

**Recommendations for
ionization chamber smoke detectors
in implementation of radiation
protection standards**

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PREFACE

In the framework of its programme, the Committee on Radiation Protection and Public Health of the OECD Nuclear Energy Agency has undertaken a study to examine radiation protection problems relative to the use of ionization chamber smoke detectors (ICSDs).

This work was executed by an Expert Group and resulted in the attached recommendations. Following approval of these recommendations by the Committee on Radiation Protection and Public Health, the OECD Steering Committee for Nuclear Energy adopted, these recommendations to Participating Countries and agreed to their publication.

TABLE OF CONTENTS

	<u>Page</u>
Foreword	7
Introduction	9
1. Definition of terms used	10
2. Scope	11
3. Principal considerations	11
4. Requirements for the manufacturing of ICSDs	12
5. Requirements for the import of ICSDs	13
6. Requirements for the use of ICSDs	14
7. Marking and labelling of ICSDs	15
8. Recommendations concerning administrative control procedures	15
9. Surveillance	16
Annex: Prototype tests	19
Appendix I: Evaluation of benefit and risk	23
1. Benefits of automatic fire detection systems	23
2. Radiation doses from installed ICSDs	26
3. Waste disposal considerations	28
4. Accidents involving ICSDs - misuse of ICSDs	32
5. Risk-benefit considerations	43
Appendix II: Technical Information	49
1. Outline of the various types of fire detector	49
2. Description and comparison of ionization and optical smoke detectors	50
3. Distribution of ICSDs	52
4. Radioisotopes used	53
5. Radiological data	55
Appendix III: Fire and incineration tests on ICSDs	61
References	64
Members of the Expert Group	67

FOREWORD

The development of industrial uses of radionuclides - in particular as products or devices intended for use by the general public - makes it necessary to define well-devised national policies which should provide adequate protection of the public without unduly restricting the use of ionizing radiation and the benefits which might be derived for man. These policies should furthermore be sufficiently consistent in order not to hinder unnecessarily international trade in this field.

The task of the National Authorities will be facilitated by proceeding by successive stages and by setting up safety criteria to be applied to categories of products which have sufficiently similar characteristics in respect of technology and use to enable a common approach.

Ionization Chamber Smoke Detectors (ICSDs) containing radioactive sources appear at present to be an important application of ionizing radiation. In the past their use has been directed mainly towards the protection of property but because of their ability to detect smoke during the early stages of a fire there has been considerable interest in recent years in using them to protect life. As a result ICSDs specifically designed for use in private homes are now available.

Within the general framework of radiation protection rules, this document is intended to promote the setting up of harmonized national policies concerning the approval, distribution, use and disposal of such detectors to ensure adequate protection of the public against any radiation or contamination hazards which might result therefrom.

This document has been established taking account of the recommendations of the International Commission on Radiological Protection (ICRP). It also follows the principles set out in the NEA Guide for safety analysis and the control of products containing radionuclides and available to the general public. (*) In applying these principles the Expert Group considered the availability of

*) "Basic approach for safety analysis and control of products containing radionuclides and available to the general public", ENEA/OECD, Paris, June 1970.

non-radioactive alternatives to ICSDs, particularly optical smoke detectors. At the moment, these latter remain rather insensitive to smoke of low opacity, but nothing precludes the expectation that progress shall be realised in this field. If in this range of opacity optical detectors were to yield efficiency approximately equal to that of ICSDs, recourse to the latter would be less justified. Currently available information indicated that the best protection for a home would be a combination of properly functioning ionization-type and optical-type detectors. Accordingly and because the individual radiological risk resulting from the use, misuse, disposal etc. of ICSDs and the collective radiological risk are estimated to be very low, the Expert Group has concluded that ICSDs should not be excluded from use because of the availability of the optical type but rather that both should be available to the public. When controlled in accordance with the provisions of this document, the benefits associated with ICSDs are significantly greater than the risks.

The terms used in this document are appropriate where the national control system is such that no products containing radionuclides are allowed to be manufactured or distributed unless they are specifically approved or exempted from the general prohibition by the competent National Authority. Where such a method of control has not been adopted, it is recommended that the technical considerations set out in the recommendations regarding the safety of products from the point of view of radiation hazards should be accepted as a suitable basis for whatever system of control is used.

INTRODUCTION

Before approving the use of any product which may irradiate the public, the competent National Authorities must be assured that the doses to individual members of the public and the population at large as a result of use, abuse, accidents and disposal are justified in terms of the benefit to be accrued from the use of that product. In addition, since it is possible that any exposure to ionizing radiation may entail a risk of deleterious effects, the National Authorities must ensure that unnecessary exposure is avoided and that doses are kept as low as is reasonably achievable.

On the weight of available information, it is clear that there are real or potential benefits in protecting both property and life associated with the use of ICSDs. During the period when fire detection installations using ICSDs are kept in service and maintained as required, the risks to members of the public are virtually limited to those resulting from external radiation. These risks and those arising from radioactive contamination resulting from abuse, accidents or uncontrolled disposal of ICSDs are small in comparison to the benefit to be obtained.

This document is intended to provide the basis for National Authorities to establish practices and procedures by which the radiation risks to members of the public can be kept as low as is reasonably achievable. This is achieved by setting limits on the activity of the sources, by prescribing certain test and design specifications and by making recommendations about administrative controls. This document is not intended to cover performance of non-nuclear components of ICSDs. In this respect, this document should be supplemented by other recommendations to assure proper function of the ICSD for without proper function the benefits are not achieved and the radiation risk is not justified.

The protection of workers engaged in the manufacture, distribution and maintenance of ICSDs and the manufacture of the radioactive sources used in them is outside the scope of these recommendations.

1. DEFINITION OF TERMS USED

1.1 Ionization of Chamber Smoke Detector (ICSD)

A detector using radioactive materials sensitive to combustion products capable of affecting ionization currents within the detector.

1.2 Single station ICSD

Self-contained device (mains and/or battery operated) in which the alarm is incorporated in the ICSD and ICSD does not need to be linked to any other external fire detection or alarm system in order to function.

1.3 Sealed source(*)

Radioactive source sealed in a capsule or having a bonded cover, the capsule or cover being strong enough to prevent contact with and dispersion of the radioactive material under the conditions of use and wear for which the sealed source was designed.

1.4 Sealed source holder

Mechanical support for the sealed source.

1.5 Activity

Sum of the activities of the radionuclide contained in the source(s) incorporated in the ICSD measured at the time of manufacture of the ICSD.

1.6 Radiological quantities and units

This document uses the definitions and symbols for radiological quantities and units given by the International Commission on Radiation Units and Measurements (Radiation Quantities and Units, ICRU Report 19 - 1971).

*) This definition is that which is given by the International Organisation for Standardization, e.g. in the Draft International Standard, Sealed Radioactive Sources - Classification, ISO 2919.2. In some countries this definition can be replaced by the following definition which is considered to be equivalent: "A source consisting of radioactive substances firmly incorporated in solid and effectively inactive materials, or sealed in an inactive container of sufficient strength to prevent, under normal conditions of use, any dispersion of radioactive substances and any possibility of contamination". [Council Directive of 1st June, 1976 laying down the revised basic safety standards for the health protection of the general public and workers against the dangers of ionizing radiation, Official Journal of the European Communities 19 - No. L187 (12th July, 1976).] These definitions are taken to include cut foil sources with exposed edges where the radioactive material is sandwiched between inactive layers.

2. SCOPE

2.1 This document is intended to promote a uniform course of action by National Authorities in the procedures for authorising the manufacture, import, use and disposal of ICSDs while ensuring that individual and collective doses to members of the public are kept as low as is reasonably achievable.

2.2 This document does not cover sources or detectors which do not comply with the definition in sections 1.1 and 1.2 above.

2.3 This document does not cover the protection of persons normally handling ICSDs as a result of their occupation (manufacturers, distributors, maintenance engineers, etc.). But they do cover members of the public and such people as members of the fire brigade.

2.4 This document should not constitute an exemption from the requirements applicable to storage and transport of ICSDs and sources under national and international rules for radiation protection.

2.5 In this document only Am-241, Ra-226, Pu-238, Kr-85 and Ni-63 are taken into consideration as these are the only radio-nuclides currently being used. For single station ICSDs, only Am-241 and Ra-226 have been considered.

3. PRINCIPAL CONSIDERATIONS

3.1 Radioactive sources used in ICSDs shall be sealed sources conforming to the relevant requirements of the Standard ISO/DIS 2919 (reference given in footnote page 10). The tests specified in this ISO Standard and the maintenance test described in the Annex shall be applied to the sources mounted in their holders.

3.2 ICSDs (or parts of ICSDs where this is permitted) shall satisfy the tests described in the Annex.

3.3 The ICSD activity shall be as low as practicable and consistent with reliable function. The half-life of the radionuclide selected should be as short as practicable, consistent with the useful life of the detector.

3.4 Under normal conditions of use, direct contact with the radioactive source(s) shall be impossible. The design of the device shall also discourage members of the public from attempting to have access to the radioactive sources. With ICSDs containing Kr-85 access to the source(s) shall require the use of a special tool which shall not be made available to the public and which cannot be readily improvised. The construction of the ionization chamber for single station ICSDs shall be such that it is considered sufficiently tamper-proof by the competent National Authorities.

3.5 Radionuclides other than those taken into consideration by these Standards shall be subject to separate decision by the competent National Authority. Approval for their use shall be contingent

upon a demonstration that they possess a similar degree of safety according to the hazard analysis outlined in Appendix I.

4. REQUIREMENTS FOR THE MANUFACTURING OF ICSDs

4.1 The manufacture of ICSDs shall be subject to authorisation by the competent National Authorities.

4.2 Each manufacturer of an ICSD shall submit an application for an authorisation to the competent National Authorities. This application should contain adequate information relating to the design, manufacture, prototype testing, quality control and maintenance procedures, and conditions of handling, storage and installation of the ICSD in question, and demonstrate that it will meet the requirements in paragraphs 3.1, 3.2 and 3.4 and, with those radio-nuclides which have not been taken into consideration by the Standards, the requirements in paragraphs 3.3 and 3.5 as well.

The information should include in particular:

- i) A description of the ICSD.
- ii) The characteristics of each type of source mounted in the detector, including the activity of the principal radionuclide and those of the radioactive impurities, if any, as well as the dose equivalent rates measured at a distance of 0.1 m from the accessible surface of the device.
- iii) Details of the design and construction of the ICSD as related to fixation and protection of the source(s), and to other safety features under normal and severe conditions of handling, storage and use of the ICSD.
- iv) The results of functional tests on prototypes showing that the detector is efficient and reliable and, if applicable, a certificate should be provided testifying compliance with the national standards in force.
- v) The estimated total activity of the principal radio-nuclide contained in all such ICSDs to be manufactured annually.
- vi) The expected lifetime of the ICSD.
- vii) Quality control procedures to be followed in the production of the ICSD, to ensure that the quality of the ICSD is the same as the quality of the devices on which the prototype tests were conducted, especially with respect to the integrity of the radioactive sources and the absence of contamination on the ICSD.
- viii) If appropriate, the names and addresses of the companies or institutions under contract and competent for maintenance, repair, recovery and disposal of ICSDs as well

as the procedures and practices to be adopted for these operations.

- ix) All additional information, in particular the results of tests and experimental studies as may be required by the National Authorities.

4.3 Competent National Authorities before granting an authorisation under 4.2 should satisfy themselves that the ICSD withstands the prototype tests specified in the Annex hereto. Competent National Authorities should also be satisfied that the quality control procedures under section 4.2 (vii) are effectively applied to ensure that each ICSD meets the requirements approved by the National Authorities.

4.4 Each year, the manufacturer of ICSDs authorised under section 4.2 shall transmit to the competent National Authorities a report giving the total number of ICSDs of each type and the corresponding total activities distributed during the previous calendar year.

