OPERATIONAL AND REGULATORY ANALYSIS OF RADIOACTIVE WASTE CLASSIFICATION

by

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A Thesis Submitted to the Faculty of the

DEPARTMENT OF NUCLEAR ENGINEERING

In Partial Fulfillment of the Requirements
For the Degree of

MASTER OF SCIENCE

In the Graduate College

THE UNIVERSITY OF ARIZONA

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TABLE OF CONTENTS

		Page
	LIST OF ILLUSTRATIONS	v
	LIST OF TABLES	vi
	ABSTRACT	vii
1.	INTRODUCTION	1
2.	NUCLEAR WASTES AND NUCLEAR WASTE OPERATIONS	3
	Types of Radioactive Waste Which Must Be Included In a Classification System	3
	Nuclear Waste Operations Which Must Be Recognized for Development of a Classification System	4
	Definitions of Operations	4
	Volume Reduction or Concentration	6
	Immobilization and Packaging	6
	Interim Storage	7
	Transportation	7
	Disposal	8
	Emergency Operations	11
3.	PREVIOUS EXPERIENCE WITH RADIOACTIVE WASTE CLASSIFICATION	13
	Common United States Systems	13
	International Atomic Energy Agency 1970 System	14
	Final Disposal Classification System	16
4.	CONSIDERATIONS FOR DEVELOPMENT OF A COMPREHENSIVE WASTE CLASSIFICATION SYSTEM	18
	Regulatory Considerations	18
	Operational Considerations	20
	System Characteristics Necessary to Satisfy Regulatory and Operational Classification Needs	22
5.	A COMPREHENSIVE CLASSIFICATION SYSTEM	23
	System Description	23
	Primary Categories	23
	Subcategories	27
	Classification Examples	33

TABLE OF CONTENTS--Continued

Page

6. APPLICATIONS OF THE PROPOSED COMPREHENSIVE CLASSIFICATION SYSTEM 36

Waste Disposal Decision 36
Respectful Responses and Implied Emergency Actions . . 36
Safety and Efficiency 42
Public Relations 42

7. CONCLUSIONS AND RECOMMENDATIONS 44

APPENDIX A: FEDERAL LABELING REQUIREMENTS 46

APPENDIX B: TECHNICAL BASIS AND PHYSICAL MEASUREMENT TECHNIQUES FOR 400 W/m^2 47

REFERENCES 50

LIST OF ILLUSTRATIONS

Figure   Page

1. Operation Flow Diagram of Radioactive Waste Life Cycle . . . 5

2. Areas of Assessment in Projections of Long-Term Safety of Geologic Systems 10

3. Classified Radioactive Material Signs 26

4. Aging of Hazard Index 29

5. Final Disposition Decision Flowchart 37

6. Green's Heat Flux Sensor 49

LIST OF TABLES

Table		Page
I.	IAEA Proposed for Categories of Radioactive Wastes (1970) . .	15
II.	Disposal Oriented System	17
III.	Waste Classification Categories	25
IV.	Gaseous Release From PWR	30
V.	Subcategories	32
VI.	Other Classification Subcategories	34
VII.	Respectful Response Chart	38
VIII.	Implied Emergency Action Chart	40

ABSTRACT

A radioactive material classification system was developed that would serve not only the regulatory needs of radioactive waste management but other operational needs and yet be general and compatible with other systems so that it might gain a wide acceptance and utilization.

This classification system provides the primary classification, categories I, II, III and IV, for the operations involving the greatest risk, the characteristics that are the need to shield and cool.

The next level of importance, the duration of the hazard, is represented by subcategories a,b,c, and d.

The last group of subcategories relate factors which also might be of concern including material mobility (s, m, l, g), explosive or fissionable characteristics (e or f), and material processing requirements (t or n).

CHAPTER 1

INTRODUCTION

A multiplicity of radioactive wastes have been and are being generated by the nuclear industry. These wastes vary widely in physical, chemical, and radiological properties. A complex system of processes and treatments are used to alter these waste forms and provide for their safe, efficient, management. In order to facilitate communication, it is necessary to arrange radioactive wastes systematically into groups or classes sharing various common factors. Other classification systems have included variations of the high-, intermediate-, and low-level waste groupings which often reflect relative activity. The high level group usually requires cooling and the intermediate group requires shielding. Unfortunately these groupings are not standardized and mean different things to different people. Several authorities have recognized the system's limitations and have attempted more formal classifications. For various reasons these formal classifications have received very limited acceptance and the need for a standardized classification system remains.

Not only have today's classifications proved insufficient to serve communications needs, but they are less than adequately effective in dealing with regulatory classification needs. The Nuclear Regulatory Commission has been charged with the responsibility for preparing regulations dealing with the handling, processing, packaging, storing, and disposing of radioactive wastes. Formulation of these regulations needs a standard, precise, waste classification system. Such a system must provide sufficient information about the characteristics of waste forms to identify each item for proper handling and processing as well as to define the applicable regulations.

Finally, the ACRS[1] has recently considered the problem of waste classification and has recommended the development of a new useful waste classification system.

The work reported here has the following objectives:

1. Identify and/or explain types of material and operations important to radioactive waste classification.
2. Identify the regulatory and operational needs of radioactive waste classification.
3. Design a comprehensive operational classification system for radioactive materials.
4. Analyze and demonstrate the use of the proposed system.

CHAPTER 2

NUCLEAR WASTES AND NUCLEAR WASTE OPERATIONS

Recognition of the relevant properties and characteristics of the materials to be classified and the application of the classification system is fundamental to development of any classification system. This chapter introduces the types of material to be classified and the major waste operations where a classification system can play a useful role.

Types of Radioactive Waste Which Must be Included in a Classification System[2]

A satisfactory waste classification system must include radioactive wastes produced from process operations in the uranium fuel cycle. The generation of the following types of wastes can be expected from operation of the full uranium fuel cycle.

Reactor Wastes:

- Filters
- Adsorbents
- Resins
- General trash
- Aqueous slurries
- Failed hardware
- Failed equipment

Reprocessing Wastes:

- Solidified high-level waste
- Solidified intermediate-level waste
- Spent fuel cladding
- Reactor and fuel hardware
- Large failed process equipment
- General trash
- Ventilation filters

Plutonium Oxide Conversion Wastes:

Solidified liquid waste
Resins
General trash
Failed equipment
Ventilation filters

Mixed-Oxide Fuel Fabrication Wastes:

Solidified liquid waste
Resins
General trash
Failed equipment
Ventilation filters

Miscellaneous:

Decontamination and decommissioning wastes
Noble-gas fission products
Fission product iodine and carbon-14
Hospital and clinical radioactive waste
Industrial radioactive waste

Nuclear Waste Operations Which Must Be Recognized for Development of a Classification System

A majority of radioactive wastes undergo numerous and varied treatments and operations between waste generation and waste disposal. The "life cycle" of a radioactive waste is represented by the following flow diagram in Fig. 1. Emergency operations may occur at any stage in the life cycle.

