Safe Use of Radioactive Tracers in Industrial Processes

Sponsored by the
IAEA and WHO

SAFETY SERIES No. 40

SAFE USE OF RADIOACTIVE TRACERS IN INDUSTRIAL PROCESSES

SPONSORED BY THE
INTERNATIONAL ATOMIC ENERGY AGENCY
AND THE
WORLD HEALTH ORGANIZATION

INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA, 1974

THIS SAFETY SERIES WILL ALSO BE PUBLISHED IN FRENCH

SAFE USE OF RADIOACTIVE TRACERS
IN INDUSTRIAL PROCESSES
IAEA, VIENNA, 1974
STI/PUB/369

Printed by the IAEA in Austria
January 1974

FOREWORD

The techniques for using radioactive tracers in industrial processes have become widely established. Although the associated risks to radiation workers and to the public have been small, this use of tracers has greatly increased in recent years. At present there are few routine applications of tracers which could lead to the continuous introduction of radioactivity into commercial products or directly into the environment, and this situation is likely to continue into the foreseeable future. Although industrial applications of tracers will continue to contribute only a very small proportion of the population dose relative to other activities, some guide is deemed necessary for those who may be involved in planning and implementing such tracer investigations as well as for those who may have to institute regulatory functions.

In 1970 the International Atomic Energy Agency (IAEA), in collaboration with the World Health Organization (WHO), engaged the services of Mr. R. Cunningham (USA), Mr. B. Fries (USA) and Mr. P. Johnson (UK) as consultants to prepare a draft manual. This draft then formed the working paper for a panel of experts convened by the IAEA and WHO in 1972. At this stage the International Labour Organization (ILO), the OECD Nuclear Energy Agency (NEA) and the Food and Agriculture Organization of the United Nations (FAO) expressed their interest in the preparation of the final guide but were unable to participate in the panel meeting. The revised text that resulted from the panel's work was reviewed and put into the present final form by Mr. Cunningham.

A number of examples of radioactive tracer applications provided by the consultants and panel members are presented in the Annexes.

CONTENTS

1. INTRODUCTION 9

1.1. Objectives and scope of the guide 9
1.2. Basis of recommendations 9

2. BASIC RADIATION SAFETY CONSIDERATIONS 10

2.1. Principles 10
2.2. Consideration of radiation workers and members of the public 10
2.3. The critical pathway and critical groups 11

3. DETERMINATION OF RADIATION DOSE 12

3.1. Dose to radiation workers 12
3.2. Dose to the public 12
3.3. Incorporation of radionuclides in consumers' products and release of activity to environment 13

4. ROLE OF COMPETENT AUTHORITY 14

4.1. Develops policy and criteria 14
4.2. Grants authorization 14
4.3. Conducts inspection 15
4.4. Maintains surveillance over the population dose .. 15

5. PLANNING AND DESIGN 15

5.1. Planning 15
5.2. Design 16
5.2.1. Introduction 16
5.2.2. Assignment of responsibility 16
5.2.3. Selection of method 16
5.2.4. Experimental design 17
5.2.5. Radiation safety and protection 17

6. OPERATIONAL PROCEDURES 19

6.1. Preliminary manipulation of the tracer 19
6.2. Introduction of the tracer into the system 19
6.3. Measurement of the tracer within the system 20
6.4. Post-operational surveillance 20

REFERENCES 21

APPENDIX I: Note on ICRP Publication No. 9 23
APPENDIX II: Information submitted to competent authority 28
APPENDIX III: Training and experience requirements 30

ANNEXES 1-9: Examples of tracer applications 31
REFERENCES TO ANNEXES 52

LIST OF PANEL MEMBERS 53

1. INTRODUCTION

Radiotracers have wide application in industry and provide valuable methods for the measurement and investigation of industrial process systems. This is because the ideal tracer is one which is identical to a component of the investigated system and yet can be unambiguously measured. In addition, the radioactive tracers offer ease of measurement and high sensitivity together with absence of interference with the studied process. Well established radiotracer methods include those for flow measurement, determination of residence times, flow patterns, mixing efficiencies, ventilation efficiency studies, location of leaks, etc. Detailed descriptions of techniques and applications are to be found in the technical literature, including the published proceedings of various IAEA symposia [1, 2]. Also, some examples are given in the Annexes to this report.

1.1. Objectives and scope of the guide

The principal objectives of this guide are (a) to identify the safety considerations in industrial radiotracing, (b) to provide guidance to competent authorities in converting ICRP recommendations into appropriate policies and regulations applicable to radiotracing, (c) to assist competent authorities in implementing an appropriate program for control of industrial radiotracing, and (d) to provide users with guidance in the planning and safe implementation of radiotracer investigations.