If possible, the competent National Authorities should be able to obtain a separation of these values into the three following categories:

- a) those for ICSDs for new installations;
- b) those for ICSDs for replacement of old devices;
- c) those for ICSDs for export.

4.5 Subsequent minor improvements or modifications to an ICSD which has been approved by the competent National Authorities will not require a further application for an authorisation provided that aspects of the ICSD which are relevant to radiation protection are not changed to decrease their protective effectiveness. An adequate description of such improvements or modifications shall be furnished to the competent National Authorities who will take the final decision.

4.6 Without prejudice to any national requirements normally relating to the control of the use of radioactive materials, the manufacture of up to a maximum of 100 ICSDs of a given type for development purposes is exempted from requirements of sections 4.1 to 4.4.

5. REQUIREMENTS FOR THE IMPORT OF ICSDs

5.1 The import of ICSDs shall be subject to authorisation by the competent National Authorities of the importing country.

5.2 In the case of import of ICSDs the requirements in sections 4.1 to 4.4 inclusive relating to manufacture shall apply mutatis mutandis to importers except that the information which may be required from the importer under section 4.2 (vii) could be in the

form of a certificate from the exporter that these requirements have been complied with. This certificate shall be endorsed by the competent National Authorities of the exporting country.

5.3 Notwithstanding the provisions of section 5.2 the importer may be exempted from the requirements of sections 4.2 to 4.3 inclusive, except 4.2 (viii), as applied to import on the condition that the importer provides a certificate proving that the manufacture of the imported ICSD has been authorised by the competent National Authorities in the country of origin in accordance with these standards.

6. REQUIREMENTS FOR THE USE OF ICSDs

6.1(*) The use of single station ICSDs conforming to the following requirements should be unrestricted:

i) Activity of Am-241

The activity per detector should not exceed $1\mu\text{Ci}$ and shall not exceed $5\mu\text{Ci}$.

ii) Activity of other radionuclides

In certain countries, where the use of Ra-226 for single station ICSDs is permitted, the activity of Ra-226 per detector shall not exceed $0.1\mu\text{Ci}$. Where other radionuclides are to be used the activity per detector shall be limited by the competent National Authorities according to the lines applied for Am-241 and Ra-226.

iii) Dose equivalent rate

Irrespective of the type of radionuclide used the dose equivalent rate shall not exceed at any accessible point 0.1 mrem/h at 0.1 m from the surface of the device.

6.2(*) The use of ICSDs other than single station ICSDs considered in paragraph 6.1 which conform to the following requirements shall be subject to the condition that their recovery and disposal are controlled.

*) "This provision has not been accepted by the United States Authorities who believe that the matter of the amount of radioactivity which may be in a smoke detector should be left to the discretion of the competent authorities in each country. The United States' competent Authorities do not specify any particular quantity limitation of radioactivity for ICSDs. Rather, through a dose commitment analysis in each case, they establish that under normal conditions of use and credible accidents, persons should not receive radiation doses in excess of a certain specified limit. This difference in approach should not constitute an obstacle to international trade; experience shows that ICSDs licensed according to the above procedure normally fall within the same range of activity as defined in paragraphs 6.1 and 6.2."

i) Activity

The activity per detector shall not exceed

20 μ Ci Am-241 or Pu-238,

or 1 μ Ci Ra-226,

or 0.5 mCi Kr-85 or Ni-63.

ii) Dose equivalent rate

Irrespective of the type of radionuclide used, the dose equivalent rate shall not exceed at any accessible point 0.1 mrem/h at 0.1 m from the surface of the device.

6.3 The use of ICSDs containing activities or with dose equivalent rates higher than specified in section 6.2 shall be controlled by the competent National Authorities. Under such control, the use of ICSDs in this group shall be subject to notification or registration, unless specifically exempted, and to recovery and disposal requirements.

7. MARKING AND LABELLING OF ICSDs

7.1 All ICSDs shall be marked with the trefoil symbol, the name or symbol of the radionuclide and the activity. In addition, a label must bear the name and address of the manufacturer or importer. For single station ICSDs the trefoil symbol may be replaced by a label bearing the words "This Smoke Detector contains radioactive material which presents no significant hazard to health if used in accordance with the instructions" or similar wording.

7.2 Marking and labelling as specified under 7.1 shall be made so as to be clearly visible when the ICSD is removed from its mounting. If access to the sources can be gained without prior removal of the ICSD from its mounting, a further label possessing the trefoil symbol and the word "radioactive" should be clearly visible on removing the cover, before access to the source(s).

7.3 ICSDs with the exception of single station ICSDs shall also have a label specifying the instructions for recovery or disposal.

7.4 All marking and labelling shall be such as to remain clearly legible during the expected lifetime of the ICSD.

8. RECOMMENDATIONS CONCERNING ADMINISTRATIVE CONTROL PROCEDURES

8.1 It is recommended that the competent National Authorities should ensure that all relevant information on the presence and utilisation of radioactive sources is brought to the attention of users of ICSDs.

8.2 The following administrative procedures are recommended to ensure proper control over ICSDs whose use is subject to special

requirements under these standards. They are aimed in particular at ensuring the recovery and properly controlled disposal of such ICSDs either during or after their expected lifetime.

8.3 Users of ICSDs under sections 6.2 and 6.3 above should be advised, by any appropriate administrative procedure to be established by the competent National Authorities, of the action to be taken for recovery or disposal. Furthermore, users should be informed that the competent National Authority must be notified as soon as possible in the event of damage to or loss of an ICSD. The manufacturer or importer should normally be responsible for ensuring that this information relating to damage or loss of an ICSD is passed to users of their ICSDs by their agents, distributors or installers.

8.4 When required, a notification or an application for registration to use an ICSD should be submitted to the competent National Authorities. The information contained in the notification or in the application for registration should include indications about the nature and activity of the ICSD and its place of use.

8.5 Where registration for use is required, the competent National Authorities should supply the applicant with a special authorisation or certificate:

- i) stating the name of the applicant;
- ii) fixing the exact conditions of use;
- iii) requiring the applicant to notify the competent National Authority immediately in the event of damage to, or loss of, the ICSD;
- iv) prescribing any necessary precautions to be taken during the repair or maintenance of the ICSD;
- v) prescribing the action to be taken for recovery or disposal.

8.6 Competent National Authorities should ensure that any ICSD for which notification or registration is required is not handed over to the user until the National Authorities have been notified of the intended use, or until a special authorisation or certificate has been issued to the user as the case may require.

8.7 With existing fire detection installations which possess ICSDs which in these standards would have to comply with paragraph 6.3, the competent National Authorities may continue to permit the replacement of those ICSDs by similar ICSDs under the same conditions as existed when they were first installed.

9. SURVEILLANCE

The competent National Authorities should maintain surveillance over the manufacture to ensure that all ICSDs meet the authorised

specifications. The competent National Authorities should also maintain general surveillance over ICSDs subsequent to their manufacture or importation in order to keep individual and collective doses arising from their use and disposal under review and to ensure that these doses are kept as low as is reasonably achievable. In particular, the competent National Authorities should ensure that records are kept of all necessary information relating to the disposal of spent devices on the one hand and to damage, defects, loss, etc., of ICSDs on the other hand. Such a surveillance will be facilitated by using the following information:

- i) reports provided by manufacturers or importers on the total activity of radionuclides used in the ICSD manufactured or imported (see paragraph 4.4);
- ii) reports which may be required by the competent National Authorities on defects noted in the course of use, which are likely to change the data used for the initial safety evaluation;
- iii) records which competent National Authorities may deem it desirable to be kept by manufacturers or importers or persons or institutions to which ICSDs have been transferred.

ANNEX

PROTOTYPE TESTS

1. PRELIMINARY TESTS ON ICSDs

These shall include:

- a) general inspection noting any obvious design defects. The competent National Authorities shall be satisfied that the ICSD is so constructed that it complies with paragraph 3.4 and that the source(s) will not become detached or suffer loss of integrity in ordinary use during the lifetime of the ICSD;
- b) measurement of external dose rates. The competent National Authorities shall be satisfied where appropriate that the external dose rate averaged over 10 cm^2 complies with the requirements of sections 6.1 and 6.2;
- c) measurement of radioactive contamination on the external surfaces and those accessible during maintenance operations of the ICSD. The ICSD shall be deemed to have failed if the levels exceed a mean of $10^{-5} \mu\text{Ci/cm}^2$ for α -emitters or $10^{-4} \mu\text{Ci/cm}^2$ for β -emitters on all examined surfaces.

2.1 ADDITIONAL TESTS ON ICSDs

The competent National Authorities shall be satisfied that the source(s) will not become detached or suffer loss of integrity as a result of the following tests. A separate ICSD shall be used in each test.

- a) Temperature: The ICSD shall be cooled to -25°C , kept at this temperature for one hour, then allowed to return to ambient temperature. It will then be heated to 100°C , kept at this temperature for one hour, then allowed to return to ambient temperature.
- b) Impact: The equipment and procedure for the impact test shall be those described in ISO 2919. A steel hammer weighing 0.5 kg shall be dropped from a height of 0.5 m on to the ICSD which is positioned on a steel anvil so as to suffer the maximum damage.

- c) Drop: The ICSD shall be dropped from a height of 10 m on to a hard unyielding surface so as to suffer the maximum damage. This test may be relaxed for single station ICSDs where a 4 m drop test is considered sufficient.
- d) Vibration: If the ICSD has not been successfully subjected to a vibration test which is specified in a national or international standard concerned with the proper functioning of the ICSD then the following test shall be applied. The ICSD shall be vibrated sinusoidally in a direction perpendicular to its normal plan of fixation; the frequency of vibration being swept from 5 to 60 Hz at a rate of 4 octaves/hour. The peak acceleration shall be 0.24 g for the range 5-20 Hz, 0.40 g for 20-40 Hz and 0.51 g for 40-60 Hz. Two sweeps through the range shall be made and the ICSD shall then be vibrated for one hour at any resonant frequencies found, the peak acceleration being $0.7\sqrt{f}$ ms⁻², where f is the resonant frequency.

2.2 ADDITIONAL TESTS ON SOURCES

- a) Maintenance: In addition to the ISO/C 32222 classification tests, two sources mounted in their holders shall be subjected to twice the number of cleaning operations to be carried out during the expected lifetime of the ICSD according to the instructions of the manufacturer. The sources shall be considered to have passed this test if they have maintained their integrity.

2.3 EVALUATION

- a) Sources containing solid radioactive substances

Following each test wipe or immersion leak tests shall be carried out according to the recommendations and methods described in ISO DTR 4826 (April 1975). The wipe test shall be carried out over the source(s) and the inactive surfaces of the detector paying particular attention to the source holder. The immersion test shall be carried out using the complete detector. If the removed activity is less than 5 nCi from each source, then the source shall be considered to have retained its integrity.

- b) Sources containing krypton-85 gas

Following each test, the activity of the source(s) shall be determined by appropriate means to confirm that rupture of the source(s) has not occurred. Leak tests shall then be carried out on the source(s). If the detected leak rate

corresponds to less than $0.1 \mu\text{Ci}$ per day from each source, then the source shall be considered to have retained its integrity.

3.1 TESTS FOR THE EFFECTS OF FIRE

The competent National Authorities shall be satisfied that the source(s) in an ICSD will not result in an unacceptable level of contamination in the event of a fire. A fire test shall therefore be carried out on the complete ICSD or on the source(s) mounted in their source holders in the presence of parts of the ICSD which are sufficiently representative of the whole ICSD. Air shall be passed through the furnace for the duration of the test at a flow rate of 1 to 5 l/min and condensed and filtered before release to atmosphere. The ICSD (or the parts thereof) shall be heated from room temperature to 600°C and retained at this temperature for one hour.

If the sum of the activity remote from the source(s) (that is, that which is in the condenser and on the filters and in the debris) and that removed from the source(s) and holder(s) either by wipe or by immersion leak testing (using the methods and procedures described in ISO DTR 4826), exceeds 5 nCi per source, then the source(s) shall be considered to result in an unacceptable level of contamination.

