pacific Ocean.

9.1. TIME SERIES OF ^{137}Cs AND ^{90}Sr

Figure 12 shows the development of ^{137}Cs and ^{90}Sr concentrations with time in surface seawater of the coastal areas of Japan. It is clear that the concentrations of ^{137}Cs and ^{90}Sr have been decreasing since 1964, rapidly up to 1975 and slowly to present. The ^{137}Cs and ^{90}Sr concentrations in recent years are between (2–4) mBq/L and (2–3) mBq/L, respectively.

The effect of the Chernobyl accident which occurred in 1986 is only visible for ^{137}Cs. The average integrated deposition between 20º to 50º N from atmospheric nuclear tests were estimated to be from 2.8 to 5.2 kBq/m^2 for ^{137}Cs and from 1.8 to 3.2 kBq/m^2 for ^{90}Sr, respectively [14]. On the other hand, the Chernobyl fallout of ^{137}Cs around Japan was only 0.18 kBq/m^2 on average, and negligible for ^{90}Sr [23]. The increase in ^{137}Cs concentration was limited to 1986 only due to fast dilution of the surface concentration.

Figure 13 shows the development of ^{137}Cs and ^{90}Sr concentrations with time (from 1964 to 1994) in sediment collected in coastal areas of Japan. The observed decreases for both radionuclides were small. The recent ^{137}Cs and ^{90}Sr concentrations were between 0.2 and 10 Bq/kg dw and 0.02 and 1Bq/kg dw, respectively. The observed ranges in concentrations extend over two orders of magnitude, which are much larger than those in seawater.

^{137}Cs and ^{90}Sr concentrations in biota samples taken in coastal areas of Japan are shown in Figs 14 and 15 for fish and seaweed, respectively. The observed concentrations have been slowly decreasing year by year, the present levels in fish are from 0.05 to 0.5 Bq/kg ww for ^{137}Cs and from 0.001 to 0.03 Bq/kg ww for ^{90}Sr. Whereas those in seaweed are from 0.02 to 0.4 Bq/kg ww for ^{137}Cs and from 0.01 to 0.05 Bq/kg ww for ^{90}Sr. The observed variations in fish are larger than those in seaweed because the fish samples include more species. A small ^{137}Cs elevation due to the Chernobyl accident was observed only in seaweed samples.

9.2. RADIONUCLIDE INVENTORIES

Evaluation was carried out for the vertical profiles of radionuclide concentrations, radionuclide inventories, and their isotopic activity ratios in both seawater columns and sediment cores of the northwest Pacific Ocean using data sets installed in the GLOMARD.

9.2.1. Water

The profiles of ^{90}Sr and ^{137}Cs in seawater columns show a gradual decrease in concentration with increasing depth, contrasting with those of ^{239,240}Pu, which show a subsurface maximum at around a depth of 700 metres, reflecting specific scavenging processes in the water column.

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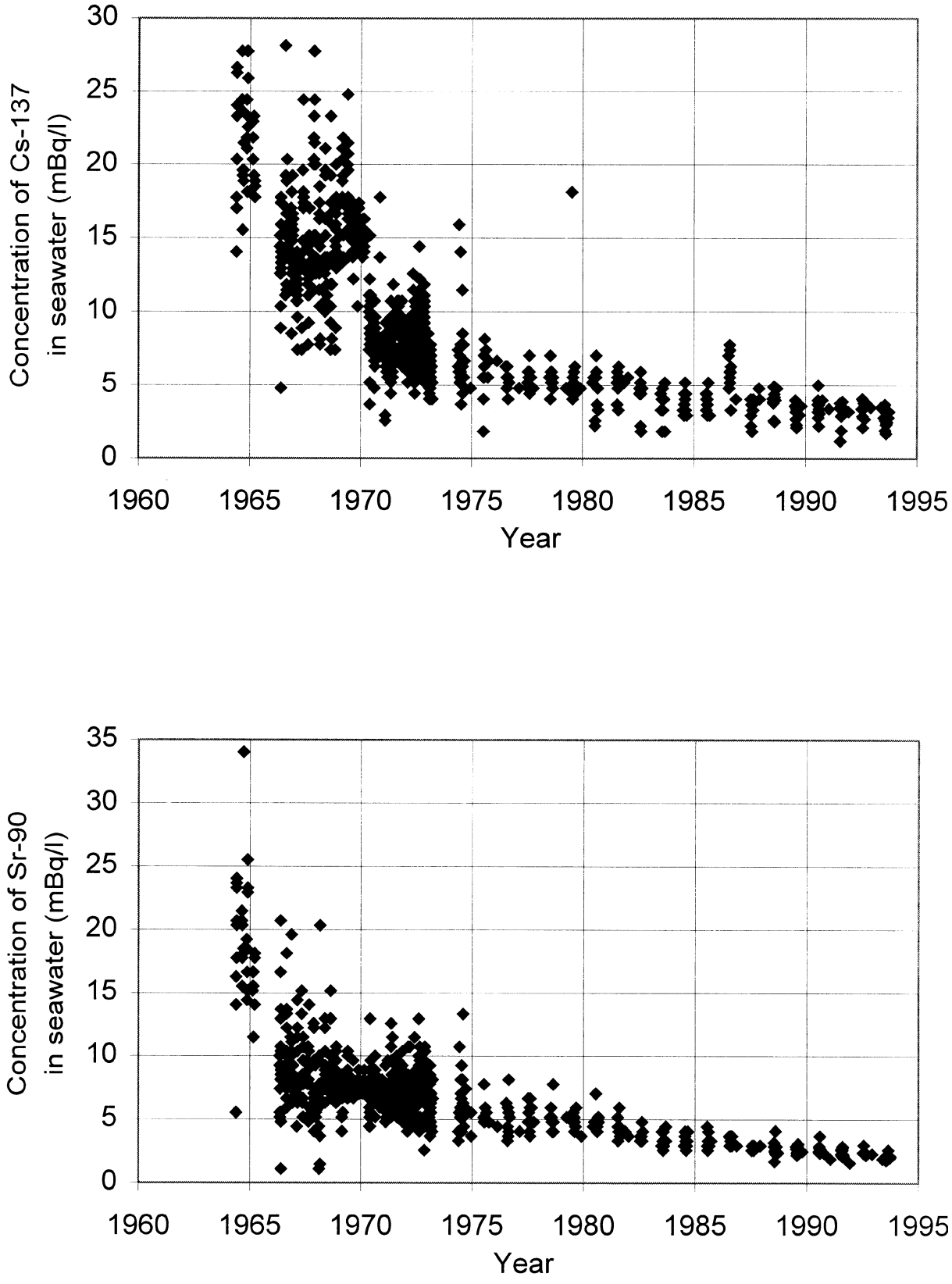