Industrial radiotracer investigations are usually conducted to obtain information about an industrial process and usually involve short-lived radioisotopes. The guide covers the safety aspects of the use of radiotracer investigations in industry, including that radioactivity which may be incorporated into consumers' products as a consequence of the investigation. The guide is not concerned with the application of radioactive tracers to geological, hydrological or agricultural investigations, although, inevitably, it will overlap with some of the earlier IAEA documents involving tracer applications conducted outside industrial process systems.

1.2. Basis of recommendations

The guide is based primarily upon the recommendations of the International Commission of Radiological Protection (ICRP) and published IAEA Safety Series. As such, revisions will be required as adjustments to international safety guidelines or advances in technology are made. The provisions of the guide should be treated as recommendations which are generally applicable.

2. BASIC RADIATION SAFETY CONSIDERATIONS

The objective of radiation protection is to limit radiation exposure so that the risk of harmful effects to the individual and to society is as small as possible compared with the benefits to be derived from the use of ionizing radiation.

2.1. Principles

Principles of protection are embodied in the recommendations of the ICRP [3] (Appendix I contains some recommendations of the ICRP concerning limitation of doses for exposures from controllable sources), upon which most international standards [4] and national codes and regulations are based.

The recommendations and guidance provided by international agencies embody some principles of particular importance to those planning to use radiotracers in industrial processes. These are: (1) Unnecessary exposures should be avoided; (2) Operational control should be provided so that the resulting doses are as low as readily achievable and are justified by the benefits; (3) Compliance with the relevant dose limits (IAEA Safety Series No. 9) should be ensured; (4) The resulting dose to the whole population should be much smaller than the corresponding limit, which should be viewed as a sum of minimum necessary contributions and not as a permitted total apparently available for apportionment.

2.2. Consideration of radiation workers and members of the public

When considering how to achieve the lowest practicable radiation dose in radiotracer work, it is necessary to distinguish between exposures to radiation workers and to members of the public. The radiation workers in a tracer investigation normally include those engaged in (a) the preparation of the tracer compound, (b) the introduction of the tracer into the process, (c) product sampling or process measurement, and (d) radiation protection duties. In some instances, a few persons not directly involved in the investigation need to remain in the controlled area established at the tracer injection point to perform duties essential to plant operation. Efforts should be made to minimize the number of such persons who should be regarded as radiation workers. All other persons should be regarded as members of the public.

The radiation received by members of the public, if any, from radiotracer investigations will generally result from release of wastes in liquid or gaseous effluents, or by incorporation of the radioisotope in a product which subsequently becomes accessible to the public. Careful selection of the radioisotope and equipment with high detection efficiency play an important role in assuring that the dose to members of the public is maintained as low as practicable. The relative dose or dose commitment from a variety of radioisotopes feasible for any given application should serve as a final basis for radioisotope selection. Once a radioisotope has been selected, planning should include a specific determination that the smallest practicable amount of radioactivity will be used, released to the environment, or contained in products.

2.3. The critical pathway and critical groups

Reconcentration of the released radioactivity, along a pathway leading to man, should be taken into account in the dose assessment. Tracer investigations which could result in radioactive materials being incorporated in products that are intended for ingestion, inhalation or application to man[1], should not be conducted unless clearly justified by sufficient benefits to society. The decision as to whether such radiotracer investigations are permissible is one of national policy. Some countries have regulations which prohibit such use.

ICRP recommendations on dose limits for members of the public are intended to provide standards for design and operation of radiation sources so that it is unlikely that individuals in the public will receive more than a specified dose. The variability resulting from a range of personal and environmental parameters makes it impossible to determine with precision the maximum doses that might be received by the individual from a given operation. In practice it is feasible to take account of this variability by the selection of appropriate "critical groups" in the population. These small and relatively homogeneous groups should be representative of those individuals in the population expected to receive the highest doses, and the ICRP considers it appropriate to apply the relevant Dose

[1] Typical products that would be excluded by this requirement are foods, drugs, cosmetics, or their components. The term "products intended for application to man" usually refers to products which are applied to the skin (such as ointment) or are in close contact with the skin (such as jewellery).

Limit to the mean dose of these groups. As pointed out in ICRP Publication No.7, in some situations, for example in preliminary planning or when the dose to the critical group will clearly be very small, it may not be necessary to make the detailed studies required for the identification of the critical group and the assessment of its dose. It will then be convenient to postulate a hypothetical group of extreme characteristics. The estimated dose to this hypothetical group will thus provide an upper limit to the dose that any real critical group could possibly receive. In the case of several sources of exposures of the population, the ICRP does not recommend how fractions of the limits could be apportioned among the various contributions. However, ICRP does point out that no single type of population exposure should take up a disproportionate share of the total dose and any exposure must be justified by a resulting benefit.