Definitions of Operations

Radioactive waste may be "processed" by chemical or physical means to achieve a reduction in the hazards to humans posed by these materials, to facilitate handling and to minimize costs. "Handling" of radioactive wastes includes the actions of personnel in the implementation and supervision of waste processing, as well as during the remainder

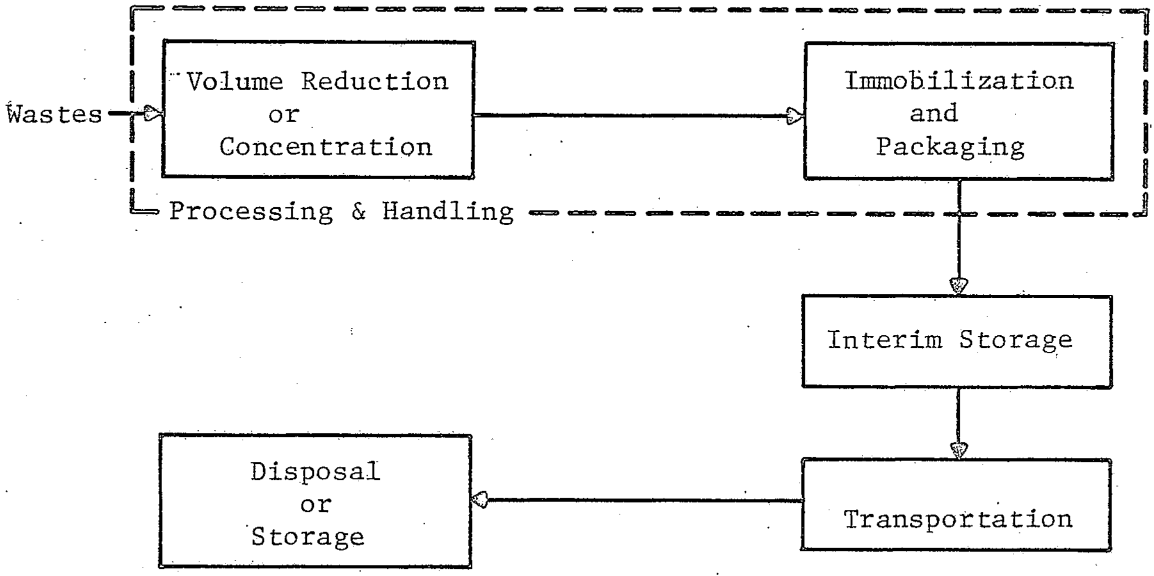


Fig. 1. Operation Flow Diagram of Radioactive Waste Life Cycle

of the waste's life cycle. General descriptions of nuclear waste operations follow.

Volume Reduction or Concentration[3]

The volume of radioactive waste may be reduced to decrease radionuclide mobility (and thus reduce danger of release and dispersal), to facilitate further treatment and/or to decrease costs. Volume reduction techniques include compaction, melting and incineration for solid wastes, and evaporation and filtration for liquid wastes.

Immobilization and Packaging[3]

Immobilization and packaging of radioactive wastes means, as the term implies, the reduction of a waste's tendency to disperse. Generally, dispersal by wind, leaching, or accidental release can be reduced by solidification, volume reduction, use of absorbents, or matrix formation. Immobilization often reduces packaging and/or surveillance requirements.

Packaging requirements for radioactive waste are a function of waste form, transportation needs, storage methods, and the physical environment in storage areas. Packaging should provide at least two independent barriers designed to contain the radioactive materials throughout handling, transport, and storage under normal and abnormal circumstances. In addition, where applicable, shielding and cooling requirements will be provided by the packaging.

Interim Storage[3,4]

Interim storage is placement of radioactive waste into a non-permanent storage location. Two reasons for interim storage are:

1. Efficiency of process operations depends on the capacity to store wastes temporarily until further processing can be implemented or as a material source to supplement interrupted flows of process inputs.
2. Substantial economics in radiation exposure, cooling requirements, resource commitment, or actual costs can be obtained by delaying final storage or implementing additional waste handling procedures. For example, the heat generation rate of high level waste after a 10 year storage period decreases to about 1/20 of the rate at the time of reprocessing. This reduction would decrease cooling requirements resulting in safer and less costly material transportation.

The design and operation of interim storage facilities are based upon consideration of safety, ease of waste retrieval, and costs. Types of interim storage include; tanks for liquid waste, above ground pad storage, below ground earth storage, concrete vaults, or water basins for solid wastes.

Transportation[3]

Transportation of many types of radioactive material is necessary between treatment facilities located at different geographic locations. The principle means of transportation are truck and rail. Radioactive material shipments must meet federal and state regulations. Federal regulations define container specifications, radiation dose rate limits, and safe handling procedures. State regulations limit vehicle sizes and weights, transportation routes, and times of travel.

Disposal[3]

Final disposal means emplacement of radioactive waste in a permanent configuration. Isolation means to remove from the biosphere. The following is a general list of disposal options which have been considered--

<u>Shallow Land Burial</u>: placement of wastes (not high level and probably relatively short-lived) at relatively shallow depths in earth materials. This method requires continued surveillance.

<u>Near Surface Storage</u>: placement of wastes in configuration similar to those for interim storage, but without consideration for retrievability. This method requires continued surveillance.

<u>Geologic Formations</u>: placement of waste in deep geologic formations.

<u>Seabed</u>: placement of waste beneath the ocean floor.

<u>Icesheet</u>: placement of waste in the large permanent masses of ice overlying continental land masses in the antarctic.

a. Allowing hot canisters to descend through ice to bedrock. Rate of descent may be controlled with anchor chains to allow retrievability for a limited time.

b. Surface structure storage of waste with coverage by accumulating snow and ice.

<u>Extraterrestrial</u>: ejection of waste from the earth by rocket to:

a. Impact with the sun

b. A solar system escape

Transmutation: transmutation or fissioning nuclei with neutrons to produce isotopes with short half-lives.

Geologic disposal concepts are currently regarded to be the best of the isolation options. The design of final isolation and disposal configurations and their handling accessories mainly reflect site specific long term safety considerations. These considerations are illustrated in Fig. 2.