FIG. 12. ^{137}Cs (top) and ^{90}Sr (bottom) trends with time in seawater in coastal areas of Japan.

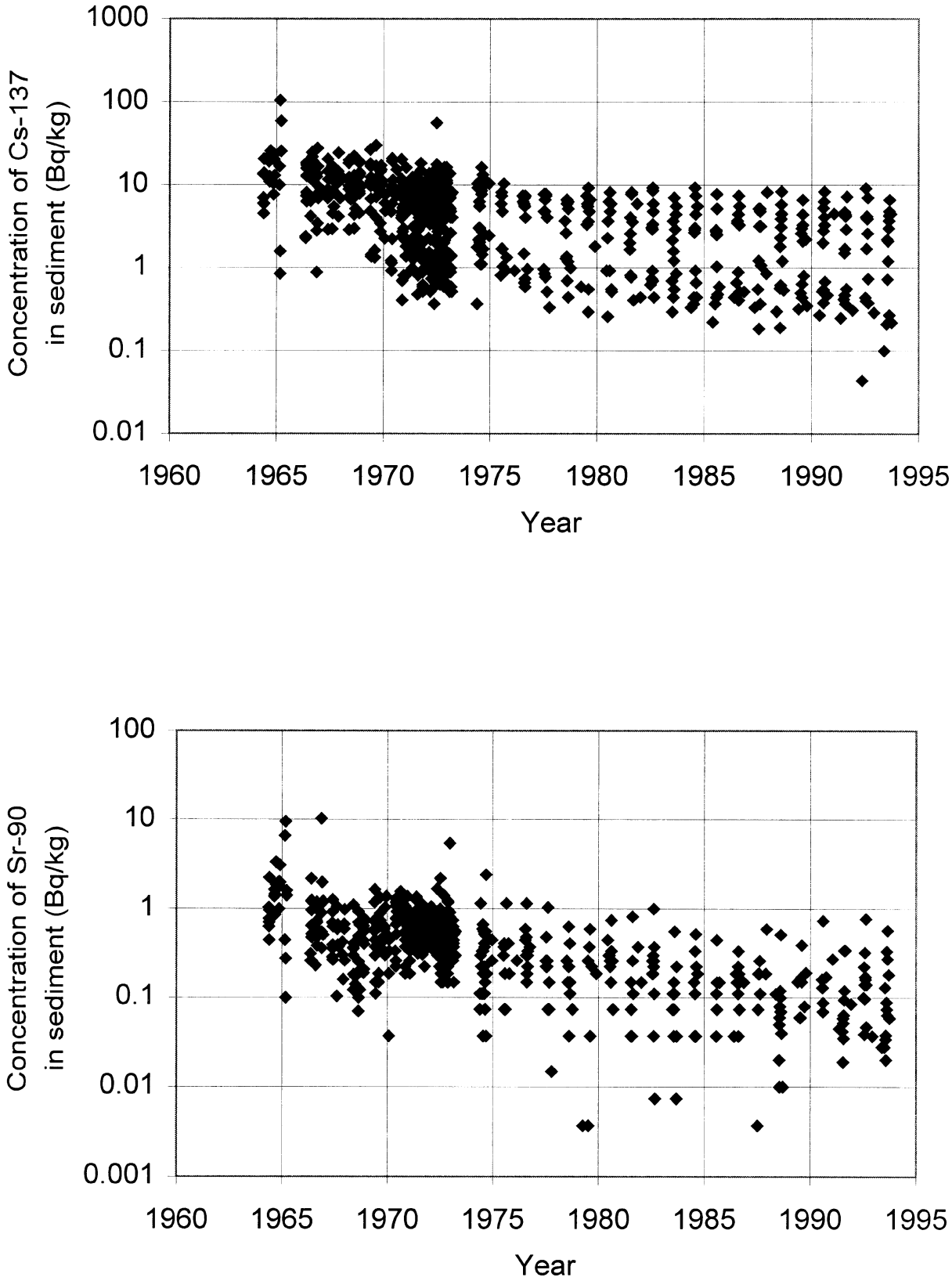

Fig. 13. ^{137}Cs (top) and ^{90}Sr (bottom) trends with time in sediment in coastal areas of Japan.