3. DETERMINATION OF RADIATION DOSE

3.1. Dose to radiation workers

The dose received by radiation workers during implementation of a tracer investigation will normally result from external radiation. Tracer investigations should be planned so that radiation workers will not inhale or ingest radionuclides although the possibility for doing so exists under emergency or accident conditions. Estimates of the dose from external radiation should be made using conventional calculational methods [5] during the planning phase of the study, and workers should be individually monitored for exposure, in addition to measurement of radiation levels during the operational phase.

3.2. Dose to the public

The principal pathway by which the public can be exposed will normally be through inhalation or ingestion of radionuclides released during the course of the radiotracer investigation. Investigations should be designed so that the dose received by members of the public when exposed to external radiation is negligible. In relation to external radiation the Dose Limits recommended by ICRP correspond to Intake Limits by ingestion or inhalation for each individual radionuclide [4]. For radiation protection purposes it is convenient to define a Derived Working Limit for concentration, $(DWL_c)^2$, assuming an extreme hypothetical critical group drinking or breathing undiluted effluent. Exposing this hypothetical group to this Derived Working Limit (DWL) continuously for one year would give a dose commitment equal to the relevant Dose Limit. If the concentration of radionuclides in liquid and gaseous effluents from a tracer investigation at the point of release from the controlled area is well within these values of uncontrolled areas, persons designing the tracer investigations would not ordinarily need to calculate the expected radiation dose to members of the public. The competent authority should assess the potential exposure to members of the public within a selected population group expected to be most highly exposed, taking into account the duration of the tracer investigation and other activities which might contribute to the total dose. If it appears that such releases may cause exposure in excess of a very small fraction of the total dose limit for members of the public, the competent authority should impose special restrictions.

3.3. Incorporation of radionuclides in consumers' products and release of activity to environment

With respect to incorporation of radionuclides in products which become available to members of the public, the concentrations of the radionuclides expected in the products should be calculated and where possible the calculations should be confirmed by measurement. If the concentrations of radionuclides in products do not exceed the DWL_c values for air and water in uncontrolled areas[3] and if reconcentration of the radionuclides is unlikely and the products are not designed for inhalation, ingestion or application to man, calculations of dose to members of the public would not ordinarily be required. If these criteria are not met, the competent authority should require identification of the group of individuals expected to be most highly exposed and the average exposure of a suitable sample of the most highly exposed group estimated.

The release of radioactivity to the environment or the incorporation of radionuclides in products as a result of radiotracer investigation has been small, and is likely to be so in the foreseeable future, relative to other activities. The total genetic dose is,

---

[2] The DWL_c for a nuclide is given by DWL_c = (Intake Limit)/V, where the Intake Limit is the value given in Ref. [4] for inhalation or injection, as appropriate, and V is the annual intake of air or water (7.3×10^9 ml and 8.03×10^5 ml respectively).

[3] Some national authorities have specific regulations pertaining to types and permissible concentrations of radionuclides in consumer products as a result of this type of activity. For example, USAEC regulations on the subject are contained in 10 CFR 30, para. 30.70.

therefore, believed to be a small fraction of the limit recommended by ICRP [3]. The genetic dose need not ordinarily be taken into account during the planning or operation phase of a tracer investigation. However, the competent authority should require periodic reports of quantities of radionuclides distributed in products which, when taken together with reports of similar releases from other activities, serve as a basis for the national authority to maintain surveillance over both the genetic and somatic doses to a population[4].

4. ROLE OF COMPETENT AUTHORITY

The utilization of radioactive tracers in industry is usually subject to control by the competent authority [4]. In discharging its duties, the competent authority normally performs the following functions with regard to the utilization of radiotracers:

4.1. Develops policy and criteria

The competent authority develops a policy regarding the use or conditions of using radiotracers. The policy decision ordinarily includes benefit-cost judgements which will be a formal benefit-cost analysis in some instances or it will be implicit in the policy decision. The competent authority also provides criteria or issues regulations about the conditions which must be met by industry to comply with established policy in carrying out radiotracer investigations.

4.2. Grants authorization

In making a request to conduct a radiotracer investigation, the industry normally provides relevant information and possibly a safety analysis of the proposed investigation. The competent authority then determines whether the proposed investigation is likely to be in

[4] After a meeting in April 1971, the ICRP issued the following statement with regard to dose from consumer products: "The Commission noted the increasing use of a number of consumer products containing small amounts of radioactive material, and the contribution to the population dose that these taken together could make even though the dose from individual sources is at present extremely small. In considering the relevance of this to the dose limit for the population, the Commission emphasized the importance of national authorities assessing the contribution being made by these products, so that an effective means of control may be instituted. In this regard, the Commission wishes to draw attention to a publication of the European Nuclear Energy Agency (OECD/NEA) Ref. [6], as an example of a method by which the total individual and population doses from all consumer products may be subject to administrative control".

conformity with established policy and criteria on the basis of the information submitted before granting authorization. (A brief but not exhaustive listing of the information to be made available by industries in their request for authorization is given in Appendix II.)