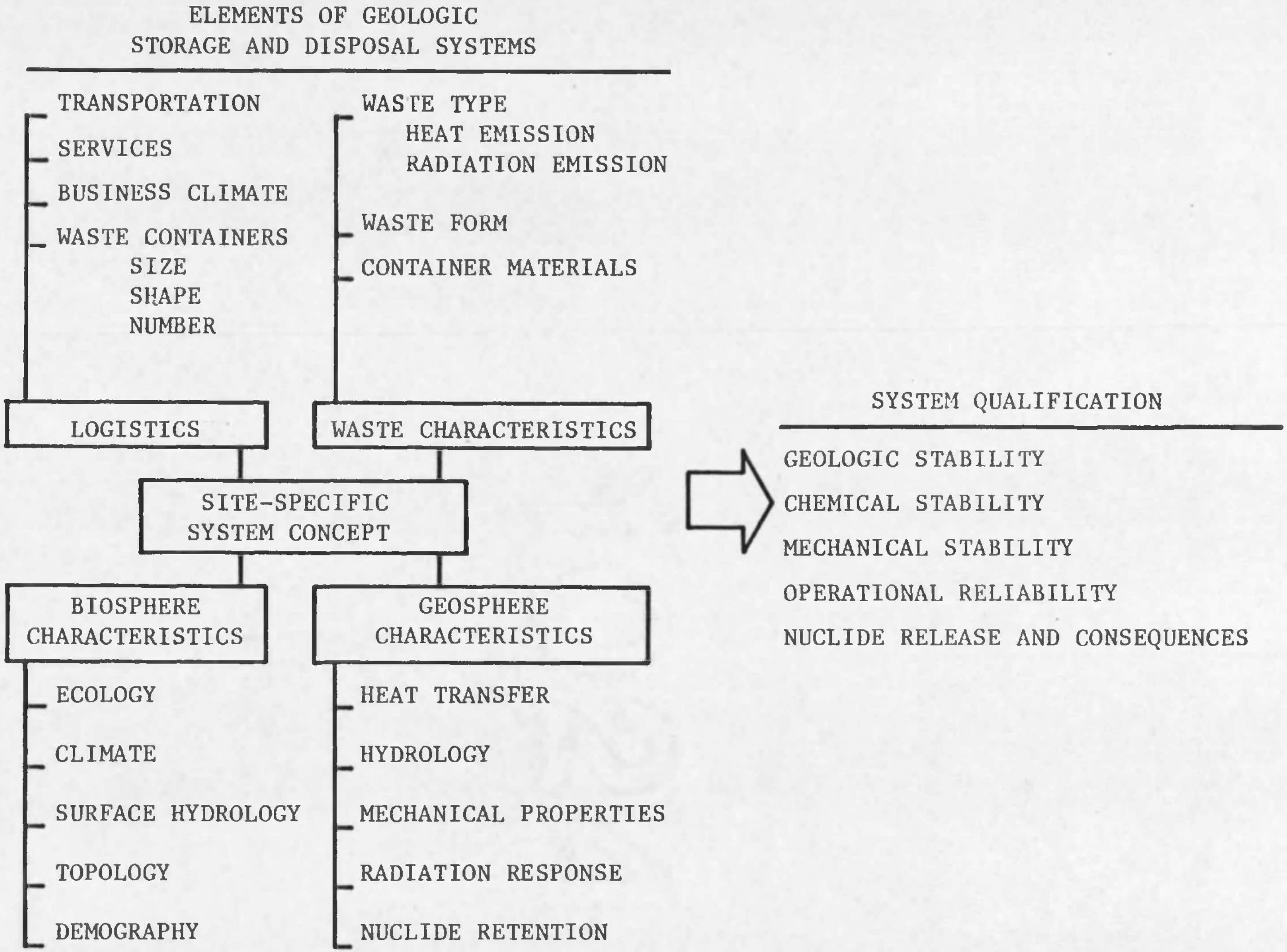


Fig. 2. Areas of Assessment in Projections of Long-Term Safety of Geologic Systems[3]

Emergency Operations

Emergency operations are needed when a radioactive material is inadvertently exposed to conditions which could result in its release and/or in doses to humans without releases in excess of those which would occur during normal controlled circumstances. Abnormal conditions which would result in a need for emergency operations are:

1. Fire
2. Criticality accidents
3. Breach of material containment

The biological hazards to humans which may result from abnormal conditions are exposure to penetrating radiaiton and/or inhalation and ingestion of radiotoxic material. Biological hazards may be minimized by:

1. Avoidance or reduction of contamination of water, air or soil by radioactive materials.
2. Isolation of radiation fields.
3. Avoidance of volatilization, melting, or containment rupture from excessive heat.

Hazard minimization measures are implemented by emergency operations and/or safety personnel. Generally these operations are:

1. Notify safety personnel not at scene,
2. Fight fires,
3. Maintain containment,
4. Control radioactive material to minimize dispersal if containment is breached,

5. Control access to minimize exposure to operating personnel as much as practical,
6. Keep unauthorized personnel away from scene.

CHAPTER 3

PREVIOUS EXPERIENCE WITH RADIOACTIVE WASTE CLASSIFICATION

All previously proposed radioactive waste classification systems are based on one or a combination of the following parameters:[2]

a. Source of the waste

b. Physical characteristics of the waste

c. The nature of the final isolation system used to contain the waste.

The pages which follow give representative samples of the three types of systems with comments on some of their advantages or disadvantages.

Common United States System

The system used currently for communication and/or regulatory classification is a source-characteristic system. The Technical Alternative Document, a five volume government sponsored survey of U.S. waste management, defines categories of the U.S. System as follows:[3]

High Level Waste: The fission product waste resulting from reprocessing spent fuel after separating uranium and plutonium from the fission products. Requires cooling.

Intermediate Level Waste: Waste requiring protection of personnel from penetrating radiation.

Low Level Waste: Wastes containing types and concentrations of radioactivity that must be controlled but shielding to protect personnel from penetrating radiation is not required.

Transuranic Waste: Any waste material measured or assumed to contain more than a specified concentration (e.g., presently proposed as 10 microcuries of alpha emitters per kilogram of waste) of transuranic elements.

It is evident that these definitions are inadequate. The Technical Alternatives Document makes no claims to the acceptance of the classifications, but several inadequacies of the system are apparent.

These definitions are so broad as to actually overlap. For example, high level, intermediate level, and low level wastes can all be transuranic wastes. Conversely, transuranic waste can also be included in the high level, intermediate level or low level waste categories. Further since all high level wastes require shielding, then it is possible to say that all high level waste are also intermediate level wastes.

The transuranic waste category makes reference to a 10μCi/kg limit. This limit is based on the level in natural uranium. Unfortunately, there is no reliable method of ascertaining transuranic levels of 10μCi/kg for all materials in the field. Consequently, any materials suspected of containing any transuranics are classified as transuranic waste. Certainly regulations cannot be written using a waste category definition which is likely to change and which cannot be accurately measured.

International Atomic Energy Agency 1970 System

A formal classification system based only on waste characteristics was developed in 1970 by a committee sponsored by the IAEA and is shown in Table I.

Table I

IAEA Proposed for Categories of Radioactive Wastes (1970)[5]

Category Liquid	Activity Level A(μCi/ml)	Remarks	
1	$A \leq 10^{-6}$	not normally treated	
2	$10^{-6} < A \leq 10^{-3}$	without shielding	treatment by
3	$10^{-3} < A \leq 10^{-1}$	shielding possible	usual methods
4	$10^{-1} < \quad \leq 10^{-1}$	shielding necessary	
5	$10^{-1} < A$	cooling necessary	
Gaseous	**Activity level A(Ci/m^3)**		
1	$A \leq 10^{-10}$	Usually not treated effluents	
2	$10^{-10} < \quad \leq 10^{-6}$	Effluents usually treated by filtration	
3	$10^{-6} < A$	Effluents usually treated by other methods	
Solid	**Radiation dose on the surface of wastes D/(R/hr)**		
1	$D \leq 0.2$	3-$_7$emitters dominant	
2	$0.2 < D \leq 2$	z-emitters insignificant	
3	$2 < D$		
4	α-activity expressed in Ci/m^3	z-emitters dominant β-$_7$-emitters insignificant not suspect from the point of view of criticality	

This system and others like it were not intended for regulatory use. Study of the system shows that, indeed, it would not serve regulatory purposes. For example, activity concentration is not sufficient information for making decisions regarding waste disposal. Knowledge of biological hazard and radionuclide lifetime are both required information.

Many of the categories have no unique characteristics from an operational standpoint except physical state. For liquid wastes categories 3 and 4 both may require shielding. These two categories seem to have been selected on a rather arbitrary basis. It would seem better to simply state the waste's activity. Thus, even though communications would be standardized, little practical or useful information is provided by this classification system.

Final Disposal Classification System

Waste classification systems based on environmental criteria have been recently suggested in rough form. One of these systems is illustrated in Table II.

Disposal oriented classification systems are of no use until a waste is ready for final disposition. Therefore, communications for operational purposes are not facilitated by these systems.

It appears that such systems attempt to guide or even presuppose the waste disposal decision. Although this type of classification system seems to have little value for "classification sake" they may be helpful at the regulatory level as surveys of possible criteria which may be considered in the disposal decision process.

Table II

Disposal Oriented System[2]

<u>Release-able</u>	Waste satisfying conditions less than those set by "lower bound" criteria.
<u>Short-duration containment</u>	Wastes satisfying conditions 1) greater than those set by "lower bound" criteria where "lower bound" criteria might be developed on the basis of: a. comparison with natural deposits and natural hazards (re: some acceptable hazard limit) b. $1,000 per person-rem (re: 10CFR50, Appendix I) c. MPC values less than 10CFR20 MPC limits and 2) with hazard durations less than those specified by "middle bound" criteria.
<u>Isolations</u>	Wastes satisfying conditions greater than those set by "lower bound" criteria but with hazard durations greater than those set by "middle-bound" criteria which might be developed on the basis of: 1. WASH - 1539 2. Between 100 years and 1000 years (re: W. A. Rodger, <u>Critical Evaluation of the Limit of Transuranic Contamination of Low Level Wastes</u>, August, 1975, Nuclear Safety Associates Bethesda, Md.)