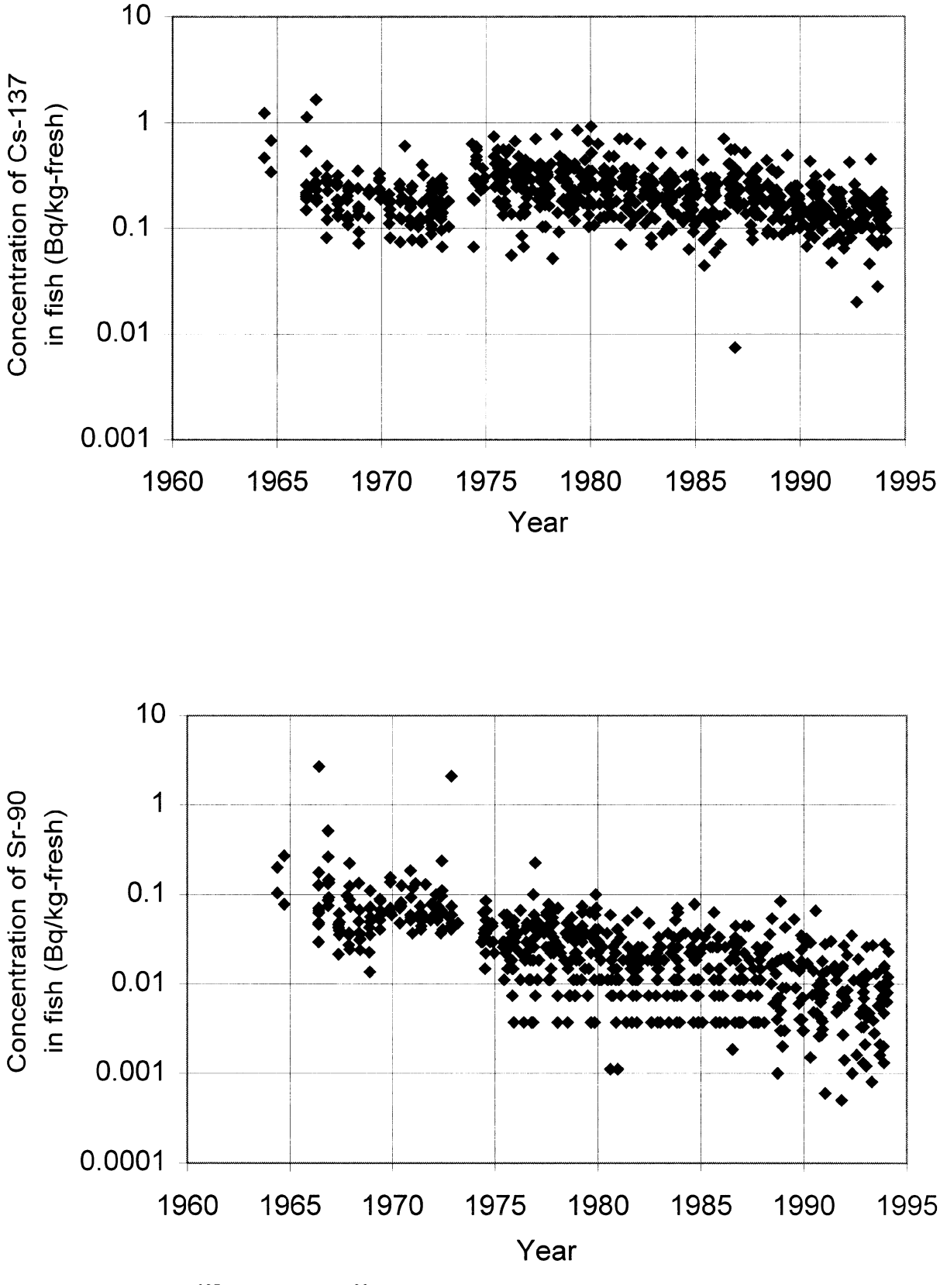

FIG. 14. ^{137}Cs (top) and ^{90}Sr (bottom) in fish in coastal areas of Japan.