ICSDs containing Kr-85 need not be subjected to this test.

3.2 HIGH TEMPERATURE INDUSTRIAL FIRE AND INCINERATION TEST

The competent National Authorities shall be satisfied that the source(s) in an ICSD will not result in an unacceptable release of activity to atmosphere in the event of a high temperature fire (for industrial ICSDs) or of incineration of waste (for single station ICSDs). A high temperature fire and incineration test shall therefore be carried out on the complete ICSD or on the source(s) mounted in their source holders in the presence of parts of the ICSD which are sufficiently representative of the whole ICSD. The procedure shall be the same as that described in paragraph 3.1 except that the ICSD (or the parts thereof) shall be heated to 1200°C and retained at this temperature for one hour.

If the activity detected in the condenser and on the filters exceeds 1 per cent of the activity of the ICSD (radioactive daughters of Ra-226 are excluded) then the source(s) shall be considered to result in an unacceptable release of activity to atmosphere.

ICSDs containing Kr-85 need not be subjected to this test.

4. CORROSION TESTS

The experts consider that in view of the existence of different corrosion tests in various national and international standards

concerned with the proper functioning of ICSDs and the lack of information on the correlation of the damage caused by these tests with that caused by the environment in which ICSDs are normally used, no suitable corrosion test can be defined. They also consider that the sources in ICSDs need not be checked for retention of integrity after such tests provided that the ICSD meets the functional requirements of the tests.

APPENDIX I

EVALUATION OF BENEFIT AND RISK

1. BENEFITS OF AUTOMATIC FIRE DETECTION SYSTEMS

1.1 Protection of property

1.1.1 Property loss

Illustrative figures of property loss due to fire in various countries are given in Table 1.

Table 1

Property Loss due to Fire

Country	Period	Fire Loss
Switzerland [77]	1960-1967	Sw.Frs.250 x 10 ⁶
United Kingdom [27]	1969-1974	£860 x 10 ⁶
United States [37]	1975	US\$4.17 x 10 ⁹

According to United Kingdom statistics most of the property loss occurs in large fires. Over the years 1965-1968, out of a total of £347,350,000 estimated fire loss in the United Kingdom, large fires (defined as those with a loss greater than £10,000) contributed 60.6 per cent of the total loss. These fires comprised less than 0.5 per cent of the total number occurring [47].

1.1.2 Benefit

Some statements which indicate the potential benefit of automatic fire detection systems in protecting property are listed below:

- "Detailed examination of the causes and nature of high loss fires suggests that an extension of fire cover provided by the public fire-fighting service would not have much more than a marginal effect on fire losses. These are most likely to be reduced by: (a) greater use of automatic detectors

giving direct warning to brigades, particularly in premises not in continuous operation,....." [47].

- "If it is assumed that the effective and widespread installation of detectors could reduce the likelihood of obtaining a large fire to the minimum value occurring during the day, then it may be estimated that a potential saving on large fires of about £25 million per annum would result. This probably underestimates the total potential financial saving in direct loss, since there is certain to be some saving in fires which would not have grown to the extent of being classified as 'large' even though discovered late, and also savings in fires due to earlier detection during the day." [57]

The average fire loss (premises and contents) in buildings in Switzerland monitored by ICSD fire alarm systems has been shown to be one-third of that in similar buildings without such systems [77].

1.2 Protection of human lives

1.2.1 Loss of life

Table 2 gives illustrative figures for the loss of life due to fire in various countries [67].

Table 2

Deaths due to Fires (1972)

Country	Fire Deaths per Million Persons
United States	57
Canada	29
United Kingdom, Sweden, Norway	18
Finland, Australia, Japan, Denmark	12 to 16
New Zealand	10
Netherlands, Belgium, France	5 to 7
Italy	3

In the United States over half the deaths occur in houses and apartments [77]. According to the United Kingdom statistics for 1971, out of 822 fatal casualties, 381 were due to the victim being overcome by gas or smoke and 574 were in private dwellings [87].

1.2.2 Benefit

The life-saving potential of fire detectors has been studied by various authors. The most detailed study is that of McGuire and Ruscoe [9]. Their results are summarised in Table 3. According to Rasbash [5] one can estimate that upwards of about one-third of the fatalities due to fire might not occur if fire detection systems were universally installed in the United Kingdom.

Table 3

Life-saving Potential of Fire Detectors in the Home

Victim	Deaths	% to be saved by ICSD	% to be saved by thermal detector
Average adult	181	45	8
Child, Infirm etc.	145	35	7
Total	326	41	8

In the United States 75 per cent of all multiple loss-of-life fires occur at night. Bright [10] conjectures that if dwellings had been equipped with some type of early-warning fire detection device many of these fatalities could have been avoided.

In Denmark, the number of persons killed in 1972 as a result of asphyxiation was 20 of which 11 cases were caused by smoking in bed; in one of these cases, 3 persons were killed. The Danish Fire-Safeguard Committee considers that the installation of smoke-detectors could have reduced the figure by about 10 [11].

These predictions seem to be borne out by experience with actual fires:

- The official report of the Committee of Inquiry into a fire in an old peoples' home, in which 18 people died, contained the following statement:
"[The establishment] was not provided with smoke detectors at the time of the fire There seems little doubt that had an automatic smoke detection system been in operation ... at the time of the fire [The staff] would have been alerted at a considerably earlier stage and might well have got the fire brigade to the premises before the fire had reached serious proportions" [12]
- Report on a fire in a mobile home: Boy was awakened by the activation of a smoke detector alarm. The report stated

that fire damage was held to a minimum because of early detection and reporting; otherwise, the loss would most likely have been total and the boy would most likely have died [13]. There are other similar reports in this bi-monthly fire record of smoke detectors being credited with holding damage to a minimum and preventing the loss of life in mobile homes and single-family dwellings.

2. RADIATION DOSES FROM INSTALLED ICSDs

During normal use of ICSDs the risks to members of the public are virtually limited to those resulting from external radiation.

The dose rate in air, $\overset{\circ}{D}_a$ (rad/h), at a distance d(m) from an installed ICSD is given by:

$$\overset{\circ}{D}_a = \frac{0.87 \times \Gamma_{\delta} \times A}{d^2}$$

where Γ_{δ} is the exposure rate constant (Rm²/Cih)

A is the activity (Ci)

0.87 is the absorbed dose (rad in air) delivered by 1R.

and δ in this assessment is taken as 21 keV

(this permits the exclusion of the major X-ray components of Am-241, Ra-226 and Pu-238. The low energy X-ray components from these radionuclides will not significantly contribute to the whole body doses because of the appreciable shielding provided by the ICSD, the intervening air and body tissue. The Γ_{δ} used will therefore be equivalent to the specific gamma ray constants for these radionuclides).

For the purposes of this assessment it is assumed that the mean whole body dose rate to an individual at a distance d(m) from an ICSD is equal to $\overset{\circ}{D}_a$ (rad/h). The annual individual dose D_i (rad) is then given by:

$$D_i = \overset{\circ}{D}_a \cdot t$$

where t is the number of hours per year spent at a distance d from the detector.

The annual collective dose, S (man rad), to the population of a given country is then given by:

$$S = D_i \times n \times P$$

where n is the number of installed ICSDs

and P is the number of individuals exposed for time t at distance d.

The average annual per capita dose D_p (rad) is given:

$$D_p = \frac{S}{N}$$

where N is the population of a country.

2.1 Doses from ICSDs installed in industrial, commercial and public buildings

The majority of ICSDs now installed in industrial, commercial and public buildings contain about $60 \mu\text{Ci}$ Am-241. The activity per detector, however, is expected to decrease and it is assumed that by the year 2000 the average activity will be about $10 \mu\text{Ci}$ Am-241. Some of the earlier detectors contain about $10 \mu\text{Ci}$ Ra-226 but those on the market at present have activities in the range 0.05 - $1 \mu\text{Ci}$. ICSDs containing Pu-238, Kr-85 or Ni-63 are not so widely available. Table 4 shows the activities assumed in this assessment.

The total number of ICSDs now installed in industrial, commercial and public buildings is estimated to be about 1 per cent of the total population (i.e. $n = 0.01N$). According to manufacturers, the market will become saturated when the number installed is about 3 per cent of the population (i.e. $n = 0.03N$). It is assumed in this assessment that, on average, two persons spend 2,000 hours/year at a distance of 4 m from each detector. Doses are calculated for a large industrial state, population 60 million (i.e. $N = 6 \times 10^7$).

These assumptions lead to the doses given in Table 5.

Table 4

Activities of ICSDs used in dose assessments

Radionuclide	Mean activity per ICSD 1976	Mean activity per ICSD 2000
Am-241	$60 \mu\text{Ci}$	$10 \mu\text{Ci}$
Ra-226	$1 \mu\text{Ci}$	$1 \mu\text{Ci}$
Pu-238	$20 \mu\text{Ci}$	$10 \mu\text{Ci}$
Kr-85	7mCi	0.5mCi
Ni-63	-	0.5mCi

2.2 Doses from ICSDs installed in private homes

For this assessment, it will be assumed that all ICSDs now installed in private homes contain $1 \mu\text{Ci}$ Am-241 or $0.1 \mu\text{Ci}$ Ra-226 and that this will continue to be the case in the year 2000.

In the United States, at present one home in 20 is equipped with a smoke detector and this is assumed to be typical of the numbers likely to be installed in a large, industrialised country in the near future.

It is assumed that one home in ten will be fitted with an ICSD by the year 2000.

Normal use

- a) On average 3 persons live in one home.
- b) 90 per cent of the ICSDs are installed in halls, etc., each irradiating 3 persons for one hour per day.
- c) 10 per cent of the ICSDs are installed in bedrooms, each irradiating 2 persons for 8 hours per day.
- d) The average distance of persons from a detector is 2 m.

Maintenance, etc.

- e) The home owner on average handles an ICSD for 5 minutes 12 times/year when installing unit, changing batteries, testing and vacuum cleaning the unit.
- f) The average distance source to body estimated during above manipulations is 50 cm.

The calculated doses received are shown in Table 6.

2.3 Conclusions

The results in Tables 5 and 6 show that external doses to individuals and to the population as a whole are very small. Individual doses obviously decrease when the activity used in each ICSD decreases, but population and average per capita doses depend on both the activity used and the number of detectors installed. Hence, in the cases of ICSDs containing Am-241 installed in industrial, commercial and public buildings the number of detectors is expected to increase, but this will probably be off-set by a decrease in activity used.

3. WASTE DISPOSAL CONSIDERATIONS

ICSDs which are part of a fire protection installation should be subjected to recovery and the normal radioactive waste disposal requirements at the end of their useful life. Only occasionally will such ICSDs be disposed of with normal refuse, in which case, because of the actual quantities of inactive waste involved, return to man will be highly unlikely, although not impossible. There is in fact one example of ICSDs having been illicitly disposed of on a tip and subsequently recovered (see Table 7 which is considered in paragraph 4).