CHAPTER 4

CONSIDERATIONS FOR DEVELOPMENT OF A COMPREHENSIVE[6] WASTE CLASSIFICATION SYSTEM

Regulatory Considerations

The Nuclear Regulatory Commission establishes regulations which outline requirements for safe use and disposal of radioactive materials. The Energy Research and Development Administration may specify any method regarding disposal of these materials within these limits. The three options currently available are dispersal to the atmosphere, storage in a facility or surface burial ground requiring surveillance, and total isolation from the biosphere in such a way as to require a minimum of societal commitment now or in the future as in deep geologic burial. Which of these options that will be required for a particular radioactive waste is dependent on the dangers posed by the waste themselves. Since nuclear waste materials are generated in numerous and varied forms, identification of the common waste characteristics which pose hazards to humans for all time is a major prerequisite to the disposal decision. These characteristics include:

1. Magnitude of the radiation
2. Biological hazard index
3. Lifetime of hazard
4. Mobility of the material

The magnitude of the radiation is the quantitative measurement of the total amount of hazard that is present without defining the degree of hazard. The magnitude, as we are speaking of it, is the rate of radioactive disintegrations as expressed by curies (Ci) (3.7×10^{10}dps) or becquerels (Bq) (1 dps). The radiation sources with the greatest magnitudes of radiation require cooling and those with penetrating radiation may require shielding even at levels below those at which some form of cooling is necessary. The magnitude of radiation that requires care and handling extends below that requiring cooling even for materials with penetrating radiation and, of course, there are some materials that have only particulate radiation requiring very little shielding.

The hazard index is more difficult to define but it is a term designed to encompass all aspects of the biological effect of radiation. It takes into account the biological halflife, the energy of the radiation, the parts of the body that a particular isotope will seek and other factors. The hazard index should provide a quantitative measure that relates the quantity of hazardous material to the adverse biological effect. Regardless of the nature, even non-radioactive of the materials, the hazard index should be proportional to the adverse effect from the hazard of the particular material. The best estimate or method of measurement of a hazard index at the present time is to divide the amount of material by the maximum permissible concentration as specified in the federal regulations.[7]

The next factor of interest is the durability or lifetime of the hazard. For radioactive materials, this is calculated from the radioactive decay rate. Simple for a single isotope, such a calculation may be somewhat complex for the case of mixtures of many isotopes of different half lives.

The mobility of the material is an important consideration since it will relate to the possible pathways leading to man as the result of some release of material. There appear to be four basic degrees of mobility which are related to the physical state. These may be correlated or designated as the gaseous state, the liquid state, the finely divided solid state, and finally the monolithic solid state.

Operational Considerations

There are other characteristics of the radioactive material classification system that must be included in the objectives of the design. A major group of these are the operational requirements which must be recognized by the operator, who will usually have fewer technical skills than those who are classifying the waste but nonetheless must respond to the material hazard. Current practices and regulations do not require the use of sufficient, standardized, and concise labeling to inform the operator of the proper care and handling of radioactive materials. Federal regulations (10 CFR, Part 20) for container labeling are given in Appendix A. Notably these regulations do not require labeling for containers:

> When they are attended by an individual who takes the precautions necessary to prevent the exposure of any individual to radiation or radioactive materials in excess of the limits established by the regulations in this part.
>
> Which are accessible only to individuals authorized to handle or use them, or to work in the vicinity thereof, provided that the contents are identified to such individuals by a readily available written record.

These labeling omissions rely on an operator's knowledge, judgment, and willingness to follow procedures. The nuclear industry knows how fragile these human factors can be. In July 1964 in a scrap recovery plant at Wood River Junction, R.I. a worker mistook a bottle of concentrated U-235 solution for a similar bottle of trichloroethane solution. He poured the U-235 into sodium carbonate solution being stirred in a make-up tank. A chain reaction occurred exposing the operator to ten thousand rads of radiation.[8]

The above incident suggests further complications because of inadequate labeling. When the responsible operator in attendance to material becomes seriously injured or killed, information regarding the nature and hazard of the material may not be readily available to other personnel arriving on the scene. Information required might be whether the material normally requires cooling as for high level waste and/or whether it is likely to escape should containment have been breached as for a liquid or gas. Without such communications emergency personnel may not restore lost cooling in time to prevent containment pressurization and explosion or they may not don proper breathing apparatus in preparation to deal with more apparent hazards such as fire fighting or rescuing injured personnel.

In any complex industrial operation, like those involving radioactive material treatment, the operator may make the errors which cause accidents. A classification and labeling system which communicates handling requirements can make an operators job of complicated procedural work or routine shuffling of numerous radioactive material containers both safer and easier.

System Characteristics Necessary to Satisfy Regulatory and Operational Classification Needs[6]

1. Simplicity. The system must provide ready classification that can be applied unambiguously to any particular material and one that will be easily recognized and readily identified.
2. Utilitarian. The system must provide real information that is actually needed in the operation and regulation.
3. Complete. The system must include all information that is needed and it must include all hazardous radioactive material with differentiation among hazards that require different procedures.
4. Flexibility. The classification system should permit changes in the classification of material whose hazard has changed and it should also be able to incorporate changes that may be required by changes in regulations, policy, hazard assessment or new technology.
5. Variability. Since different properties have different operational importance it is not necessary that all properties be identified for each operation. A simpler system for some operations can be provided by including different levels of classification. We can have major categories and subcategories.
6. Precise and concise definition. Each class will be designated by a roman numeral and each subclass by one or more letters. This provides a simplistic symbol that is readily recognized.

CHAPTER 5

A COMPREHENSIVE CLASSIFICATION SYSTEM

System Description[6]

The system consists of multilevel classifications with four primary categories and four lines of subcategories. Each subcategory has from two to four levels. Operationally, many users would need information from perhaps one or two lines. Transportation and handling might need only the primary category. One subcategory defines the life of the hazard. Thus the system can be simplified in application to suit the requirements. A simple connotation and symbol are also included.

Primary Categories

The primary categories will provide operating and control information that is necessary in the conduct of each of the operations mentioned above. These relate primarily to handling requirements. They are distinguished by the need for cooling, for shielding, and for recognizing the existence of a real biological hazard. The materials present in various quantities of highest concentration of radioactive materials will require some form of cooling in order to avoid melting the containers and releasing materials through volatility and to avoid burns on the operators handling the container. (With the possible exception of some alpha or beta emitting sources in materials in large quantities at high concentrations virtually all materials requiring cooling also require shielding since they will usually have a significant component of penetrating radiation.) As the quantities of materials decrease then the need for shielding decreases until finally shielding is no longer required to prevent external exposure around the radioactive material. The lowest category is one in which the quantity of radioactive material is so small as to present no hazard if the material is ingested or inhaled. This category is needed in order to define the relationships among the other three categories. The categories are summarized in Table III. A modification of the present radioactive warning signs has also been developed which is suggested as a way of visual identification of these various classes Fig. 3. The next problem is to establish the criteria that will distinguish between the materials and establish the quantitative value of the boundary separating each pair of categories.