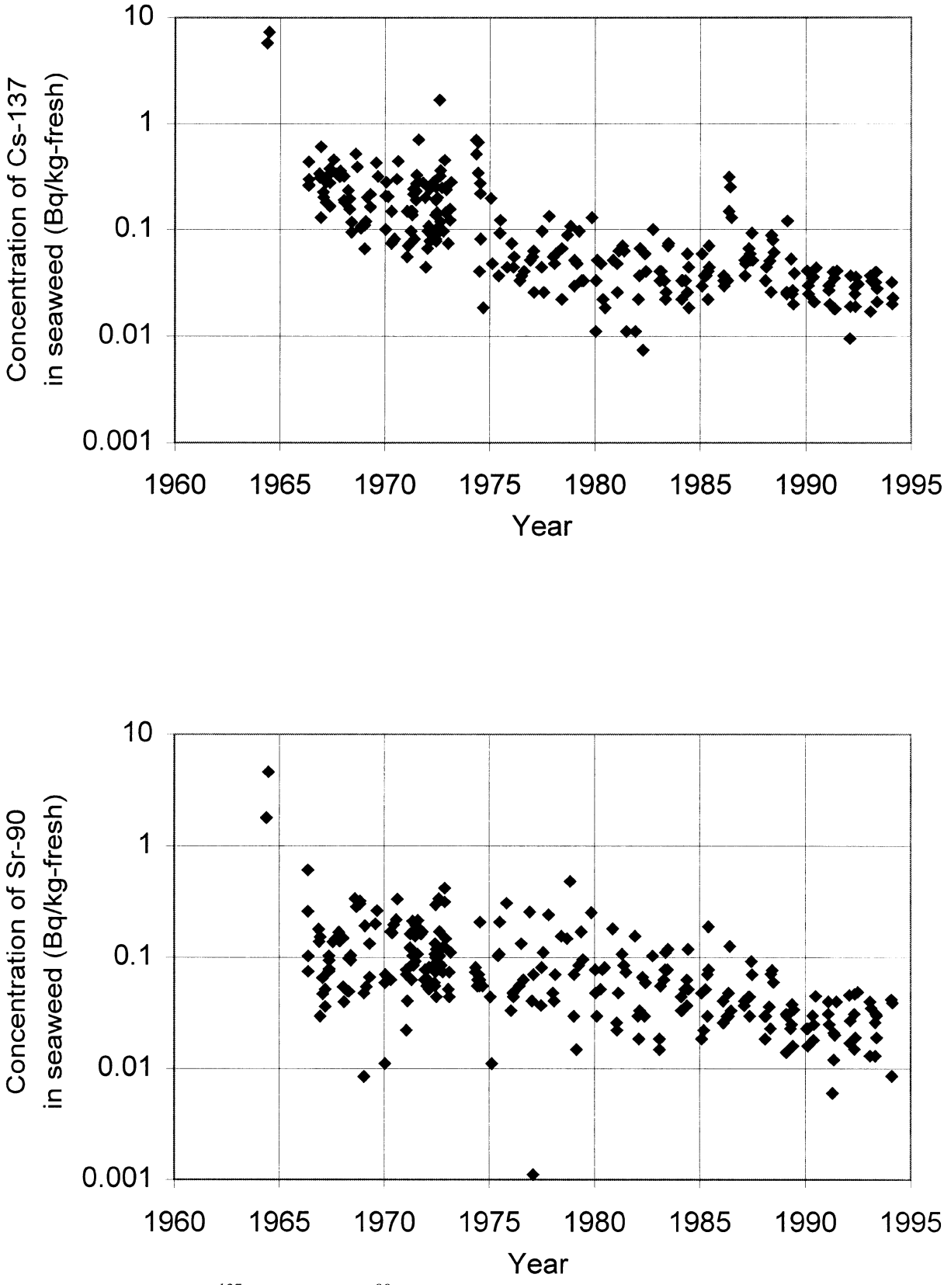

FIG. 15. ^{137}Cs (top) and ^{90}Sr (bottom) trends with time in seaweed of coastal areas of Japan.

The inventory of a radionuclide in a seawater column was calculated by interpolating the radionuclide concentration measured at each depth. The distribution of ^{137}Cs inventories in seawater columns collected in the northwest Pacific Ocean and its marginal seas around Japan is shown in Fig. 16 for the period 1990–1993. Similar maps were produced for the time intervals 1977–1981, 1982–1985 and 1986–1989. Inventories of ^{90}Sr and ^{239,240}Pu for the same time period (1990–1993) are shown in Figs 17 and 18, respectively. The inventories of the three radionuclides for each period vary within a factor of four. No latitudinal gradients can be clearly observed in the inventories presented, although the UNSCEAR (1993) report estimates an increase in the deposition density for ^{90}Sr from 1.8 kBq/m^2 for 20º–30º N to 3.2 kBq/m^2 for 40º–50º N. However, a higher data density is needed for more precise evaluation.

Only the ^{90}Sr inventories have shown a clear decrease with time.

9.2.2. Sediment

The radionuclide concentrations in sediment cores tend to decrease with increasing depth. Some of the profiles, however, have had peaks at depths of a few centimetres below the surface. Although the concentrations range over more than one order of magnitude, and no time dependency can be seen clearly, the mean concentration of ^{137}Cs is approximately 2.5 Bq/kg dw, and that of ^{90}Sr and ^{239,240}Pu are about ten times lower.

The radionuclide inventories in sediment cores were estimated by totalling the radionuclide concentrations in each layer of sediment. The distributions of the ^{137}Cs inventories in sediment cores sampled in the northwest Pacific Ocean and its marginal seas around Japan are shown in Fig. 19 for the period 1990–1994. Similar distribution patterns were observed for the time intervals 1982–1985 and 1986–1989. Figures 20 and 21 show ^{90}Sr and ^{239,240}Pu inventories, respectively, for the period 1990–1994. The inventories of all three radionuclides show variations within an order of magnitude, which are larger than those in seawater columns. The mean values of the inventories of ^{137}Cs, ^{90}Sr and ^{239,240}Pu in sediment cores are approximately 3%, 0.5% and 15% of those in seawater columns, respectively. The results confirm that the removal of ^{239,240}Pu is more effective than ^{137}Cs and ^{90}Sr from seawater columns to bottom sediment.