It is on the other hand, much more difficult to ensure recovery and controlled disposal of single station ICSDs installed in private dwellings. It could happen that certain countries will devise systems of recovery of used ICSDs similar to those which exist in certain cases for the recovery of over-aged medicines, used oils, pesticides, etc. As a consequence, the present study can only be

Table 5

Externally -ray doses from detectors installed in industrial, commercial and public buildings in a large industrialised country (population 60×10^6)
(Each radionuclide is assumed to be used exclusively to calculate the doses)

Radionuclide	Exposure rate constant ($Rm^2/Gi\ h$)	Present (1976) Doses			Future (2000) Doses		
		Annual individual dose $D_i\ \mu\ rad$	Annual collective dose $S\ man\ rad$	Average annual per capita dose, $D_p\ \mu\ rad$	Annual individual dose $D_I\ \mu\ rad$	Annual collective dose $S\ man\ rad$	Average annual per capita dose, $D_p\ \mu\ rad$
Am-241	0.015 ^(b)	98	117	2.0	16	59	0.99
Ra-226(a)	0.91 ^(c)	99	119	2.0	99	356	5.9
Pu-238	2.0×10^{-5} ^(b)	≈0.0	0.0	0.0	0.0	0.0	0.0
Kr-85(a)	0.0013 ^(b)	990	1190	20	71	254	4.2
Ni-63	0.0	0.0	0.0	0.0	0.0	0.0	0.0

- (a) The bremsstrahlung components from Ra-226 and Kr-85 have not been considered because they depend on the materials used in the construction of the ICSD; they will not give a further contribution of more than a factor of about 2 (see ref. 14).
- (b) Calculated using the decay schemes in tables 1, 3 and 5 of Appendix 2 according to the reference Nachtigall 'Table of specific gamma ray constants', Thiemig-Verlag, München 1969.
- (c) See reference NCRP Report No. 41 "Specifications of Gamma-Ray Brachytherapy Sources 1974 concerning equilibrium with its daughter products without any platinum shielding.

Table 6

External doses from detectors installed in private homes

Radionuclide	Present (1976) Doses				Future (2000) Doses			
	Annual individual dose D_i μ rad		Annual collective dose S man rad	Average annual per capita dose, D_p μ rad	Annual individual dose D_i μ rad		Annual collective dose S man rad	Average annual per capita dose D_p μ rad
Am-241 (1μ Ci)	1h/day 1.2	8h/day 9.5	5.1	0.09	1h/day 1.2	8h/day 9.5	10.3	0.17
Ra-226 (0.1μ Ci)	1h/day 7.2	8h/day 58	31	0.52	1h/day 7.2	8h/day 58	62	1
Supplementary doses received during installing, changing batteries, testing and vacuum cleaning the unit								
Am-241 (1μ Ci)	0.05 μ rad/year		0.05	8×10^{-4}	0.05 μ rad/yea		0.1	1.7×10^{-3}
Ra-226 (0.1μ Ci)	0.32 μ rad/year		0.32	5.3×10^{-3}	0.32 μ rad/year		0.64	1.1×10^{-2}

incomplete and it will be assumed that all single station ICSDs will be disposed of with normal refuse at the end of their useful working life.

There are several methods of waste treatment. The most important are summarised in Figure 1. The relative importance of these methods may differ from country to country and therefore a general assessment of doses valid for all countries is not possible.

In the opinion of the Expert Group there are two waste treatment methods which need further consideration namely direct deposition in tips; and incineration with subsequent re-use of the ashes and slag.

The following assumptions are used in these assessments:

- Population feeding one disposal route 1.5×10^6
- Number of private homes 5×10^5
- Number of single station ICSDs 5×10^4
(applicable for the year 2000 - see section 2)
- Average life of a single station ICSD 5 years
- Average activity in a single station ICSD $1 \mu\text{Ci Am-241}$ or $0.1 \mu\text{Ci Ra-226}$
- Total amount of refuse 5×10^8 kg/year

On the basis of these assumptions, 10^4 single station ICSDs, with a total activity of 10 mCi Am-241 or 1 mCi Ra-226, will be disposed of at one disposal plant each year.

3.1 Direct deposition in tips

Waste ICSDs will be associated with large quantities of inactive waste which will provide considerable shielding of any photon-radiation which is already very small. Further shielding will also be provided once the tip has been filled and covered over with soil.

One possible route for return of the activity to man is through the salvage of an ICSD from a tip which is accessible to the public. Normally only those ICSDs which are still in reasonable condition would be expected to be recovered from the tip and these would no doubt still bear their labels warning of the presence of radioactive material. However, tampering with the source is still feasible and similar considerations to those given in the next section will apply.

Transfer of activity to ground water and subsequently to drinking water is another possible route. Owing to the non-transportable form of the radionuclides used and the construction of the sources it is likely that the activity will leach only slowly. Immersion tests confirm this [75]. Both nuclides are known to move slowly through soil. According to reference [76] the velocity of Ra-226 is 2×10^{-3} of the ground water velocity, and that of Am-241 is 10^{-4}

of the ground water velocity. In addition drinking water supplies are unlikely to originate near waste disposal tips. The doses to the public from this method of disposal will therefore be insignificant.

3.2 Incineration

One route of return of activity to man could be release of activity to air during incineration of waste. Tests have shown that, with well designed sources, less than 1 per cent with Am-241 and about 5 per cent with Ra-226 at 925°C will become airborne [177]. Incineration temperature may be higher than 925°C, but preliminary tests [187] at higher temperatures have shown that the amounts of activity released with Am-241 sources are not increased. Also the use of off-gas clean-up processes will further reduce the amount of activity released from the stack of an incineration plant. It can therefore be safely assumed that 1 per cent for Am-241 and 5 per cent for Ra-226 will be upper limits for the activity released to the atmosphere. These values are used in the assessment below. It is also assumed that the effective stack height of the incineration plant is 50 m. If the activity is evenly distributed throughout the waste, then the maximum downwind concentrations averaged over the year, calculated according to reference [197], is $10^{-12} \mu\text{Ci}/\text{m}^3$ for Am-241 and $5 \cdot 10^{-13} \mu\text{Ci}/\text{m}^3$ for Ra-226.

Assuming a breathing rate of 20 m³/day, a person exposed to the maximum concentration for one year would inhale $7.5 \times 10^{-9} \mu\text{Ci}$ of Am-241 or $3.7 \times 10^{-9} \mu\text{Ci}$ Ra-226. These intakes correspond to the dose equivalent commitments to bone of 7.4×10^{-6} rem and 4.6×10^{-7} rem respectively using the data given in reference [207].

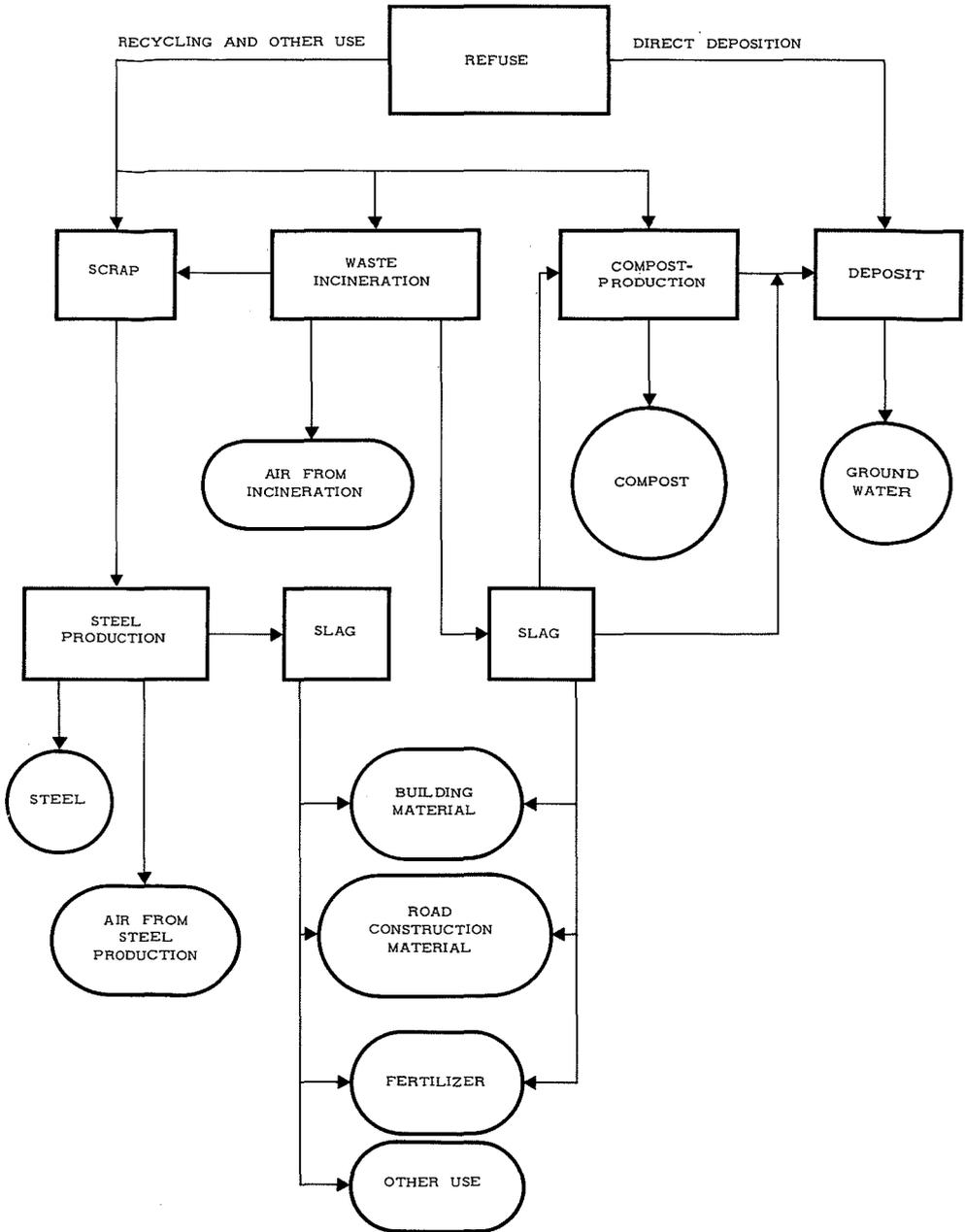
The majority of the activity will remain with the slag. The mass of the slag available for dilution of the activity will be very large and sufficient to provide very considerable shielding. Sources turning up at the surface of the slag deposit or any other material made from it will be very rare. An analysis [217] of the doses which might result from the various uses to which the slag might be put (see Figure 1) has shown that these routes of exposure are unimportant.

4. ACCIDENTS INVOLVING ICSDs - MISUSE OF ICSDs

In order to identify those situations where ICSDs might be subjected to stresses greater than those expected under normal conditions of use, a survey of known incidents in the United Kingdom has been carried out. A summary of some of the more important ones is given in Table 7; there have been others usually involving loss or misplacement of ICSDs which have subsequently been recovered. Unless otherwise stated, the ICSDs involved contained about

Figure 1

METHODS OF WASTE TREATMENT



60 μ Ci Am-241. In no case has there been any detectable contamination of a member of the public or the fire brigade.

The incidents can be categorised as follows:

- fire;
- explosion;
- misuse or mutilation;
- theft or loss.

4.1 Fire

As seen from Table 7, fire is one of the most common incidents involving ICSDs. The probability of serious damage to an ICSD by fire is however very small when compared with the total number of ICSDs installed. In order to assess the potential hazard, two situations are considered; during the fire and following the fire.

i) During fire

The radioactive sources used in ICSDs are, apart from those containing Kr-85, in the form of their non-volatile compounds. It would therefore be expected that only very small amounts, if any, would become airborne during the fire. The amount would depend upon such factors as the nature of the source and its holder and the nature and the temperature of the fire. This expectation has been borne out by both practical experience (see Table 7) and experiments [References 15, 17, 25, 267]. Kr-85 sources on the other hand would be expected to rupture in the event of a fire releasing all their activity.

For the assessment it is assumed that for solid sources 0.1 per cent of the activity will become airborne and be in the respirable range. For Kr-85 sources it is assumed that all the activity will be liberated. The most exposed individuals are assumed to be firemen fighting the fire; other individuals, although initially they may be closer to the seat of the fire, are likely on average to be at greater distances. Assuming that these firemen inhale 0.1 per cent of the airborne activity, then the resulting intakes from the solid sources are given in Table 8. Since such intakes will be very occasional, they can be compared with half the maximum permissible annual intake (MPAI) by inhalation for occupationally exposed workers (in each case the transportable form is considered).