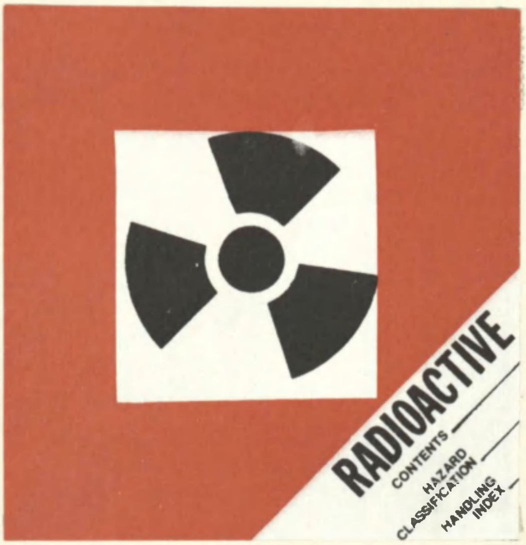
An accepted way of identifying and defining the boundaries would be to relate the identity of the particular isotopes. A complete identification thus would depend on a full listing of all known radioisotopes. An alternative method would be to classify them according to the energy of the radiation released. Also in Table III we have shown the minimum quantity of material that would place that material in the classes shown, as a function of the energy of the penetrating radiation for Class II. The basis for the calculations in this table are that the materials that would generate a quantity of heat equivalent to 400 W/m^2 (see Appendix B) in a shielded container that has a height of 3.3m and a diameter of 0.3m is given by the quantities listed. All materials generating more heat than this would also be included in Class I. In Class II the criteria was material that would have 200 mR/h[9] at the surface without any shielding but less than 400 W/m^2 of heat generation. Class III will be

Table III

Waste Classification Categories

Symbol	Hazard	Criteria: Total Energy of Radiation MeV	Maximum Quantity for 3.3m x 0.3m Cylinder	
			PBq	KCi
I	Quantity of radioactivity so great that self heating may cause dispersion unless cooling is provided	>400 w/m^2		
		0.1 - 0.5	15.5	420
		0.5 - 1.5	5.2	140
		1.5 - 3	2.6	70
		3 - 4	2.0	50
		4 - 5	1.5	40
			GBq	Ci
II	Quantity of radioactivity insufficient to require cooling but penetrating radiation requires shielding	0.1 - 0.5	44	1.2
		0.5 - 1.5	18	0.5
		1.5 - 3	11	0.3
		3 - 4	8.4	0.23
		4 - 5	7.2	0.2
III	Contains radioactivity of significant hazard but does not require shielding from penetrating radiation			
IV	Innocuous - no health hazard from ingestion of radioactivity			

Category I



Category II

Category III

Category IV

Fig. 3. Classified Radioactive Material Signs

material that has more than MPC present as specified in the regulations[7] but requires no shielding.

Subcategories

We must consider certain subcategories used to delineate the other factors and properties of concern in various operational needs particularly those involved with waste management. The subcategories relate to lifetime, mobility, necessity for treatment and special handling. The system as envisioned would not necessarily include all of the subcategories and other subcategories might be added as deemed appropriate.

The first subcategory and the one that appears to be of greatest concern is that relating to the duration of the hazard. Stated earlier, the hazard index is presently defined as the quantity divided by the maximum permissible concentration. This means that it can be considered a dilution factor, the amount that one would have to dilute one unit of material in order to reduce the concentration to levels acceptable for ingestion. There are some concerns about the validity of the maximum permissible concentration and as our technology and analyses continue these quantities may be changed, in which case the definition of another hazard index would be indicated. This would not invalidate any of these considerations but would simply require modification of the definition of the hazard index itself. Here we need to consider only the changes in hazard occurring by aging. The only changes that are notable for radioactive hazards are: first and most important, the change in the quantity or magnitude of the radiation and second, the possible changes in physical state. The latter will not occur in any predictable and universally defined manner so we will not incorporate such changes as part of the classification system. The duration of the hazard and its decrease with time as a result of radioactive decay is easily defined by the radioactive decay equation:

$$N = N_o e^{-\lambda t} \tag{1}$$

and of course N can be the number of curies, the number of becquerels or the magnitude of the hazard index. For complex mixtures, the hazard index for the mixture would be the sum of the hazard indices for each isotope present. The decay rate is, of course, a property of the particular isotope so that the change of the hazard index of the mixture would be equal to the sum of the several equations shown in equation (1) and given by the following equation:

$$\Sigma N = \sum_j N_{o_j} e^{-\lambda_j t} \tag{2}$$

In Fig. 4 curves are drawn to illustrate the change in hazard index for a canister containing one year old high level waste in glass, for the quantity of gaseous effluent from a PWR shown in Table IV, for a canister containing 3.5 Ci of ^{60}Co and for a quantity of natural uranium are needed to provide the fuel that generated the canister of waste. These calculations are straightforward and quite easy with the availability of exponential functions or a computer, but a table which would give approximate values may be useful. We have selected four different categories of the time required for the particular material to decay until its hazard index reaches that permitted in Category IV. The first group, subcategory a, includes material of relatively short half-life but, which would have a storage time short enough so that it would be

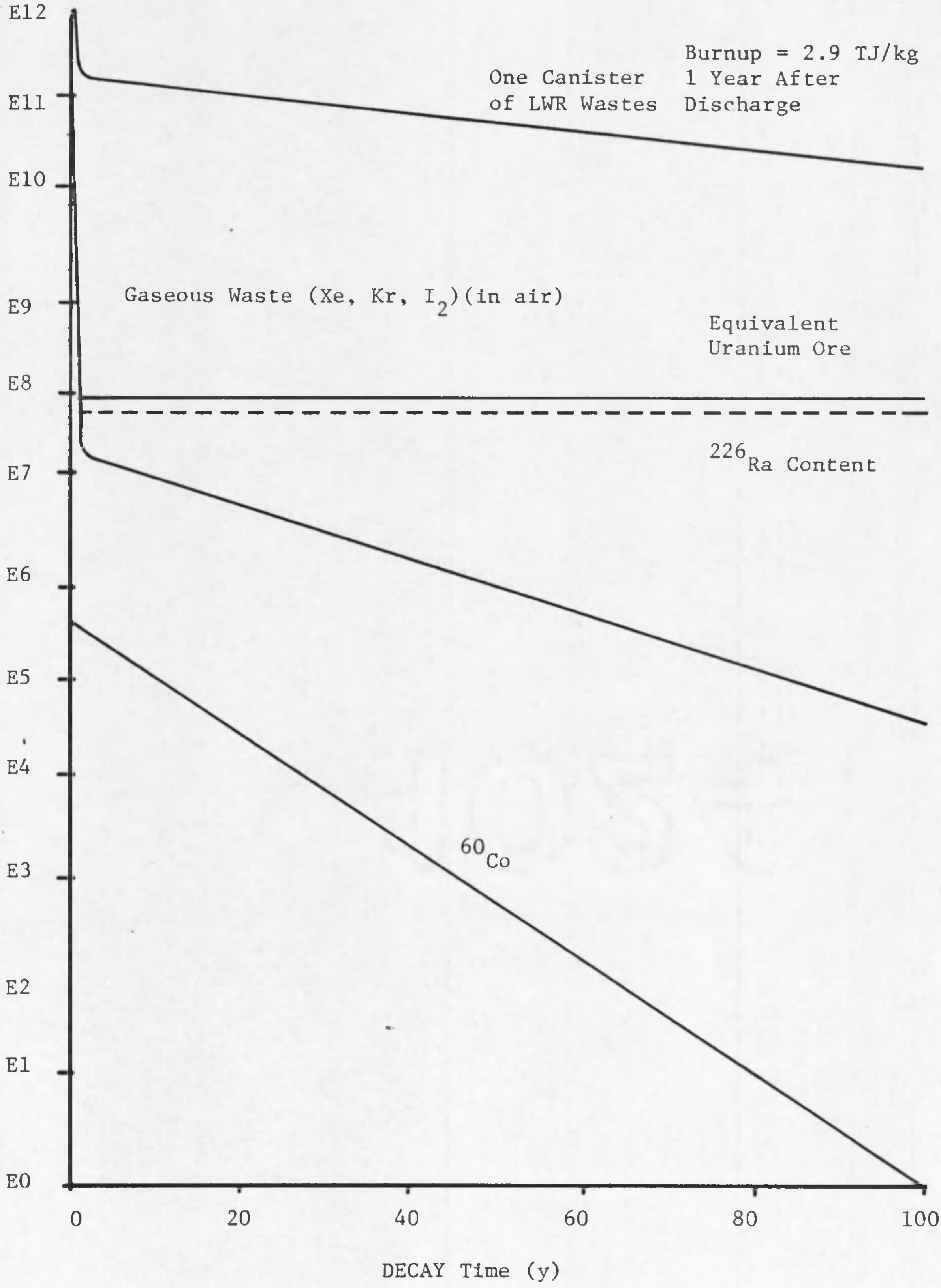


Fig. 4. Aging of Hazard Index[7]