9.2.3. Conclusions on radionuclide inventories in the Sea of Japan

The inventories of ^{90}Sr, ^{137}Cs and $^{239+240}$Pu in the water column of the main dumping site in the Sea of Japan [24] are 3.0, 5.8 and 0.10 kBq/m^2, respectively. In comparison, the respective inventories in the water column in the northwest Pacific Ocean are 1.0, 2.0, and 0.11 kBq/m^2, respectively. As can be seen, the ^{90}Sr and ^{137}Cs inventories in water of the main dumping sites in the Sea of Japan are significantly higher than those observed in the northwest Pacific Ocean. However, these discrepancies can be explained by specific oceanographic processes which take place in the Sea of Japan [25, 26]. Therefore, the effect of radioactive waste dumping on the observed radionuclide inventories requires additional investigation.

The total ^{90}Sr and ^{137}Cs inventories in water and sediment are in good agreement with the expected global fallout deposition densities. On the other hand, those for ^{239,240}Pu and ^{241}Am in the northwest Pacific Ocean show a surplus, possibly additional input from close in fallout transported from the Central Pacific Ocean.

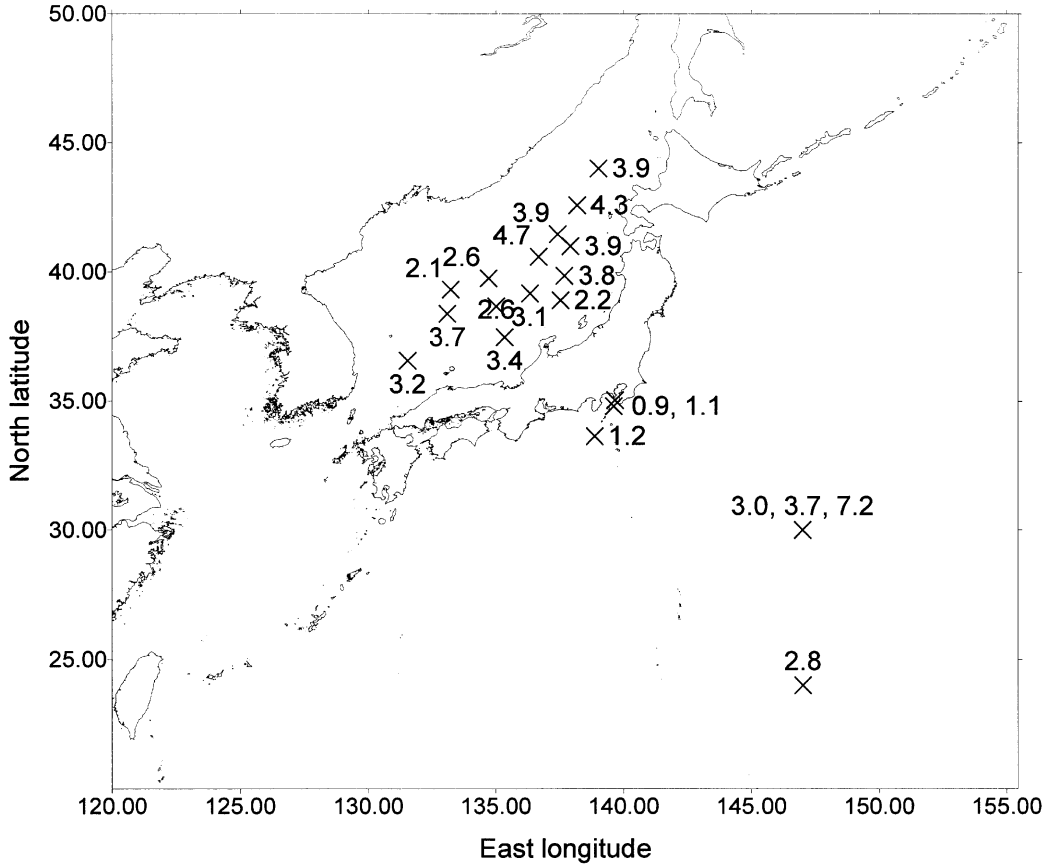

*FIG. 16. Inventories of ^{137}Cs (kBq/m**2) in seawater columns (1990–1993).*

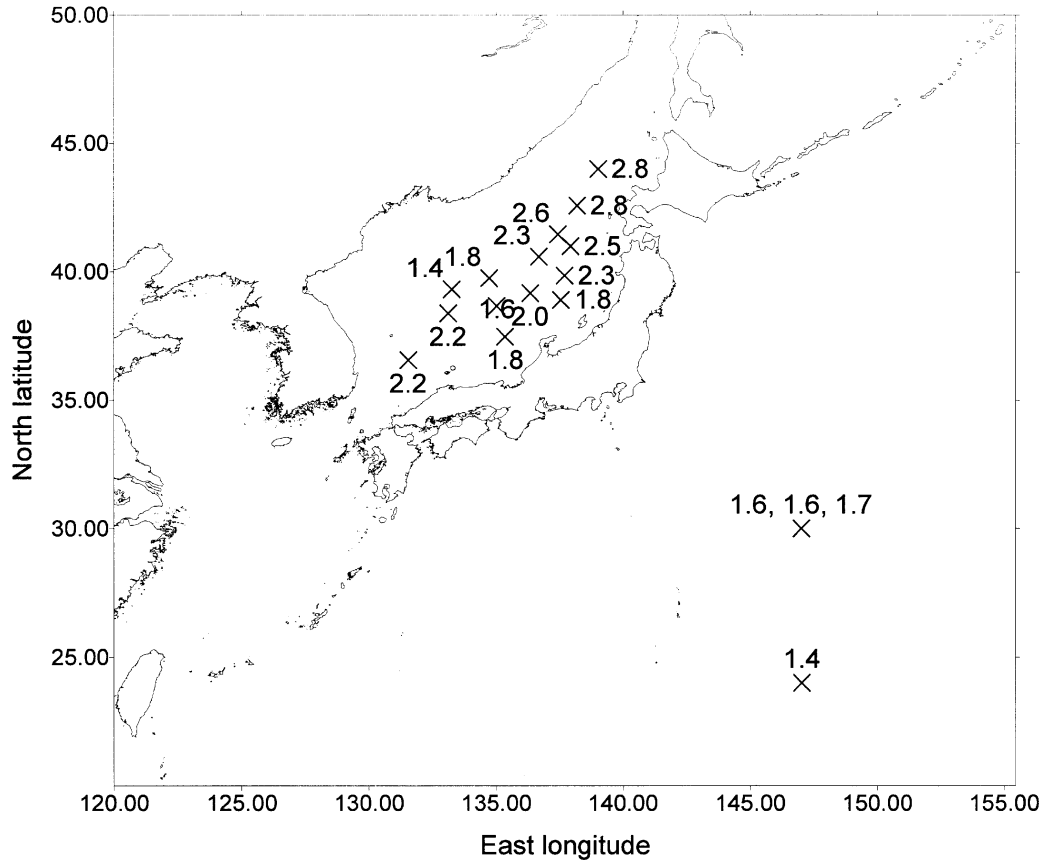

*FIG. 17. Inventories of ^{90}Sr (kBq/m**2) in seawater columns (1990–1993).*

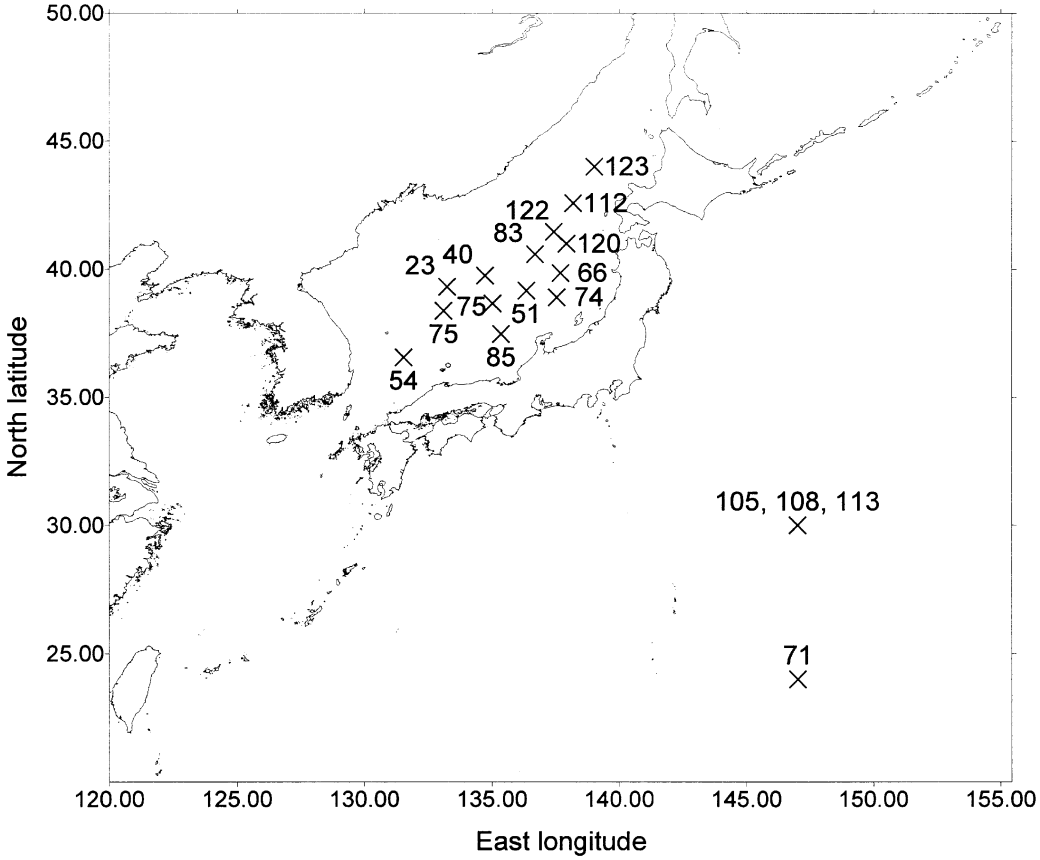

*FIG. 18. Inventories of $^{239+240}$Pu (Bq/m**2) in seawater columns (1990–1993).*