Assuming the Kr-85 detector activity to be 0.5 mCi, then 0.5 μ Ci will be inhaled. If this takes place during one hour and the breathing rate is assumed to be 1 m³/h, then the average concentration of Kr-85 in the air during that hour will be 0.5 μ Ci/m³. This will deliver a dose to the skin (the critical organ for submersion in Kr-85) of 50 μ rad averaged over a depth of 50-100 g/m² [207]. This should be compared with half the maximum permissible annual dose to the skin for occupationally exposed workers which is 15 rem.

Table 7

Summary of known incidents involving ICSDs in the United Kingdom

Date	Incident	Number of detectors involved	Comments
1966	Fire	2	Lost in rubble at depth of ~ 5 feet
1968	Theft	20	Later recovered, sources found to be intact
1968	Fire involving polyurethane and polyester foam	59	Building collapsed. Detectors considerably damaged but majority recovered. Contamination in one place $4 \times 10^{-5} \mu\text{Ci}/\text{cm}^2$ removed by chipping away concrete
1969	Fire in contractor's hut containing detectors awaiting installation	155	3-4 mCi Am-241 not recovered
1969	Theft	3	Not recovered in spite of incident being widely publicised on radio and in newspapers
1970	Theft of car containing detectors	3	Recovered three days later
1970	Discovery of stolen detector in truck of coal	1	Warning given by radioactive label
1970	Theft	1	
1971	Discovery of detector in lime pit	1	Warning given by radioactive label
1971	Bomb explosion in Northern Ireland	2	One recovered virtually undamaged. The other was severely damaged but no evidence of foil break-up
1972	Discovery of detector in road	1	Warning given by radioactive label
1972	Bomb explosion in Northern Ireland	2	Detectors had been torn from their mountings. One and parts of the other were recovered after searching. No contamination of those involved in recovery nor of the areas where the detector parts were located

Table 7 (cont'd)

Date	Incident	Number of detectors involved	Comments
1972	Bomb explosions and subsequent fire in factory in Northern Ireland	70	58 recovered intact. Remaining 12 had been located in an area wrecked by a bomb blast but unaffected by fire. 11 of these were recovered intact. Remaining one was lost in large quantities of rubble which was treated as radioactive waste
1972	Fire in cornflakes factory	50	Detectors considerably damaged, probably due to use of bulldozer by fire brigade. Evidence of foil break-up. Accounted for 39 detectors. Rubble treated as radioactive waste. Some fixed activity on floor. Swabs of the hands of children thought to have been involved showed no detectable contamination
1973	Fire in hotel	33	4-5 detectors missing in about 700 tonnes of rubble used as hard core for roads. See reference /22/
1973	Fire in woodworks	50	Extremely hot fire. Two detectors and parts of one detector recovered. Loose contamination on all three detectors about 5 nCi. Rubble treated as radioactive waste. Most of activity found was firmly fixed to localised areas of the concrete floor. Air sampler during disposal operation showed that person most at risk was unlikely to inhale more than 1/100 maximum permissible annual intake for occupational exposure
1974	Fire in steel works	1	17 μ Ci spot fixed to concrete floor. Rubble disposed of on slag heap
1974	Source removed from detector in colliery	1	Not recovered. Dose rate from similar source 40 mrem/h at 1 cm. Hazard to miners thought to be very small

Table 7 (cont'd)

Date	Incident	Number of detectors involved	Comments
1974	Member of the public recovered detectors from tip 3 years earlier. He had removed 10 foils and had attempted to isolate the radioactive material from the sources. The work was carried out in his garage	50 Ra-226	No contamination of garage, dustbin or bedroom found. Whole body measurement on individual showed no Ra-226 above normal. See reference [23]
1974	Mutilation of detectors	4 (100 μ Ci max. Am-241)	Negative urine test on boys involved. Foils although not damaged showed on wipe tests removed contamination levels for the open chamber sources greater than 5 nCi (range 6-8 nCi). See reference [24]
1975	Fire in warehouse containing paper	12	Four detectors recovered intact. Other 8 located in most extensively damaged part of the warehouse after intensive search; one source was attached to container head, the rest were distributed over small areas of between 0.5-2.5 m ² . Fire temperature estimated at 1200-1300°C. Detection system known to have functioned and early warning probably prevented fire from spreading. Examination of the radioactive debris showed that the sources had broken up into small fragments; the removed contamination which amounted to less than 1 per cent of the fragment activity was found to be in the respirable range (AMAD = 1.35 μ m)
1975	Laboratory dismantled and detectors scrapped	2	Incorrect disposal discovered during visit from service engineer one month after disposal. One detector subsequently recovered from tip

Table 7 (cont'd)

Date	Incident	Number of detectors involved	Comments
1975	Fire in warehouse containing empty plastic containers and cardboard packing material	18	12 detectors recovered intact. 3 detectors had partially disintegrated but sources recovered intact. 3 detectors had completely disintegrated but most of the activity recovered in rubble for controlled disposal. No detectable contamination of persons or equipment involved in recovery operations
1975	Discovery of the inner chamber of a detector	1 (part)	Warning given by radioactive label but no manufacturer identification as this is normally on the missing part of the detector. Total activity of two source $2\mu\text{Ci Am-241}$
1976	Fire	3	One detector recovered intact but damaged by fire. Sources totalling $50\mu\text{Ci Am-241}$ and $3\mu\text{Ci Ra-226}$ recovered intact. Rubble containing $10\mu\text{Ci Am-241}$ recovered. Remaining rubble containing $50\mu\text{Ci Am-241}$ treated as radioactive waste
1976	Bomb explosions and subsequent fire in hotel in Northern Ireland	87	32 detectors recovered intact. 7 detectors recovered exhibiting smoke and water damage. 39 detectors recovered severely damaged. 9 detectors lost in large quantities of rubble
1976	Fire in warehouse containing synthetic fibres	14 ($100\mu\text{Ci}$ max. Am-241)	7 detectors recovered intact. Sources of remaining 7 detectors recovered intact but in some cases fused into aluminium holders. No evidence of leakage of radioactive material in spite of high temperature of fire
1976	Discovery of detector washed up on beach	1	Warning given by radioactive label. Detector was unaffected by sea as sealed in polythene bag; probably originated from a ship's replacement stock

Table 7 (cont'd)

Date	Incident	Number of detectors involved	Comments
1976	Loss of detector during modifications to a factory building	1	All detector parts were recovered following a search through rubble. All sources were undamaged and there was no detectable contamination of the outside of the detector casing
1976	Fire test on rig incorporating a detector	1 (15 μ Ci max. Am-241)	Maximum temperature of fire was 1200°C. Both sources were recovered intact. There was no detectable contamination of the rubble or parts of the detector recovered. Wipes of the sources and immediate surroundings showed no detectable removed contamination except for one source where 0.24 nCi was removed
1976	Fire in wooden hut containing detectors awaiting installation	15 (100 μ Ci max. Am-241)	12 detectors recovered intact. Parts of other detectors recovered. No detectable contamination of fire officer's boots or areas where detectors were found. No evidence of source break-up
1976	Bomb explosion in hotel in Northern Ireland	2 (1 μ Ci Ra-226)	Bomb had been placed immediately below 1 detector. Parts of detector housings were blown off but otherwise detectors were recovered intact. Wipes of detectors and sources showed no detectable removed activity
1976	Discovery of a second detector washed up on beach	1	Warning given by radioactive label. The plastic bag containing the detector contained a small volume of seawater but this did not appear to have affected the integrity of the sources

Table 7 (cont'd)

Date	Incident	Number of detectors involved	Comments
1977	Fire in automobile transmission testing shop	2	One detector recovered intact. Activity from other detector which fell into hottest part of the fire appeared to be in the form of discrete pieces spread over an area of 0.3 m x 0.3 m. Contaminated debris was recovered and treated as radioactive waste

Note: Unless otherwise stated, detectors involved contained about 60 μ Ci Am-241.

Table 8

Radio-nuclide	Detector Activity (μCi)	Activity Released (μCi)	Activity Inhaled (μCi)	$\frac{1}{2}$ MPAI (μCi)
Am-241	10	0.01	10^{-5}	8×10^{-3}
Pu-238	10	0.01	10^{-5}	2×10^{-3}
Ra-226	1	0.001	10^{-6}	4×10^{-2}
Ni-63	100	0.1	10^{-4}	80

ii) Following fire

Experience with fires involving ICSDs has shown that in general the solid sources remain as discrete lumps scattered over a small area below where the detector was mounted. With foil sources the activity is often fused to the concrete floor. The quantities of rubble involved are usually large. Analysis of the rubble from the hot fire in a warehouse containing paper in 1975 (see Table 7) showed that less than 1 per cent of the recovered activity was in the respirable range (this can be taken as an upper limit since the contamination removed by wiping recovered sources is usually much less than this depending on the materials used in mounting the source).

The most exposed individuals are assumed to be those involved in the clear-up operations. These operations are inevitably dusty; inhalation is therefore likely to be the limiting pathway. Assuming that one detector was protecting 100 m^2 , that 1 per cent of the activity is resuspendable and respirable, that the resuspension factor is $2 \times 10^{-6} \text{ m}^{-1}$ [457], that the clear-up operations last 8 hours and that the breathing rate is $10 \text{ m}^3/8 \text{ hours}$, then the resulting intakes are given in Table 9. These are again compared with half the maximum permissible annual intake (MPAI) by inhalation for occupationally exposed workers (in each case the transportable form is considered).

Table 9

Radio-nuclide	Detector Activity (μCi)	Air Concentration (μCi)	Activity Inhaled (μCi)	$\frac{1}{2}$ MPAI (μCi)
Am-241	10	2×10^{-9}	2×10^{-8}	8×10^{-3}
Pu-238	10	2×10^{-9}	2×10^{-8}	2×10^{-3}
Ra-226	1	2×10^{-10}	2×10^{-9}	4×10^{-2}
Ni-63	100	2×10^{-8}	2×10^{-7}	80

4.2 Explosions involving ICSDs

In those few situations where ICSDs have been involved in explosions the sources have been relatively undamaged. The fire which might follow an explosion is likely to produce more damage, in which case the above assessment holds.

4.3 Misuse or mutilation of ICSDs

The most significant abuse is the dismantling of an ICSD by an unauthorised person. There have been a number of incidents reported in the United Kingdom (see Table 7) each involving industrial ICSDs. In none of the cases where the people involved have been monitored has there been any detectable contamination of individuals. The possibility of misuse of ICSDs installed in private homes might be expected to be higher than in the more controllable industrial situation. However, the potential hazard is off-set by making the ionization chamber tamper-proof and by limiting the activity of the sources to lower levels than specified for general industrial use.

An incident has recently been reported in the United States in which a female employee of a firm manufacturing single station ICSDs accidentally swallowed two $2.5 \mu\text{Ci}$ Am-241 sources. The sources were voided intact. Although it took longer than would normally be anticipated for them to be excreted (16 and 24 days) measurement showed that very much less than 0.015 per cent of the total activity was transferred across the gut into the blood. The author concludes that "this was not significant from the point of view of radiological protection" [277].

A limited amount of testing of sources has been carried out to determine the effect of misuse [77]. Scratching across the active area of foil sources increased the amount of removable contamination on a subsequent wipe to several tens of nanocuries. Assuming therefore that 1 per cent of the source activity could be transferred to fingers and subsequently ingested, the individual intakes are given in Table 10. Since such intakes will be rare they can be compared with the maximum permissible annual intake (MPAI) by ingestion for members of the public (in each case the transportable form is considered).

With Kr-85 sources the most important hazard would be external irradiation of the skin from contact with an intact source. The dose rate measured at the surface of a 0.5 mCi Kr-85 source is 420 rad/h due to beta radiation. If the source were broken open and all the activity released into a room of 30 m^3 with a ventilation rate of one air change per hour, the dose to skin averaged between 50-100 g/m^2 would be 1 mrad during the first hour of exposure. This should be compared with the dose limit of 3 rem/y applicable to members of the public.