Table IV

Gaseous Release from PWR

		Bq.		
Element	0 sec	1 day	1 month	1 year
Xe	3.08×10^{14}	8.08×10^{13}	1.12×10^{12}	4.86×10^{2}
Kr	2.04×10^{14}	4.58×10^{11}	1.20×10^{11}	1.13×10^{11}
I	3.61×10^{14}	8.95×10^{13}	2.06×10^{12}	3.08×10^{5}
		Ci		
Xe	8.33×10^{3}	2.17×10^{3}	3.02×10^{1}	1.31×10^{-8}
Kr	3.91×10^{3}	12.4	3.25	3.05
I	9.75×10^{3}	2.42×10^{3}	5.57×10^{1}	8.3×10^{-6}
		Hazard Index		
Xe	8.33×10^{10}	2.17×10^{10}	3.02×10^{8}	1.31×10^{-1}
Kr	3.77×10^{10}	1.21×10^{9}	3.25×10^{7}	3.05×10^{7}
I	7.67×10^{9}	3.17×10^{9}	1.86×10^{8}	1.38×10^{2}

reasonable to retain the material in the plant until it has decayed to innocuous levels. Large quantities of material of a short half-life would rapidly become innocuous but for material with longer half-life, small quantities could be easily stored until the material reached innocuous levels. The best compromise between costs of storage in plant and at a commercial repository at this time appears to be material that could be stored for five years. The second group, subcategory b, is material that has a short enough half-life so that it presents no significant long term hazard but which would require just a minimum control so that it does not become accidentally dispersed. This would include material that would require about 20 years to be reduced to an innocuous level. The third class, subcategory c, is material that has a longer time before it would reach innocuous levels and it might require some special consideration in a commercial repository such as containing it in a vault, in concrete or other means. It should be emphasized that the delineation between these two categories will depend on policy of the Nuclear Regulatory Commission which has not yet been defined. So, in a sense, the specification of these categories implies a recommendation for a policy and is in that regard, presumptious. The maximum time that would be allowable would be 100 years. All material that would remain a hazard for a time greater than 100 years would be assigned to a federal repository and would fall into subcategory d. These observations are summarized in Table V.

We have indicated the greatest half-life of the isotope, the quantity of material that could be present and materials still classified in the particular categories. The next subcategories relate to the

Table V

Subcategories[6]

Symbol	Time for Hazard to Reach Category IV	Criteria	
		$t_{\frac{1}{2}}$	Maximum Quantity; HI
a	5 yrs	0 - 1 mo	1.15×10^{18}
		6 mo	1024
		1 yr	32
		5 yr	2
		HLW (LWR, 1 y old)[6]	6
		HLW (LWR, 0 old)	720
b	20 yrs	0 - 1 mo	unlimited
		6 mo	unlimited
		1 yr	10^6
		5 yr	16
		20 yr	2
		HLW (LWR, 1 y old)[6]	11
		HLW (LWR, 0 old)	1600
c	100 yrs	0 - 1 mo	unlimited
		6 mo	unlimited
		1 yr	unlimited
		5 yr	10^6
		20 yr	32
		HLW (LWR, 1 y old)[6]	83
		HLW (LWR, 0 old)	12,000
d	>100 yrs	all	unlimited

mobility of radioactive material and they are arranged in order of increasing hazard in consistency with the a,b,c,d subcategories. These additional subcategories are s for solid, m for mobile (finely divided solids), l for liquid and g for gaseous as shown in Table VI. These criteria are simply those quantities that will define that particular state of division. Other subcategory items that would be of interest are whether or not the material would require additional treatment and whether or not the material is explosive and/or fissionable.

The waste classification system then would consist of a series of symbols. The first one would denote the handling hazard, the second would denote the duration of the hazard and the third one would indicate other properties that may be of interest.

Classification Examples

As an example, we could have our most hazardous material, high level waste, in a canister ready for shipment to a waste disposal site and it would be classified

Idsn .

There are some symbols, such as e and f, which would not be used since the material is not explosive nor is it fissionable. A second example might be a ^{60}Co source such as used in radiation therapy, for example, 600 curie (^{60}Co) would be classified

IIcsn .

A third example might be the radioactive iodine, krypton, and xenon contained in gaseous effluents from a pressurized water reactor. Assume we have trapped the composition shown in Table IV. This material would be

IIag .

Table VI

Other Classification Subcategories

Symbols	Subcategory	Criteria
s	Solid	Immobile
m	Mobile	Will disperse or become airborne if container is spilled
l	Liquid	Will flow onto a flat surface from a small hole
g	Gaseous	Will mix with the atmosphere through a small hole
t	Treatment	Must be converted to another form before further processing
h	No Treatment	
e	Explosive	Not chemically stable
f	Fissile	Special nuclear materials

The use of this classification system as well as any other system that can be readily considered must depend on a knowledge of nuclear, chemical, physical and biological properties of the material. This is best categorized by identifying the particular isotopes. This should not be too difficult to do in a process situation since the plant operators will know the composition of each stream and routine analysis will verify this composition. In the event unknown material is involved, an analysis would be required and it would certainly be in order in any event. If the material is harmless, most radiation levels can be shown to be minimal or acceptable.

CHAPTER 6

APPLICATIONS OF THE PROPOSED COMPREHENSIVE CLASSIFICATION SYSTEM

Waste Disposal Decision

The seemingly cumbersome decision of radioactive waste final disposition is rendered simple by use of the proposed waste classification system. The disposition decision will determine the safe control of the particular radioactive waste now and in the future. Since the classification system is based on hazards to be controlled, classification of a material results in a disposal designation in all cases. This result hinges of course on the existence of standard governmental policy regarding the necessity to isolate a material with a specified lifetime of a, b, c, or d. Assuming this policy has been established the disposal decision can be accurately represented by the following flowchart, Fig. 5.

Respectful Responses and Implied Emergency Actions

The proposed classification system must generate a respectful response from operations personnel during handling, processing, or transportation. At the same time, the classification system must inform personnel of immediate emergency actions required during abnormal circumstances. Tables VII and VIII illustrate these functions of the classification system:

