JAERI-M
8592

CONCEPTS AND STRATEGIES FOR MANAGEMENT OF NUCLEAR WASTES

November 1979

Working Group for Waste Management

日本原子力研究所
Japan Atomic Energy Research Institute

Concepts and Strategies for Management of Nuclear Wastes

Working Group for Waste Management*

Japan Atomic Energy Research Institute

(Received November 9, 1979)

Management of nuclear wastes arising in the course of nuclear fuel cycles has now become an extremely important issue in respect of fully implementing nuclear energy programs. In this work, three modes of reactor strategies are chosen and discussed; (1) Once-through type light water reactor, (2) U-Pu cycle light water reactor, and (3) U-Pu cycle fast breeder reactor. The arising of wastes in each mode of nuclear fuel cycle is first estimated for unit nuclear power generation of 1 GWe·year and the amount of wastes to be managed in each year is then calculated as the point starting for solving the problems in waste management. Assuming the 2nd and the 3rd reprocessing plants are not operative, the decrease of waste arising is also estimated, which, nevertheless, claims the need for spent fuel storage pools. In addition, the arisings of decommissioning wastes are evaluated to identify their effect on waste management.

Based on above fact, a generic logic of waste management is brought about, placing major emphasis on volume reduction, barrier- and decay-effects. According to the characteristics, the wastes arisen at each stage of nuclear fuel cycle can be categorized into (1) extremely low-level waste, (2) low- and intermediate-level waste, (3) alpha-waste and (4) high-level waste, and the suitable isolation periods for the specified categories can be set by the aid of hazard index, suggesting that the disposal options may possibly be selected. The waste disposal gives environmental impacts through dispersion and migration of contained nuclides into biosphere; the dispersion and migration paths are investigated and a mathematical expression to evaluate the impacts as dose commitment is presented. A multi-barrier concept is proposed since combined artificial and natural barriers have possibility of lengthening the migration path to enable safe disposal. Finally, items of research/development in waste management are represented from the viewpoints of (1) establishment of management system, (2) safety assessment covering verfication of technology and system, and (3) regulation, giving recommendations for national policy making as well as for international co-operation.

Keywords: Radioactive Waste Management, Strategies, Fuel Cycle, Waste Arisings, Environmental Impact, Multi-Barreir Concept, Volume Reduction

* Working Group for Waste Management

Hiroshi Murata	(Chairman)	President
Hiroshi Amano	(Secretary)	Division of Environmental Safety Research
Mitsuho Hirata	(Secretary)	Office of Planning
Kunio Araki		Division of Environmental Safety Research
Toshiaki Iijima		Division of Reactor Safety Evaluation
Kazuhiko Imai		Division of Environmental Safety Research
Taro Ito		Division of Environmental Safety Research
Atsushi Kasai		Division of Environmental Safety Research
Mitsuru Koike		Office of Planning
Akira Matsumoto		Division of Health Physics
Noboru Moriyama		Division of Environmental Safety Research
Hiroshi Okashita		Division of Chemistry
Muneaki Senoo		Division of Environmental Safety Research
Yoshiki Wadachi		Division of Environmental Safety Research

放射性廃棄物処理処分に関する基本概念と戦略

日本原子力研究所
廃棄物処理処分基本概念および戦略検討グループ

（1979年11月9日受理）

原子力の開発に関連して，核燃料サイクルの各施設で発生する放射性廃棄物の処理処分が重要な課題となっている。本報告は核燃料サイクルとして，(i)軽水炉(Once-through)，(ii)軽水炉（U－Pu），(iii)高速増殖炉（U－Pu）の三つのサイクルを取り上げ，1GW(e)・年の発電量を単位とした放射性廃棄物の発生量を求め，各年度に処理処分すべき廃棄物の量を算定し，問題提起の出発点とした。これに沿って，第二および第三再処理工場の稼動の有無に伴う廃棄物の減少量および燃料貯蔵プールの必要量を見積った。更に将来実施される原子炉の解体による廃棄物の影響を調べた。