Table 10

Radionuclide	Detector Activity (μCi)	Activity Ingested (μCi)	MPAI for members of the public (μCi)
Am-241	10	0.1	3.0
Pu-238	10	0.1	4.0
Ra-226	1	10^{-2}	10^{-2}
Ni-63	100	1	22

4.4 Theft or loss of ICSDs

There are several examples of this given in Table 7. In a number of cases, the ICSDs have been recovered, the warning given by the radioactive label usually being responsible. Unrecovered ICSDs are likely to be abandoned in some remote place or disposed of with normal refuse. In either case, it is difficult to envisage a hazard more serious than that resulting from the misuse or mutilation of ICSDs considered above.

5. RISK-BENEFIT CONSIDERATIONS

5.1 Benefit in reducing property damage

The primary purpose of installing ICSDs in private homes, hotels, old peoples' homes etc. is to prevent loss of life in fires by giving early warning thus allowing occupants to escape. Although ICSDs in industrial and public buildings can also save lives, the main reason for installing them has been to reduce property damage.

It is difficult to estimate how much property losses would be reduced by widespread installation of ICSDs for a number of reasons. Firstly, the type of automatic fire defence system required in a building depends on its size, the risk of fire in it, the value of its contents and various other factors. (*) In many buildings an automatic alarm alone is likely to be an acceptable safeguard, since early warning of the outbreak of fire will allow manual fire-fighting procedures to be implemented rapidly and the fire to be brought under control before extensive damage occurs. However, in buildings where fire can spread so quickly that there is insufficient time for manual activity it is necessary to install an automatic extinguishing system as well as a detection system [57]. Since ICSDs may be installed either as an alarm system, or connected to an extinguishing system or to equipment designed to limit the spread of fire (e.g. smoke doors, mechanisms to shut down ventilation etc.), the estimation of the

*) In particular the speed of intervention which itself depends less on an early alarm than on the availability of help.

reduction in property loss achieved by fitting ICSDs is rather complicated.

Secondly, there are no reliable statistics comparing fire property losses in buildings fitted with ICSDs with those in buildings with other types of fire defence systems. ICSDs are suitable for buildings whose contents are valuable and could be damaged by smoke or extinguishing agents. For other buildings ICSDs may not provide cost effective fire protection because the reduction in fire insurance premium granted when they are installed is lower than that granted when an automatic extinguishing system is fitted [287]. ICSDs may therefore only be installed in certain types of buildings and fire loss statistics are not usually given in enough detail to enable calculation of the reduction in property loss they could produce.

In view of the difficulties discussed above it does not seem possible to carry out a full risk-benefit analysis for ICSDs based on property loss. A rough estimate of the potential financial saving on large fires if automatic detection systems were widely installed is given below.

5.1.1 Assumptions

- i) Out of a total fire loss of $\pounds 120 \times 10^6$ per year, $\pounds 25 \times 10^6$ per year might be saved on large fires (1969 figures for the United Kingdom).
- ii) Large fires account for 60 per cent of the total fire losses in any one year.
- iii) The total fire loss in 1976 will be $\pounds 250 \times 10^6$.

5.1.2 Calculation

$$\begin{aligned} \text{Fire loss in large fires in 1969} &= \pounds 0.6 \times 120 \times 10^6 \\ &= \pounds 72 \times 10^6 \end{aligned}$$

Percentage saving if detectors

$$\text{reduced the likelihood of large fires to the day-time minimum} = \frac{25}{72} \times 100 = 35 \text{ per cent}$$

$$\begin{aligned} \text{Potential saving on large fires in 1976} &= \pounds 250 \times 0.35 \times 0.6 \times 10^6 \\ &= \pounds 52.5 \times 10^6 \end{aligned}$$

5.2 Risk-benefit analysis for normal use (external radiation)

Because of the difficulties of carrying out a complete risk-benefit evaluation this paragraph only deals with the risk from external radiation doses received during normal use of ICSDs. The above analysis in paragraphs 2, 3 and 4 shows that these risks are the most important. It is noted that the doses received from normal use of ICSDs will be to the whole body while those resulting from waste disposal and accidents etc. have been calculated for the critical organs (bone, skin).

It is recognised that radiological risks estimates have in general been derived from the observation of effects at high doses

and dose rates. At the low levels of dose associated with the use of ICSDs it may well be that the use of these risk estimates will indicate a greater detriment to the population than will actually be the case. The values for the risk from the use of ICSDs derived in the following paragraphs should therefore be used with caution.

It is now estimated that for uniform exposure of the whole body, the total hereditary detriment is likely to be less than the detriment due to somatic injury in the irradiated individuals [29, 46]. Because of this and the difficulties of quantifying the hereditary risks, only the somatic risks are taken into consideration in this risk-benefit analysis. Even if the total hereditary detriment were also taken into consideration, the total (somatic plus hereditary) detriment would not be expected to increase the values obtained below by more than a factor of two.

5.2.1 Parameters

For the evaluation of the life-saving benefit of ICSDs the following data are used:

Number of fatal fire casualties:	18 per million persons per year
Proportion of fire deaths occurring in private dwellings:	70 per cent
Life-saving potential of ICSDs:	40 per cent of all fatal fire casualties.

For the evaluation of the risk from normal use of ICSDs the data in Table 11 is used.

5.2.2 Industrial, commercial and public buildings Benefit

If ICSDs are installed in all such buildings the expected number of lives which could be saved is:

$$\begin{aligned} 0.3 \times 0.4 \times 18 &= 2 \text{ per million population per year} \\ &= 120 \text{ per year for a population of 60 million.} \end{aligned}$$

Risk (cancer induction)

The annual collective dose S from ICSDs containing $60 \mu\text{Ci}$ Am-241 is 117 man rad (see Table 5). Assuming a risk coefficient of 125 cancer deaths per 10^6 man rem the number of fatal cancers which could be induced as a result of one year's exposure is:

$$117 \times 125 \times 10^{-6} = 1.5 \times 10^{-2} \text{ cancer deaths in a population of 60 million during the period up to about 30 years after irradiation.}$$

Table 11

Risk coefficients for cancer death per unit
exposure of a population /297

Cancer	Cancer deaths per 10 ⁶ man rem
Leukaemia	20
Lung	20
Bone	10
Liver	10
G I Tract	20
Breast	20
Thyroid	5
All other cancers	20
Total	125(*)

5.2.3 Private homes

Benefit

If 1 in 10 homes are fitted with ICSDs the number of lives which could be saved is:

$$0.7 \times 0.4 \times 0.1 \times 18 = 0.5 \text{ per million population per year} \\ = 30 \text{ per year in a population of} \\ 60 \text{ million.}$$

Risk (cancer induction)

The annual collective dose S from ICSDs containing 1 μ Ci Am-241 is 5.1 man rad (see Table 6). Using the same risk coefficient as above (see 5.2.2) the number of fatal cancers which could be induced as a result of one year's exposure is:

$$6 \times 10^{-4} \text{ in the period up to about 30 years after irradiation.}$$

5.3 Risks from waste disposal, accidents etc.

To complete the risk-benefit evaluation, the risk from waste disposal, accidents and misuse must be added to that from normal use.

*) This may be compared with the risk coefficient given in "The Effects on Populations of Exposure to Low Levels of Ionizing Radiation" Report by the Advisory Committee on the Biological Effects of Ionizing Radiations (BEIR), National Academy of Sciences, Washington 1972: BEIR estimate a risk of 50-165 deaths per 10⁶ persons per rem during the first 25-27 years after irradiation.

5.3.1 Waste disposal

As was stated in section 3 of this appendix, a general assessment of doses valid for all countries is not possible but a nominal assessment of the doses which might result from activity released to atmosphere during incineration of waste was carried out. The maximum dose equivalent commitments to bone for Am-241 and Ra-226 calculated in section 3.2 for the incineration of 10^4 single station ICSDs during one year at one disposal plant are 7.4×10^{-6} rem and 4.6×10^{-7} rem, respectively. If it is assumed that the average dose equivalent commitment to the local population feeding the incinerator plant is a factor of 3 lower than the maximum, then the average dose equivalent commitments would be about 2.5×10^{-6} rem for Am-241 and 1.5×10^{-7} rem for Ra-226. The collective dose equivalent commitments to bone for the local population of 1.5×10^6 people would then be 3.8 man rem and 2.3×10^{-1} man rem, respectively. Using a risk coefficient of 10 bone cancers per 10^6 man rem, these values lead to a possible induction of 4×10^{-5} bone cancers for Am-241 and 2×10^{-6} bone cancers for Ra-226.

The genetic risks for waste incineration can be safely neglected.

5.3.2 Fire

Using the assumptions in section 4, the possible intakes and the resulting doses to firemen and persons clearing up after the fire are as follows:

Table 12

Dose equivalent commitments to firemen, etc.

	Intake (μCi)	50 y Doses (rem) to bone(*)
Firemen	Am-241 10^{-5}	9.9×10^{-3}
	Ra-226 10^{-6}	1.3×10^{-4}
Persons clearing up	Am-241 2×10^{-8}	2.0×10^{-5}
	Ra-226 2×10^{-9}	2.5×10^{-7}

*) Calculated according to [20].

From Table 7, in the period 1971-1976 there were on average about two fires each year involving ICSDs, while five detectors per year were lost or mutilated.

Since there are about 10^5 fires in buildings in the United Kingdom every year, reference [47], the probability of a fireman attending a fire involving ICSDs is very low. The doses to firemen and persons clearing up after a fire are small so the risk to these persons is negligible in comparison with the other non-radioactive hazards involved.

5.3.3 Misuse or mutilation

The most likely pathway leading to exposure to radiation from the misuse or mutilation of ICSDs, (except ICSDs using Kr-85) would be that involving transfer of contamination from damaged sources to fingers and subsequent ingestion of the activity (see section 4.3). Although in section 4.3 an incident is reported where complete sources were swallowed it should be noted that this occurred where loose sources were being handled. The swallowing of complete sources by members of the public misusing or mutilating ICSDs cannot be ruled out but is thought to be highly unlikely and is therefore not considered here.

The intakes calculated in section 4.3 for someone misusing or mutilating an industrial ICSD containing $10 \mu\text{Ci}$ Am-241 or $1 \mu\text{Ci}$ Ra-226 are $0.1 \mu\text{Ci}$ or $10^{-2} \mu\text{Ci}$, respectively. The resulting dose equivalent commitments to bone are 8.1×10^{-2} rem for Am-241 and 3 rem for Ra-226. With single station ICSDs containing $1 \mu\text{Ci}$ Am-241 or $0.1 \mu\text{Ci}$ Ra-226 these dose equivalent commitments should be reduced by a factor of 10.

Incidents in which ICSDs are mutilated rarely involve more than one or two persons and ingestion of activity is likely to be no more than once in a lifetime. In view of the small doses involved the risks are therefore negligible.

5.4 Conclusions

On the basis of the above considerations it seems clear that the benefit which can be obtained from the use of ICSDs, both in terms of reducing property damage and saving lives, significantly outweighs any radiological risks involved in their use, misuse, disposal etc.

APPENDIX II

Technical Information

1. Outline of the various types of fire detector, (with particular reference to the need for smoke - sensitive types)

Fire detectors include:

- a) Heat - sensitive devices responding to temperature change of the air or gas surrounding them.
- b) Smoke - sensitive devices responding to smoke or other particulate products of combustion.
- c) Radiation - sensitive devices responding to electromagnetic radiation in the infra-red or ultra-violet bands.

Heat detectors respond only after a fire has reached the size where its convective heat output is measured in hundreds of kilowatts [307]. Such a fire is not only creating fire damage at a fast rate, but has already created a large volume of potentially lethal and corrosive fumes.

Human life is threatened by even a small fire, and many types of property such as foodstuffs, tobacco, electronic equipment, and precision machinery are susceptible to damage from smoke, and temperature changes. Consequently, earlier warning of fire is required than can be given by heat detectors, and this means smoke detectors [e.g. detectors for life safety are required to give alarm before the obscuration of visibility exceeds 9 per cent in 1 metre (0.4 dB/metre)]7.