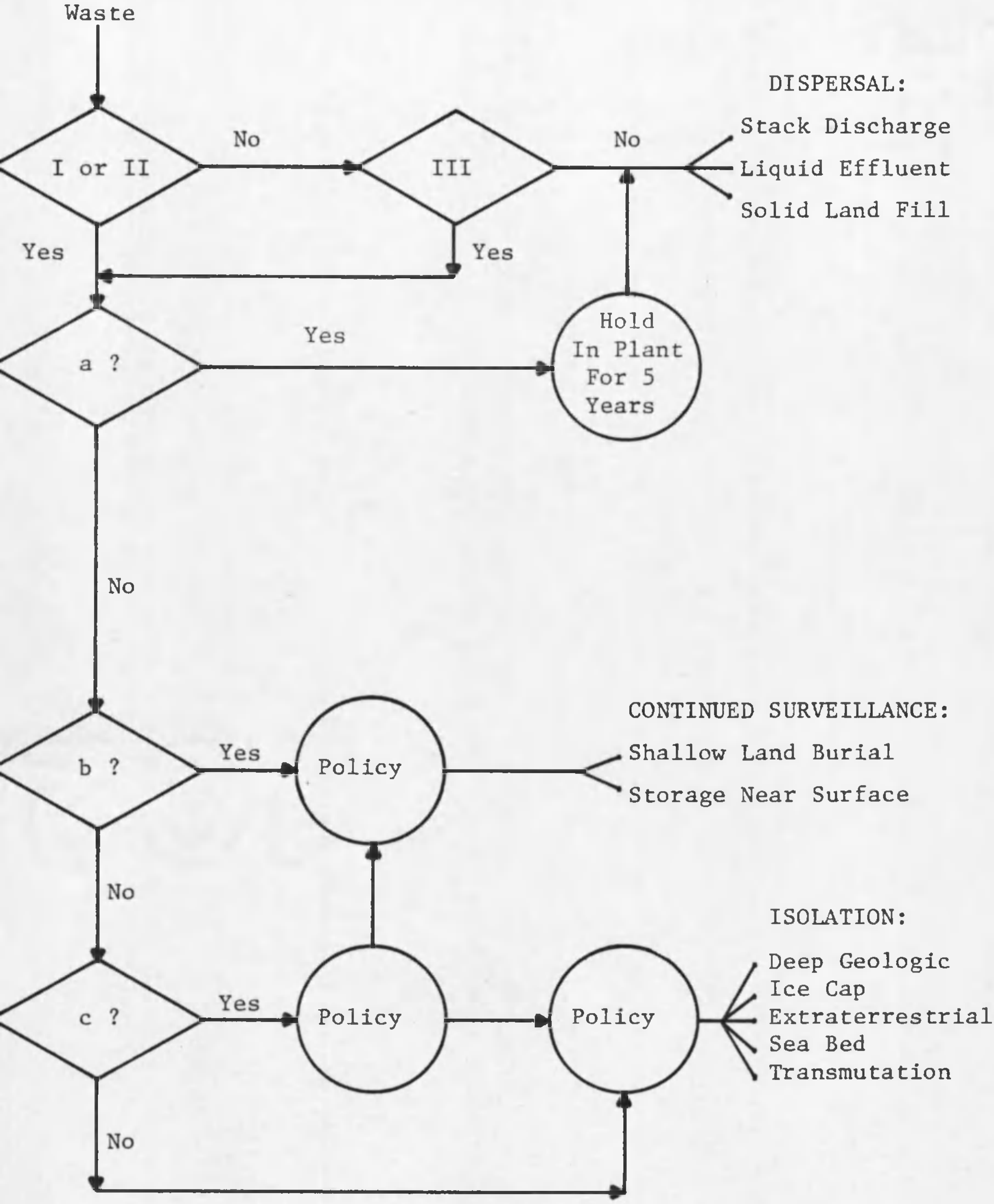


Fig. 5. Final Disposition Decision Flowchart

Table VII

Respectful Response Chart

Symbol	Respectful Response Samples
I	Highly dangerous and toxic material Cooling and shielding must be provided Time spent in close proximity to material should be for occupational purposes only Normal precautions for radiation area must be followed
II	Highly dangerous and toxic material Shielding must be provided Time spent in close proximity to material should be severely restricted Normal precautions for radiation areas must be followed
III	Toxic material Handling of container must not allow material release
s	________________________
m	Material has dispersion potential
1	Possibility of leakage or spills exists Check for leakage before handling Air monitoring devices may detect leakage

Table VII cont.

Symbol	Respectful Response Sample
g	Do not open container for any reason except when release is desired Air monitoring devices are necessary to detect leakage
e	Take any special precautions dictated by nature of materials chemical instability
f	Before handling this material all factors affecting criticality should be considered by a specialist: For example, hydrogenous materials, such as water could initiate a criticality incident.

Table VIII

Implied Emergency Action Chart

Symbol	Implied Emergency Action Samples
I	Maintain cooling during emergency Notify safety personnel of possible cooling loss and necessity to reinstate cooling if lost Control occupancy in unshielded areas If containment is breached and contents released general population hazard exists requiring possible evacuation. Cleanup will require defensive apparatus against heat, radiation, ingestion and/or inhalation
II	Control occupancy in unshielded areas If containment is breached and contents released general population hazard exists requiring possible evacuation. Cleanup will require defensive apparatus against radiation, ingestion and/or inhalation
III	If containment is breached and contents released general population hazard exists requiring possible evacuation. Cleanup will require defensive apparatus against ingestion and/or inhalation
s	A breach of containment will not produce a release hazard in a short time (< 1 week) Water may be applied to material to fight fires
m	Minimize spread of material

Table VIII cont.

Symbol	Implied Emergency Action Samples
l	If containment is breached leakage will probably occur and may be stopped by use of absorbents (rags)
g	If containment is breached leakage will occur. Evacuation will probably be necessary except for personnel wearing breathing apparatus
e	Take measures required to minimize explosive nature of material; fire may result in explosion
f	Monitor radiation levels to detect criticality; before handling material or containers have situation evaluated by criticality specialist

Safety and Efficiency

Federal regulation (except where already noted) require labeling of "CAUTION, RADIOACTIVE MATERIAL" together with other information such as activity levels, mass enrichment, radiation levels, and dates considered appropriate to minimize exposure (Appendix A). The broad scope of these regulations permit wide variations in the information contained on these labels. Such variation from package to package make it difficult for regulatory inspectors and operations to recognize and comprehend the implications of particular labels readily. This is especially true in and around process plants where numerous and varied types of radioactive materials are stored. As a participant in regulatory inspections for ERDA at fuel fabrication, scrap recovery, and reactor plants I often had to study labels very carefully to ascertain whether a certain container was stored or handled in the appropriate fashion. The standardized, hazard oriented, classification and labeling system proposed herein would have made my job significantly easier. For the operator or stevedore who must do his job quickly and efficiently and who would like to handle material before taking time to ponder terms like 2 rem/hr at surface, 1.25 (enrichment, or plutonium scrap the proposed system could be a life saver as well as a time saver.

Public Relations

Lastly, during the past several years public opposition to nuclear power has grown to considerable proportions. Nuclear critics have encouraged much of this opposition by conjecturing about the dangers of nuclear wastes. The nuclear industry has had difficulty quelling public fears because of a lack of government decisiveness on waste disposal and because of a general failure to educate the people as to the true nature of the nuclear waste problem. The task of regulating the nuclear industry can no longer be accomplished with public acceptance unless communication exists between the public and the nuclear community. Regulators can help, in the necessary translation into lay terms of nuclear waste issues, by adoption of a classification system that communicates and identifies the real nuclear waste hazards.

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

The proposed radioactive waste classification system provides for ready classification of all hazardous radioactive materials. Class I materials are those that may release radioactivity by selfheating. Class II materials present an extreme present time penetrating radiation hazard. Class III materials may cause biological damage from ingestion, inhalation, or other internal means but not from penetrating radiation. Minor categories delineate the other factors and properties of concern and include duration of biological hazard, material mobility if released fissionable or explosive characteristics, and the necessity of further material treatment. Therefore, the system classification relates the characteristics of the radioactive materials to the hazards which must be controlled and permits changes in the classification of a material whose hazard has changed. This hazard concept of classification will not become obsolete with the advent of new government regulation and policy or with the new technology.

If the proposed system is finally adopted, it will provide the following benefits to the nuclear industry:

1. The system allows for regulatory decisions to be made about nuclear waste because the characteristics critical to these decisions are also critical to the classification system.
2. The system promotes safe handling of nuclear materials by

clearly communicating handling requirements as well as providing information critical to successful emergency operations.

3. The system allows for clearer communications between the nuclear community and the public about nuclear waste issues.

The numbers assigned in this study for boundary criteria are recommended but are not essential to the system's design. Before adoption of the proposed classification system, the Nuclear Regulatory Commission should sponsor studies which will verify practical, definitive, and measurable boundaries between the waste categories. After such studies are completed, the classification system should be adopted on a trial basis to insure system compatibility with regulators and industry.

APPENDIX A

FEDERAL LABELING REQUIREMENTS[7]

CAUTION[1]
RADIOACTIVE MATERIAL(S)

(f) *Containers.* (1) Except as provided in subparagraph (3) of this paragraph, each container of licensed material shall bear a durable, clearly visible label identifying the radioactive contents.