以上のことを基にして，廃棄物の処理処分に対する基本的な考え方を提案し，管理上重要な減容効果，バリアー効果，減衰効果を強調した。放射性廃棄物は，その特性に従って4種，すなわち(i)極低レベル廃棄物，(ii)低中レベル廃棄物，(iii)高レベル廃棄物，(iv) α廃棄物に分類し得ることから，Hazard Indexを目安にとれば必然的に必要隔離期間が定まり，対応して可能性のある処分法が示唆される。処分後の廃棄物が人類に与える影響を評価するため，廃棄物中に含まれた放射性核種の環境への移行過程を調べ，その影響の大きさを線量預託として数式的に評価する方法を開発した。天然および人工バリアーが放射性核種の移行を阻止することから，安全な処分を行うには多重バリアーの概念が必要であることを提案した。これらの概念に従って，今後開発すべき項目を，(i)管理体系の実現に係ること，(ii)安全評価に係ること，(iii)制度，規制に係ることの各観点からまとめ，わが国のとるべき方向，政策に対して国際協力を含めて提言を行った。

廃棄物処理処分基本概念および戦略検討グループ

座長	村田　浩	（理事長）
主査	天野　恕	（環境安全研究部）
主査	平田実穂	（企画室）
	荒木邦夫	（環境安全研究部）
	飯島敏哲	（安全解析部）
	今井和彦	（環境安全研究部）
	伊藤太郎	（　〃　）

笠　井　　篤（環境安全研究部）
小　池　　満（企　画　室）
松　元　　章（保健物理部）
森　山　　昇（環境安全研究部）
岡　下　　宏（原子炉化学部）
妹　尾　宗　明（環境安全研究部）
和　達　嘉　樹（　　〃　　）

CONTENTS

目　　次

LIST OF TABLES

LIST OF FIGURES

CONDUCT OF THE STUDY

Policy making of or accommodation with management of nuclear wastes has always high priority being as the most serious task in connection with the promotion of practices for implementing nuclear energy programmes.

Over fifteen years, in fact, JAERI has conducted the studies of radiation and environmental protection associated with safety engineering RD&D work of nuclear fuel cycle facilities as well as joint studies and experiments in close co-operation between institutions on most aspects of nuclear waste management.

As a draw up to the contribution on the policy making and accomodation in Japan, JAERI has set forth an Expert Group directed by the president of the Institute at the end of early spring in 1979 to discuss the nuclear waste management issues and to assess technical measures for presenting recommendations on the general practices and strategies to be adopted, particularly with regard to the management on treatment and disposal of high-level and alpha-bearing wastes.

During the work of its task on the Group, it was able to take into account the latest study of the International Nuclear Fuel Cycle Evaluation.

The composition and expertise of the Group was as follows:

Dr. H. Murata	(Chairman)	President
Dr. H. Amano	(Secretary)	Division of Environmental Safety Research
Dr. K. Araki		Division of Environmental Safety Research
Dr. M. Hirata	(Secretary)	Office of Planning
Mr. T. Iijima		Division of Reactor Safety Evaluation

Mr. K. Imai	Division of Environmental Safety Research
Mr. T. Ito	Division of Environmental Safety Research
Mr. A. Kasai	Division of Environmental Safety Research
Dr. M. Koike	Office of Planning
Mr. A. Matsumoto	Division of Health Physics
Mr. N. Moriyama	Division of Environmental Safety Research
Dr. H. Okashita	Division of Chemistry
Dr. M. Senoo	Division of Environmental Safety Research
Dr. Y. Wadachi	Division Of Environmental Safety Research

The Expert Group wishes to express deeply its appreciation for their assistance to Mr. M. Mizuno, Div. of Technical Information, and Messrs. S. Dojiri and H. Matsuzuru, Div. of Environmental Safety Research in compiling and evaluating the technical material necessary.

The Group also wishes to express its appreciation for their assistance on the consultative basis to Mr. N. Amano, Director, Dr. S. Suguri, Deputy Director of Tokai Research Establishment, and Dr. S. Nomura, Head, Office of Planning, JAERI.

1. INTRODUCTION

1. Energy crisis in the coming 1980s gives far greater encouragement upon many nations of the world to even more promote the development of alternative energy technologies. It has been in the widely held recognition that, in the light of indigenous environmental characteristics of Japan, an urgent necessity focuses on the furtherance of electric generating capacity by nuclear power with LWRs and the establishment of whole nuclear fuel cycle facilities as well.

2. Despite considerable efforts, the projected expansion of nuclear capacity seems in reality not to be achieved as expected because of some constraints including site acquirement. To improve the situation, it is imperative that the nation-wide consensus should be obtained in promoting the development and utilization of nuclear energy by making perpetual efforts for higher assurance of the safety and integrity of nuclear reactors and fuel cycle facilities.