Formerly there were arguments for preferring to use heat detectors based on their lower cost and higher reliability. These arguments have been shown to be no longer valid for reasons such as the following:

- a) Some 80 per cent of accidental fires begin with smouldering and the production of smoke and other particulate products, rather than with flame. This means that smoke detectors can give much earlier warning.
- b) It is accepted that one smoke detector can be used to protect an area appropriate to two or more heat detectors. This results in a marked cost saving in installation and wiring labour, as well as in equipment.

- c) Engineering development has produced compact, cheap, and reliable smoke detectors consuming negligible power.

There is now ample evidence that heat detectors provide a much more limited protection of life and property than smoke detectors in indoor applications [References 10, 31, 327].

Radiation detectors have a useful role to perform in fire protection, particularly out of doors. However, because most accidental fires begin with smouldering, to which radiation detectors do not respond, they cannot be used alone except in specialised risks.

Consequently, radiation detectors are an adjunct to smoke detectors, and in no way are they an alternative.

2. Description and comparison of ionization and optical smoke detectors

There are two main classes of well-proven commercially available smoke detectors which depend for their operation on the use of the following principles:

- a) the change of resistance of an ionization chamber;
- b) the obscuration or scatter of light.

2.1 Ionization chamber smoke detectors (ICSDs)

The ICSD normally comprises an ionization chamber in which the inter electrode space is ionized by means of a radioactive source. When potential is applied between the two electrodes, free ions and electrons are attracted to the appropriate electrodes. In transit across the chamber, random collisions will result in some ions and electrons re-combining, but many reach the electrodes and in doing so, give the chamber a characteristic resistance. When smoke enters the chamber some ions attach themselves to the relatively heavier smoke particles and, consequently, move more slowly. Transit time is longer and the chance of re-combination is greater. Fewer ions reach the electrodes and the characteristic resistance increases.

In practice, the increase in resistance is detected either by a decrease in chamber current or where a series element is used to form a bridge circuit by an increase in voltage.

In principle, any kind of ionizing radiation can be used to ionize the air in an ICSD. In practice, alpha or beta emitters will be used. Alpha emitters have, in general, been preferred because of the low penetration of α -particles and the high density of ionization they produce. However, for a variety of reasons, beta emitters are also sometimes employed.

In order to keep levels of activity to a minimum, it is desirable to work with the highest possible chamber resistance that is

compatible with the limitations of the electronic sensing circuitry. Notwithstanding this, other factors involved in the detailed design give rise to the spread in activity levels found in commercially available ICSDs [337].

2.2 Optical smoke detectors

a) Point type

A point type optical smoke detector normally comprises a nominally light tight chamber, with louvred access for smoke, in which a light source (usually a filament lamp or a light emitting diode) provides a cone of light (visible or infra-red). Offset from this cone is a photosensor (usually a photo cell or phototransistor) which receives light only when the presence of the smoke particles in the cone cause it to be scattered. The change in characteristics of the photosensor are detected and used to trigger an alarm.

b) Beam type

A beam type optical smoke detector normally comprises light emitter and receiver units mounted on opposite walls of a protected area (mirrors are sometimes used to simplify the installation or give extended coverage). When smoke penetrates the beam, the transmitted light is attenuated either by absorption or by scattering and the resultant drop in the receiver output is used to trigger an alarm.

2.3 Comparison of ICSDs and optical detectors

a) Sensitivity

The performance of the two types of detector is broadly equivalent in real fire conditions although each may have advantages in specific situations. They detect a range of aerosol sizes which overlap, ranging more towards the smaller invisible sizes such as are produced by clean burning dry cellulosic material for the ICSDs and towards the larger sizes such as are produced by smouldering PVC insulation for the optical detectors.

b) Reliability

The reliability of the ICSDs is essentially limited by the preservation with time of a high level of insulation.

The reliability of optical detectors is essentially limited by the stability and life expectancy of the light sources and photosensors.

Both types are susceptible to occasional false alarms due to environmental causes [347]. Dust is a problem which affects both types and for them to function properly they require periodic cleaning and inspection.

There is no evidence that either type has a clear advantage in reliability or in freedom from false alarms.

c) Cost

The price of these devices is of about the same order, depending on the quality of construction and the ingenuity of individual manufacturers.

Running costs are relatively insignificant for both types but the optical detectors normally draw a higher supply current and are therefore at a disadvantage in respect of standby battery requirements.

Installation costs tend to be lower for ICSDs because these for the most part work on two wire systems. Optical detectors, taking higher currents usually require a third wire for signalling purposes.

d) Application

In the past, most installed detectors have been of the ICSD type. This has been mainly due to the following reasons:

- i) lower wiring costs;
- ii) lower standby battery costs;
- iii) no requirement for regular lamp changes.

With the advent of semi-conductor light sources and more advanced circuit techniques these factors are no longer quite so relevant. It remains to be seen however whether optical detectors can be engineered, produced and applied in large numbers with comparable overall effectiveness 357. Meanwhile, the majority of currently manufactured detectors continue to be of the ICSD type.

3. Distribution of ICSDs

ICSDs have been available on the market for some 25 years already, and the monitoring, alarm and extinction systems, both electrical and electronic, connected to them are now highly sophisticated. Because of the purpose for which they are used, these devices are nearly always very carefully designed.

A great number of detectors are in use in every industrialised country; for example, at the end of 1975 there were about 650,000 in the Federal Republic of Germany, 500,000 in France, 193,000 in Sweden, 42,000 in Norway, 25,000 in Denmark, 120,000 in the Netherlands and 3,000,000 in the United States.

The detectors in use in Sweden are distributed as follows:

Industry	37 per cent
Governmental and local authority, buildings, hotels, stores, etc.	25 per cent

Hospitals	11 per cent
Old people's homes	8 per cent
Schools, etc.	8 per cent
Private dwellings	1 per cent (introduced in 1974 only)
Other	10 per cent

4. Radioisotopes used

ICSDs now in service employ sources of Am-241, Ra-226, Pu-238, Kr-85 and Ni-63.

4.1 Am-241 sources

The great majority of ICSDs use Am-241 sources (0.5-130 μ Ci). Activities above 80 μ Ci are now found only in types of detector no longer being produced. Many detector designs now use less than 10 μ Ci.

Foil sources

Rolled foil sources, where the radionuclide is contained in a gold matrix which is sealed between a silver backing and a thin gold or gold alloy cover over the alpha emitting surface, are at present the most commonly used sources in ICSDs.

Americium oxide is uniformly mixed with gold, formed into a briquette and sintered at above 800°C. The briquette is then mounted between a backing of silver and a front cover of gold or gold/palladium alloy and sealed by hot forging.

The composite metal briquette is cold rolled in several stages to give the required activity and overall areas. (A further plating of gold over the front cover is also sometimes applied). During this process, the front cover is reduced in thickness to 0.002-0.003 mm and the metal layers are consolidated to produce a single strip of metal approximately 0.2 mm thick. The metal strips have an overall width typically 20 mm and the active material is confined to a central zone usually 3 or 12.5 mm in width. The foils produced are normally in one metre lengths and are subdivided by cutting into strips or punching out small pieces to produce the sources used in ICSDs [157].

For use in ICSDs these small pieces are fixed onto metallic or plastic holders by mechanical methods such as crimping or by soldering or welding. In some of the designs, the cut edges are completely sealed. In the case of designs not using fully sealed edges, the normal leakage and contamination requirements (< 0.005 μ Ci) can be achieved providing foil activity loading per unit area and total activity are restricted.

All designs in this category will meet the minimum requirements of ISO 2919 (C 32222), many will meet C 44444 and with optimum

designs classifications as high as C 66646 can be achieved. In the latter case, appropriate holder materials such as stainless steel or monel alloy must be used and sources must comply with restrictions on foil loading and total activity. The amount of activity released following exposure to a severe sulphur dioxide corrosion test and by heating to temperatures above 1,000°C can also be kept to low levels with optimum source designs /T57.

Enamel sources

These consist of americium oxide incorporated into an enamel and fixed to a support of alumina.

The alumina support is usually in the form of a disc, 8 mm in diameter and 4 mm thick. The surface, which is to receive the active enamel, is initially covered with a high melting enamel (1,400°C). This has the advantages of facilitating the fixation of the enamel on the alumina support and of ensuring that the source retains its integrity at high temperatures.

The active enamel is obtained by intimately mixing americium nitrate with an inactive enamel. Heating to 900°C converts the americium nitrate to oxide and incorporates it into the enamel. After cooling the active enamel is crushed and reheated, this process being repeated several times to obtain an enamel of uniform activity.

The final source is made by distributing the active enamel in suspension on the enamel surface of the alumina support. The source activity is determined by the proportion of active enamel in suspension and the volume of the suspension. Heating is carried out to 1,000°C according to a well defined programme which avoids in particular the devitrification of the enamel /367.

The results of tests have shown that such sources possess a good resistance to high temperature and corrosion and comply with the minimum requirements of ISO 2919 (C 32222) /367.

4.2 Ra-226 sources

Although the use of Ra-226 sources in ICSDs has been largely superseded by the use of Am-241 sources, there are still some low activity (0.05 - 1 μ Ci) detectors on the market. All the sources are of the foil type and are constructed in identical manner to those for Am-241 described above. The radioisotope is in the form of its sulphate.

The properties of Ra-226 foils are similar to those described for Am-241 foils. In addition, measurements of radon emanation showed that at room temperature emanation rates from a 0.66 μ Ci source were considerably lower than 10^{-4} nCi/hour. At elevated temperatures, emanation rates of tens of nCi/hour were measured /T57.

4.3 Pu-238 sources

Recently, sources using Pu-238 in the form of its oxide are used in several new types of ICSDs. These sources are obtained by the deposition of a thin uniform layer of the plutonium oxide on a nickel support. High temperature treatment causes oxidation of the nickel and the production of a protective layer of nickel oxide over the radioisotope. A sealed source with "special form" approval and complying with the requirements of ISO 2919 (C 32222) is thereby obtained.

With this type of source under high temperature conditions (up to 1,300°C) in air a protective layer of nickel oxide will form which will prevent dispersion of the radioisotope.

4.4 Kr-85 sources

There are two types of Kr-85 sources used in ICSDs; one with 7 mCi Kr-85 in a glass capsule, the other with 0.5 mCi Kr-85 in an aluminium capsule. The former are now only made as replacements for ICSDs already installed and are not used in ICSDs currently being manufactured. The latter consist of an aluminium capsule, diameter 3.2 mm and volume 180 mm³. The wall thickness of the capsule is 0.1 mm and the internal gas pressure is less than 50 per cent of atmospheric pressure.

On heating the aluminium capsules containing Kr-85 to 410°C for two hours, no measurable leakage was detected. Provisional testing has also indicated that these aluminium capsules mounted in polycarbonate holders will comply with the ISO 2919 requirements, although it is not clear whether such testing is appropriate for gaseous sources because in the event of source rupture the gas will be released and rapidly dispersed.

Dose rates measured at the surface of the source are high amounting to about 420 rad/hour due to β -radiation and 7 mrad/hour due to photon-radiation.

4.5 Ni-63 sources

The radionuclide Ni-63 is uniformly electroplated as the metal onto a metallic backing. A front cover approximately 0.2 μ m thick is applied by electroplating. The active component normally in the form of a circular disc is mounted in a metal holder to form the source assembly. Source designs such as those described have achieved higher ratings than those specified in ISO 2919.

5. Radiological data

A summary of the radiological data for the radioisotopes used is given below.

5.1 Am-241

Am-241 decays with a half-life of 433 years [37] to Np-237 (half-life = 2.14×10^6 years). Its principal emissions [38, 39, 40] are given in Table 1.