(2) A label required pursuant to subparagraph (1) of this paragraph shall bear the radiation caution symbol and the words "CAUTION, RADIOACTIVE MATERIAL" or "DANGER, RADIOACTIVE MATERIAL". It shall also provide sufficient information[1] to permit individuals handling or using the containers, or working in the vicinity thereof, to take precautions to avoid or minimize exposures.

(3) Notwithstanding the provisions of subparagraph (1) of this paragraph, labeling is not required:

(i) For containers that do not contain licensed materials in quantities greater than the applicable quantities listed in Appendix C of this part.

(ii) For containers containing only natural uranium or thorium in quantities no greater than 10 times the applicable quantities listed in Appendix C of this part.

(iii) For containers that do not contain licensed materials in concentrations greater than the applicable concentrations listed in Column 2, Table I, Appendix B of this part.

(iv) For containers when they are attended by an individual who takes the precautions necessary to prevent the exposure of any individual to radiation or radioactive materials in excess of the limits established by the regulations in this part.

(v) For containers when they are in transport and packaged and labeled in accordance with regulations of the Department of Transportation .

(vi) For containers which are accessible[2] only to individuals authorized to handle or use them, or to work in the vicinity thereof, provided that the contents are identified to such individuals by a readily available written record.

(vii) For manufacturing or process equipment, such as nuclear reactors, reactor components, piping, and tanks.

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[1] As appropriate, the information will include radiation levels, kinds of material, estimate of activity, date for which activity is estimated, mass enrichment, etc.

APPENDIX B

TECHNICAL BASIS AND PHYSICAL MEASUREMENT TECHNIQUES FOR 400 W/m^2

Technical Basis

The International Atomic Energy Agency suggested that for packages with a surface heat flux of 400-500 W/m^2 over their exposed surfaces, it is anticipated that there will be no real difficulty ensuring package heat dissipation.[9] This assumes the use of no special mechanical cooling configurations. The numbers suggested by the IAEA came from a British article by A. J. Brook and F. E. Dixon.[10] The numbers were presented and developed as follows:

> Although the conditions to ensure effective heat dissipation from packages which, on heat transfer grounds, require to be carried as a "full-load" should always be subject to approval by a heat transfer specialist, nevertheless in order to give some indication of the amount of heat loss which may be achieved without the use of special ventilation arrangements, ancillary cooling equipment, etc., it is now proposed to give a brief indication of heat dissipation under "full-load" conditions.
>
> Under the "full-load" conditions as defined in the IAEA regulations,[11] the permitted packaging surface temperature is increased to 82°C, while maintaining the ambient of 38°C. While realizing that the assumption that this surface temperature can be uniformly attained over the entire surface would probably be an erroneous one for most designs of packages likely to be carried under "full-load" conditions, it is of interest to note that insertion of this value in the equations

$$Q_c = \frac{0.29\ \Delta T^{1.25}}{L^{0.25}} \quad \text{Vertical} - \frac{\text{BTU}}{\text{hr ft}^2}$$

$$Q_c = \frac{0.27\ \Delta T^{1.25}}{L^{0.25}} \quad \text{Horizontal}$$

L = package height or width

$$Q_r = 0.173\ 10^{-8}\ E\ [T_1^{\ 4} - T_2^{\ 4}]$$

T_1 = package temp. °R

T_2 = ambient °R

with an emissivity arbitrarily chosen as 0.8, leads to heat losses of:

Qc = 216 W/m^2 (vertically)
Qc = 200 W/m^2 (horizontally)
Qr = 300 W/m^2

On this basis the heat loss from a 1 m cube could be no more than 2564 W, i.e., fluxes of 513 W/m^2 over the exposed surface, or 428 W/m^2 over the total surface area, although under the likely practical conditions of non-uniform fluxes from the interior of the package to its surface, the amount of heat which could actually be lost would be somewhat less.

Physical Measurement Technique

In industry it may be desirable to measure the container surface heat flux values by physical means especially when the exact contents of a waste package is not known. Donald Green of the Instrument Division of Hanford Engineering Laboratory has suggested the device shown in Fig. 6 in block diagram form which could be readily developed for the heat flux measurement. The sensing area of this device can be applied to any portion of the package surface or used as a wrap around sheet.

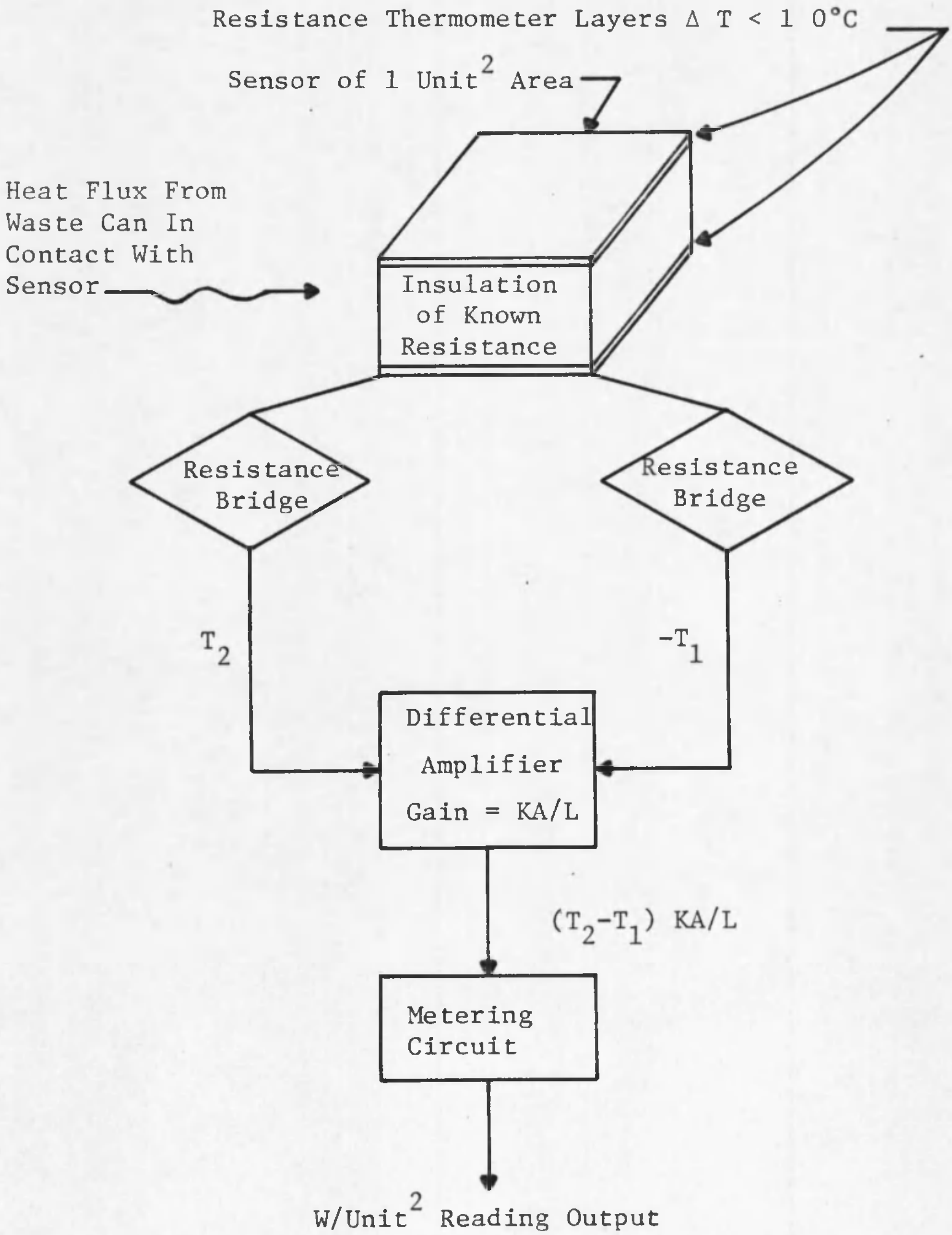

Fig. 6. Green's Heat Flux Sensor

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