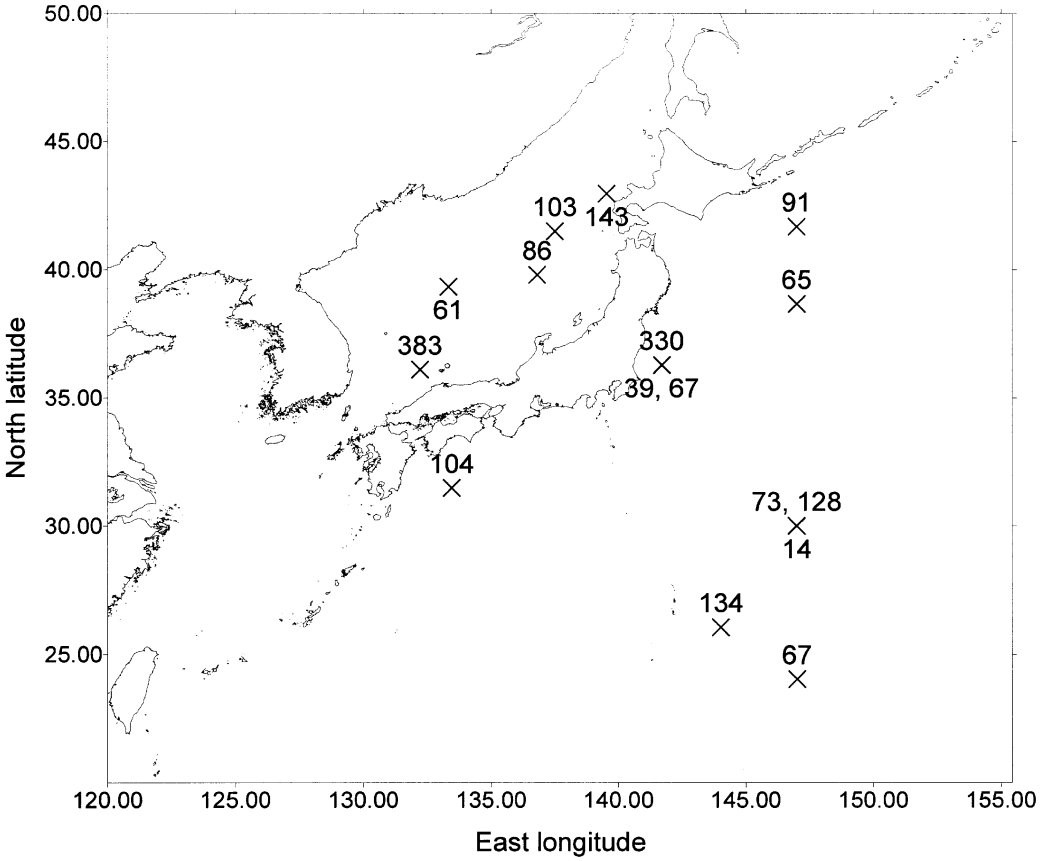

*FIG. 19. Inventories of ^{137}Cs (Bq/m**2) in sediment cores (1990–1994).*

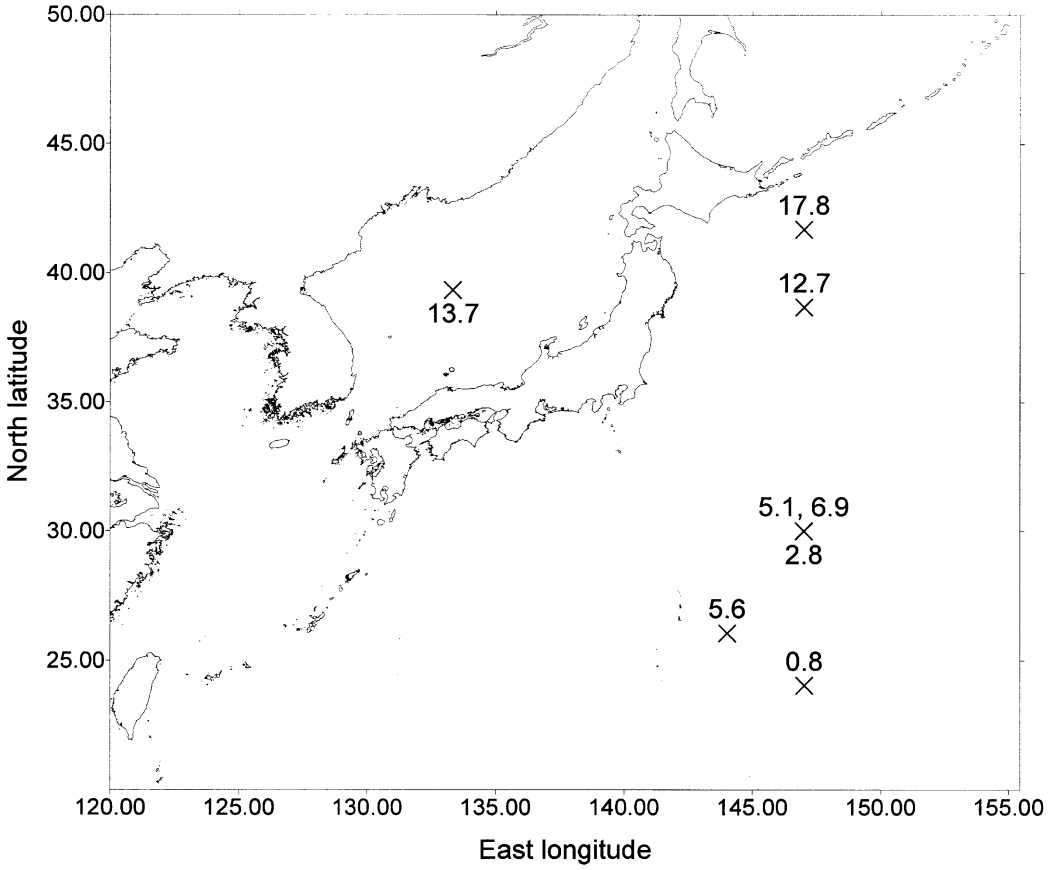

*FIG. 20. Inventories of ^{90}Sr (Bq/m**2) in sediment cores (1990–1994).*

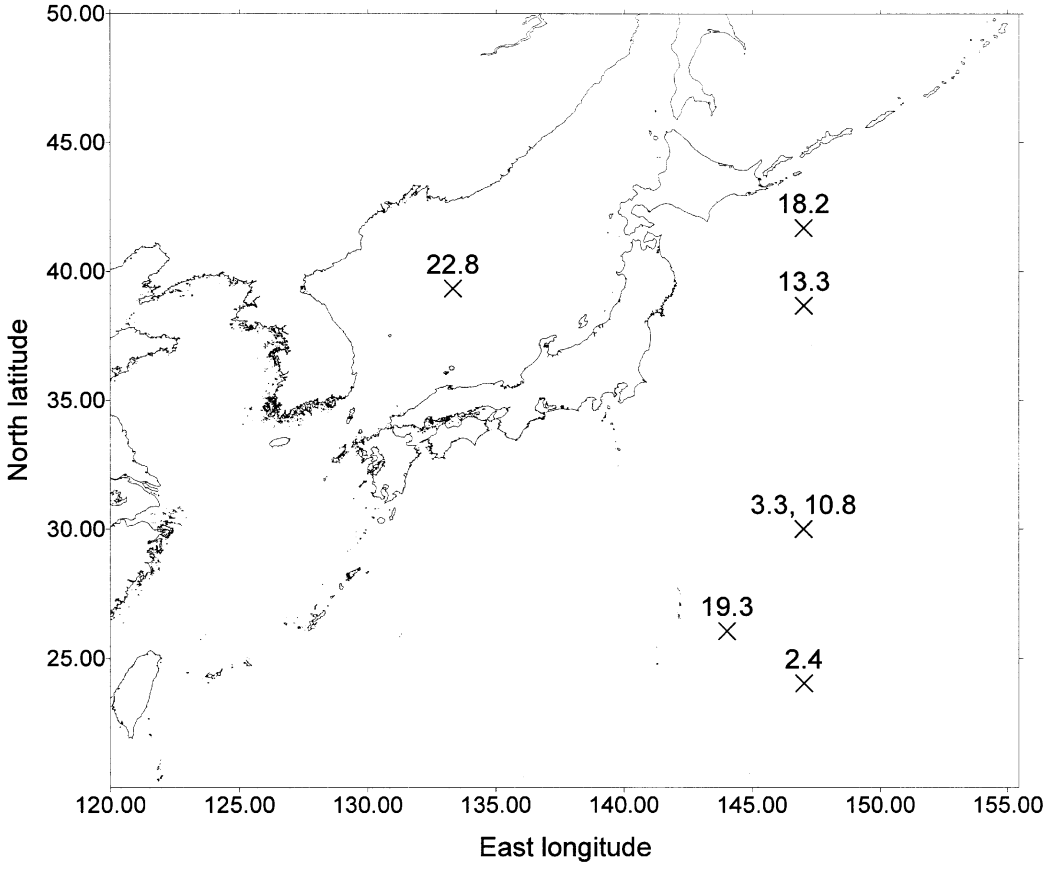

*FIG. 21. Inventories of $^{239+240}Sr$ (Bq/m**2) in sediment cores (1990–1994).*

As a result of radionuclide data evaluation in the Sea of Japan and the northwest Pacific Ocean, there is no definite evidence of the effect of radioactive waste dumping.

However, unique oceanographic features in the behaviour of radionuclides have been found.

10. CONCLUSIONS

Further investigations are required to more fully assess radioactivity in the marine environment. Research and analysis at MEL will focus on the sources that have introduced radionuclides into the world's oceans and seas; the distribution of anthropogenic and natural radionuclides in the marine environment; and the contribution of anthropogenic and natural radionuclides to doses that the world population receives from marine radioactivity through ingestion of seafoods. The studies will help to clarify the respective contributions from different sources of radioactivity, with results supporting decision-making in various fields.

The work on the development of the Global Marine Radioactivity Database will continue. The new version of GLOMARD will be connected to the Geographical Information System. This will allow the production of more precise two- and three- dimensional maps. On them, radioactivity data will be correlated with data on bathymetry, temperature or salinity.

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