Table 1

The principal emissions of Am-241

Emission	Energy	Percentage (No./100 disintegrations)
α	5.48 MeV	85
	5.44 MeV	13
	5.31-5.54 MeV	2
X-rays	11.9 keV	0.86
	13.9 keV	13.2
	17.8 keV	19.3
	20.8 keV	4.9
	26.35 keV	2.4
γ	26.35 keV	2.4
	59.5 keV	35.3

The normal radioactive impurities are plutonium isotopes, principally Pu-239 (less than 1 per cent by weight) and trace amounts of fission products.

5.2 Ra-226

Ra-226 decays with a half-life of 1,600 years to Rn-222. Because of the short half-lives of Rn-222 (3.8 days) and subsequent daughters, these also need to be considered. Only with aged Ra-226 sources will radioactive equilibrium with its daughters including Po-210 and Bi-210 be complete. Table 2 lists the principal emissions of Ra-226 and its short-lived daughters [References 38, 40, 41].

5.3 Pu-238

Pu-238 decays with a half-life of 87.75 years [38] to U-234 (half life = 2.47×10^5 years). Its principal emissions [42] are given in Table 3.

Unlike Am-241 and Ra-226, Pu-238 is normally not isotopically pure. Table 4 summarises the usual isotopic compositions. In addition, Pu-238 will contain trace amounts of Am, Np, U and Th, in all less than 0.1 per cent by weight. There are also trace amounts of fission products amounting to 13.4 Ci/gramme of Pu.

Table 2

The principal emissions of Ra-226
and its short-lived daughters

Radionuclide	Emission	Energy (MeV)	Percentage (No./100 disintegrations)	
Ra-226	α	4.78	95	
		4.60	6	
Rn-222	γ	0.186	4	
Po-218	α	5.49	100	
Pb-214	β	0.510	0.07	
Pb-214	α	6.00	100	
Bi-214	β	1.03 (max)	6	
		0.74	36	
		0.69	42	
		0.51	15.5	
		0.21	0.5	
	γ	0.242	6.7	
		0.295	16.9	
		0.352	32	
Po-214	α	5.51	0.008	
		5.45	0.012	
	β	3.26 (max)	20	
		2.6	4	
		1.889	9	
		1.55	15	
		1.51	18	
		1.02	23	
		0.42	11	
		γ	0.273	5.3
			0.609	47
			0.769	5
			0.935	3
			1.120	17
			1.238	6
			1.378	5
1.40	4			
1.509	2			
1.728	3			
1.764	17			
1.848	2			
2.117	1			
2.204	5			
2.445	2			
Po-214	α	7.69	100	
		9.06	0.0022	
Pb-210 (20 year)				

The radionuclidic purity of Ra-226 is greater than 99.9 per cent, the principal impurities being Ac-227 and Ra-228.

Table 3

The principal emissions of Pu-238

Emission	Energy	Percentage (No./100 disintegrations)
α	5.4989 MeV	71.1
	5.46 MeV	28.7
	5.359 MeV	0.13
	5.214 MeV	0.005
X-rays	11.6 keV	0.2
	13.5 keV	5.1
	16.4-17.5 keV	7.1
	20.5 keV	0.1
γ	43 keV	0.038
	100 keV	0.009
	153 keV	0.0013
	201 keV	5×10^{-6}
	766 keV	3.3×10^{-5}
Fission neutrons	2 MeV	$4 \times 10^{-7} (*)$

*) This value corresponds to about 2,500 fission neutrons per g. Pu-238 in agreement with [367].

Table 4

The usual isotopic compositions of Pu-238 sources

Isotope of plutonium	Normal grade plutonium (% by weight)	Medical grade plutonium (% by weight)
236	≈ 1 ppm	< 0.6 ppm
238	81	90
239	15	9
240	3	0.6
241	0.6	0.03
242	0.1	< 0.01

In spite of its low relative abundance, Pu-236 is the impurity of principal concern. It decays with a half-life of 2.8 years to U-232 which in turn decays through a series of daughters. One of the daughter products is Tl-208, a 2.6 MeV γ -emitter, which grows in at such a rate that its maximum abundance is achieved 18 years after production of the plutonium source. This aspect must be taken into account when calculating external γ -radiation dose rates [43]. For medical grade plutonium, in general, the total γ -radiation

dose rate is somewhat lower than or comparable to the neutron dose rate caused by spontaneous fission of Pu isotopes. Both dose rate contributions are increased by (α,n) reactions on impurities present in the radioactive material.

5.4 Kr-85

Kr-85 decays with a half-life of 10.73 years [38] to stable Rb-85. Its emissions are given in Table 5.

Table 5

The principal emissions of Kr-85

Emission	Energy (MeV)	Percentage
β	0.15 (max)	0.43
	0.672 (max)	99.57
γ	0.514	0.43

5.5 Ni-63

Ni-63 decays with a half-life of about 100 years to stable Cu-63. It is a pure β -emitter; the maximum energy of the β particles is 65.87 keV (100 per cent) and the average energy 17.23 keV [44].

The radionuclide purity of Ni-63 is normally greater than 99 per cent with no detectable γ -emitting impurities.

APPENDIX III

Fire and incineration tests on ICSDs

Two high temperature tests for ICSDs are given in the Annex. The one at 600°C is designed to simulate the effects of a fire of moderate temperature. This temperature is thought to be typical of that which might be reached in a domestic fire. The other at 1,200°C is designed to simulate the effects of a very hot industrial fire or, in the case of single station ICSDs, the incineration of ICSDs disposed of with household waste. Extensive high temperature testing of ICSDs has been carried out by the National Radiological Protection Board (NRPB) in the United Kingdom and the tests described in the Annex have been largely formulated on the basis of the experience gained. To assist other national laboratories wanting to undertake the tests, the method used by the NRPB is described here in more detail. The NRPB experiment has been designed to facilitate the assessment of total leakage (in the case of the 600°C test) and airborne contamination (in the case of the 1,200°C test) and has been shown to give reproducible results [47, 48].

The NRPB experiment utilises a closed flow system with the appropriate temperature being provided by a tube furnace. Complete ICSDs should ideally be tested in their normal operating positions (except perhaps in the incineration test) but, because of the cost of very large combustion tubes, the source(s) and holder(s) are tested together with representative parts, cut-up if necessary, of the remainder of the ICSD. The components are placed in the tube in the same relative positions as in the complete ICSD, and the tube then positioned such that the complete sample is within the uniform hot zone of the furnace. The sample is heated from room temperature to the test temperature, and allowed to return to room temperature after the test has been completed.

The size of the tube used is 25 mm external diameter and about 70 cm long, of which about 14 cm protrudes from each side of the furnace. For temperatures up to 1,000°C, quartz tubes (internal diameter, 22 mm) are used. For higher temperatures, such as in the incineration test, recrystallised alumina tubes (internal diameter, 17 mm) are required. Air is drawn through at a flow rate of 3 litres min^{-1} . For the quartz tube, this corresponds to an air speed of

about 13 cm sec⁻¹. This air speed is sufficiently low to permit the observation of any chemical or physical reaction between the airborne products and the sources. For the recrystallised alumina tube with its increased wall thickness, the air speed is about 22 cm sec⁻¹. In view of the object of the 1,200°C test (i.e. limitation of airborne activity), such an increased air speed is not undesirable.

The flow is achieved by pumping rather than a positive pressure. Blockages sometimes occur in the tube and therefore a slight negative pressure is better from a safety point of view.

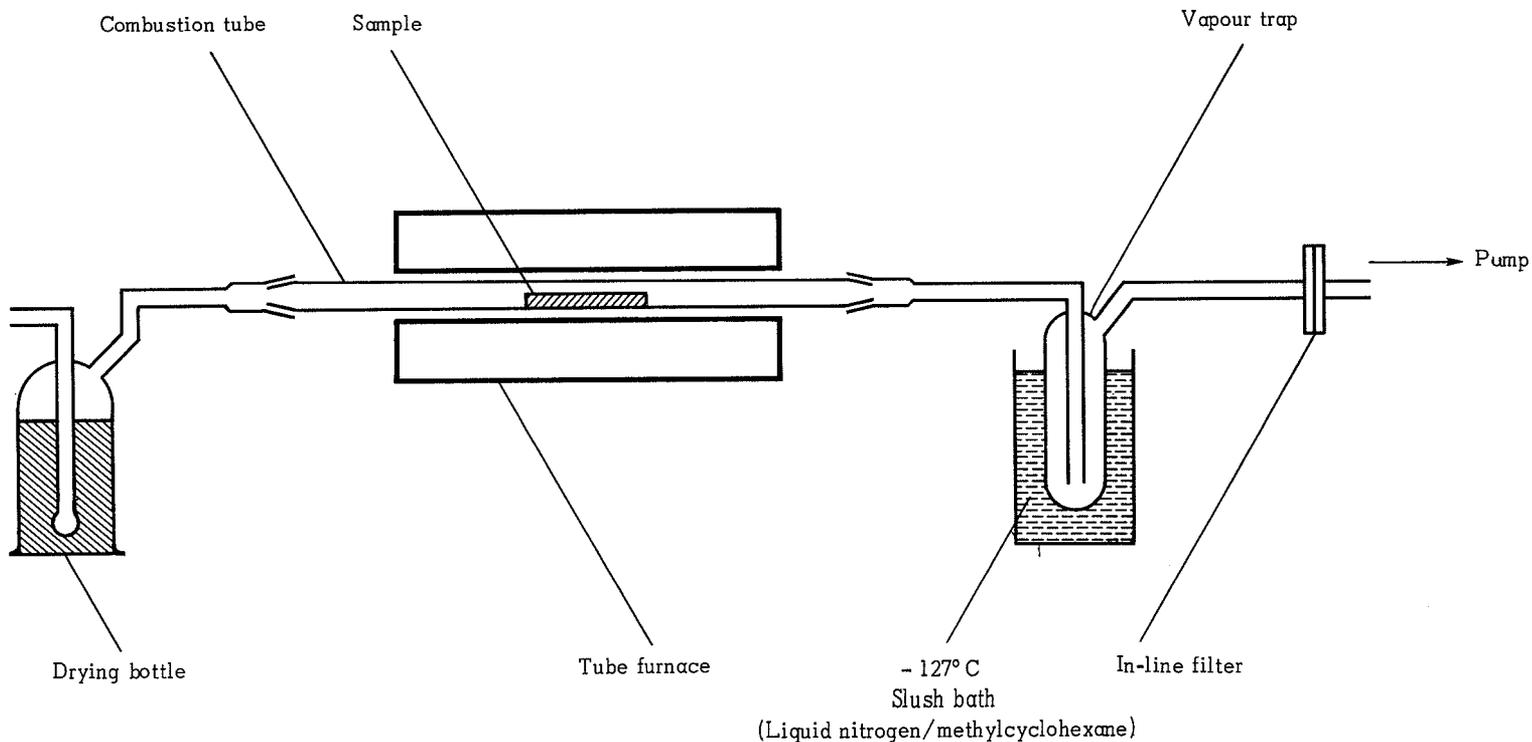
The air is dried immediately prior to entering the tube, so that results are not complicated by varying initial humidity. After traversing the tube, the air is passed through a vapour trap and an in-line filter before release into a fume cupboard. A vapour trap is essential if there is plastic in the sample, otherwise the degradation products may clog the in-line filter. The trap is kept at -127°C. Even at this temperature, some degraded plastic may pass through the trap and condense in the connecting tubing. For the purpose of leakage assessment, the degraded plastic from both the inlet and outlet tubes to the vapour trap are bulked with the trap sample. The lengths of tubing employed are as short as practicable.

Following the 600°C test the ICSD debris is removed from the combustion tube and the source(s) located and separated from the rest of the debris. The activity in the debris, in the vapour trap and in the in-line filter are counted separately. The source(s) and holder(s) are wiped using alcohol moistened cotton swabs.

Following the 1,200°C test the activity in the vapour trap and in the in-line filter are counted separately. The 1 per cent limit specified in the Annex is applied to the total of the activity measured.

The general form of the apparatus used for both tests is shown in the diagram.

Figure 1
FIRE TEST APPARATUS



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