4.3. Conducts inspection

The competent authority may conduct inspections to determine compliance with safety requirements. It also undertakes appropriate action if safety requirements are not being met. Records of the receipt, transfer, use and disposal of radioactive material and of exposure to personnel participating in the investigation should be available to the competent authority to conduct inspection.

4.4. Maintains surveillance over the population dose

5. PLANNING AND DESIGN

5.1. Planning

Once the objectives of a proposed investigation have been defined, it is necessary to select a suitable technique (radioactive or non-radioactive). If the radiotracer technique offers advantages, the particular method to be adopted has to be selected and each stage examined with regard to radiation safety. Careful technical planning at the outset will assist toward an effective investigation with the minimum radiation exposure. Discharge of radioactivity resulting from the investigation, or incorporation of radioactive materials into products must also receive careful consideration to ensure that it is kept to the lowest practicable level.

In the majority of investigations, the effect on the environment will be negligible owing to:

(a) the small quantities of activity involved;
(b) the short half-life of the radionuclides;
(c) the expected dilution coupled with limited period of discharge.

In these cases, the data required by the competent authority for review and approval will ordinarily be minimal, since it can readily be demonstrated that concentration of radioactivity at the point of release will be well within the DWL values. In others where this cannot be readily demonstrated, estimate of population dose should be made (i.e. in relation to the "critical group" as defined in ICRP Publication No. 7, Ref. [7]).

Complete information on concentration of activity in liquid and gaseous effluents and in products, product dilution factors and details of the critical group may not be readily available during the planning stage. However, on the basis of known data or findings of previous radiotracer work of a similar character, laboratory tests or calculations based on conservative assumptions, it is possible to estimate the order of magnitude of concentration in effluent or material of interest.

5.2. Design

5.2.1. Introduction

In designing a radiotracer investigation, the following factors have to be considered:

(a) Assignment of responsibility
(b) Selection of method
(c) Experimental design
(d) Radiation safety and protection.

These factors are all interrelated and will thus have to be dealt with together.

5.2.2. Assignment of responsibility

Because of the nature of radiotracer work which is carried out in industrial process plant, or in the field, it is essential to clearly define responsibility. It is necessary to designate a person as project leader to be responsible for the investigation. There is also need to make a specific person responsible for radiation safety who may or may not be the project leader. The general training and experience requirements for personnel undertaking radiotracer work in industry are outlined in the Appendix III. In addition, background knowledge of industrial conditions and acquaintance with the specific plant operations are necessary.

5.2.3. Selection of method

The selection of method for a radiotracer investigation involves the choice of technique, radiotracer and instrumentation. Factors influencing selection include:

(a) Satisfactory behaviour of tracer: the basic requirement for a radiotracer is that it should accurately represent the component of interest in the system to be studied [1, 8].
(b) Nature and energy of the radiation emitted and efficiency with which it can be detected.
(c) Half-life (as short as possible) consistent with the duration of the investigation.
(d) Aspects relating to radiation safety and protection (see 4. 2. 5).

5. 2. 4. Experimental design

The experimental design which will yield the desired information in the most efficient way must be established before conducting the investigations. This involves:

(1) The prediction of tracer behaviour under process conditions and possible deviations from anticipated behaviour.

(2) "Dummy runs" to perfect operating procedures and to overcome potential trouble spots. An alternative is a preliminary experiment on the full scale system itself using a small fraction of the radiotracer activity to be employed in the actual application.

(3) Identifying critical steps in handling the radioactive material.

(4) Preparation of detailed plan for the implementation of the investigation including evaluation of the anticipated experimental data. For the evaluation of the total tracer requirement and for the estimation of radiation exposures, engineering information about the process is required. Such information includes approximate flow rates, vessel volumes, dimensions of plant units and the location of discharge points.

5. 2. 5. Radiation safety and protection

5. 2. 5. 1. General principles

Radiation safety and protection aspects enter into all the steps of design dealt with above. The choice method determines the radiation dose inherent in the operation. The selection of tracer will be a compromise between various considerations as previously mentioned. The radiation dose will be determined by factors such as:

(1) Activity of tracer
(2) Nature and energy of emitted radiation
(3) Half-life
(4) Radiotoxicity
(5) Radiochemical purity.