3. The incident happened at the end of March 1979 at the Three Mile Island Power Station in Pennsylvania of the United States, was the largest unforeseen occurrence experienced in commercial nuclear facilities. The risk of which has fortunately been abating without giving any serious impact upon environment such as significant radiation exposure to ambient inhabitants, however, it still gives a warning to every and all concerned in the world of the importance of assuring the safety of nuclear facilities.

4. Learning lessons from the TMI incident, the necessary counterplans for safety assurance have been intensively conducted not only in the involved organizations of Japan but also in the other major industrialized countries including the United States. In addition, international nuclear-related organizations, for instance, IAEA and OECD-NEA, are now going ahead with a number of cooperative programmes for various counterplans viewing from the international standpoint.

5. In respect of the peaceful utilization of nuclear energy such as nuclear electric generation, what should contribute to maintain sound development of it in future depends not only upon safety and reliability assurance of nuclear facilities but also prompt set-up of adequate counterplans from long-term political and technological viewpoints to meet the requirements in managing radioactive wastes produced in the course of nuclear energy utilization.

6. From its early stages, noting the implications of waste management, the importance of this issue has long been voiced from among scientists, engineers and others concerned all over the world. In fact, RD&D programmes for treatment and disposal technologies of radioactive wastes have been advanced; some have already been implemented, while some other programmes are now very close to practicalization. Nevertheless, as observed in the Republic of Federal Germany, the issue may grow to become a grave societal and political concern resulting in deferring all new construction programmes of nuclear power plant until it is resolved at last. Eventually, it constitutes a serious obstacle to carry out the energy policy directed to be free from too heavy dependence on oil resource.

7. Nuclear wastes can be classificd according to their radiation levels and physical states. The more the nuclear fuel cycle consolidated, the more radioactive wastes arose, in particular it would be even so in long-lived alpha nuclides. In order to fully protect our living environment from such qualitative and quantitative increase of various nuclear wastes apparently anticipated hereafter, not merely the strengthening of countermeasures for treatment and disposal of specific wastes should be promoted, but also a prudent strategy for waste management be establised viewing from a comprehensive and long-term standpoint. With advancing necessary and appropriate RD&D based on the established strategy, a policy capable of obtaining the most difficult national consensus should then be set forth.

8. Crucial points of the strategy are summarized as follows:

i) Readjust the necessary tasks of research and development upon time evolution such as short-, medium- and long-term.

ii) Evaluate the artificial- and natural-barriers including time-duration barrier by means of accurate and rational techniques.

iii) Upgrade and standardize the art of environmental monitoring.

iv) Design a system engineering approach to establish safety standards.

Although not a small number of RD&D exercises has been done so far, a comprehensive strategy in the respect of nation-wide consensus has not always appeared to be sufficient.

2. OVERVIEW AND SUMMARY

2.1 Nuclear Fuel Cycles and Radioactive Wastes

a. Comparison of three fuel cycles

9. As a fundamental factor for the study on the problems of waste management, the arising of wastes at each step in various modes of nuclear fuel cycles should first be estimated.

10. From among several methods on this type of study, the equilibrium nuclear fuel cycle method is adopted for present work in which; the assumed steady state over an indefinite period of time is maintained, the mass flow quantities are kept in the constant values, and the amounts of wastes can be derived from those values. It must also be pointed out that this method is effective to identify the sensitive points due to changes in technologies and/or working conditions.

11. Three modes of reactor strategies are selected for references: (i) Light water reactor with once through mode, (ii) Light water reactor with U-Pu cycle mode, and (iii) Fast breeder reactor with U-Pu cycle mode. The amounts of waste from each step of cycles are given as the number of packages assuming the suitable treatment methods respectively. For light water reactors, the ratio of BWR and PWR is assumed to be 1 to 1. The details of these assumptions are shown in Table 1, and the results of estimations for the three fuel cycles are summarized and illustrated in Figs. 1, 2 and 3.

12. As seen from the figures,

- (i) the amount of milling waste in the light water reactor with once through mode is largest among three fuel cycles,
- (ii) the total number of packages in the fast breeder reactor with U-Pu cycle mode is smallest, and those of the other two cycles do not differ significantly,

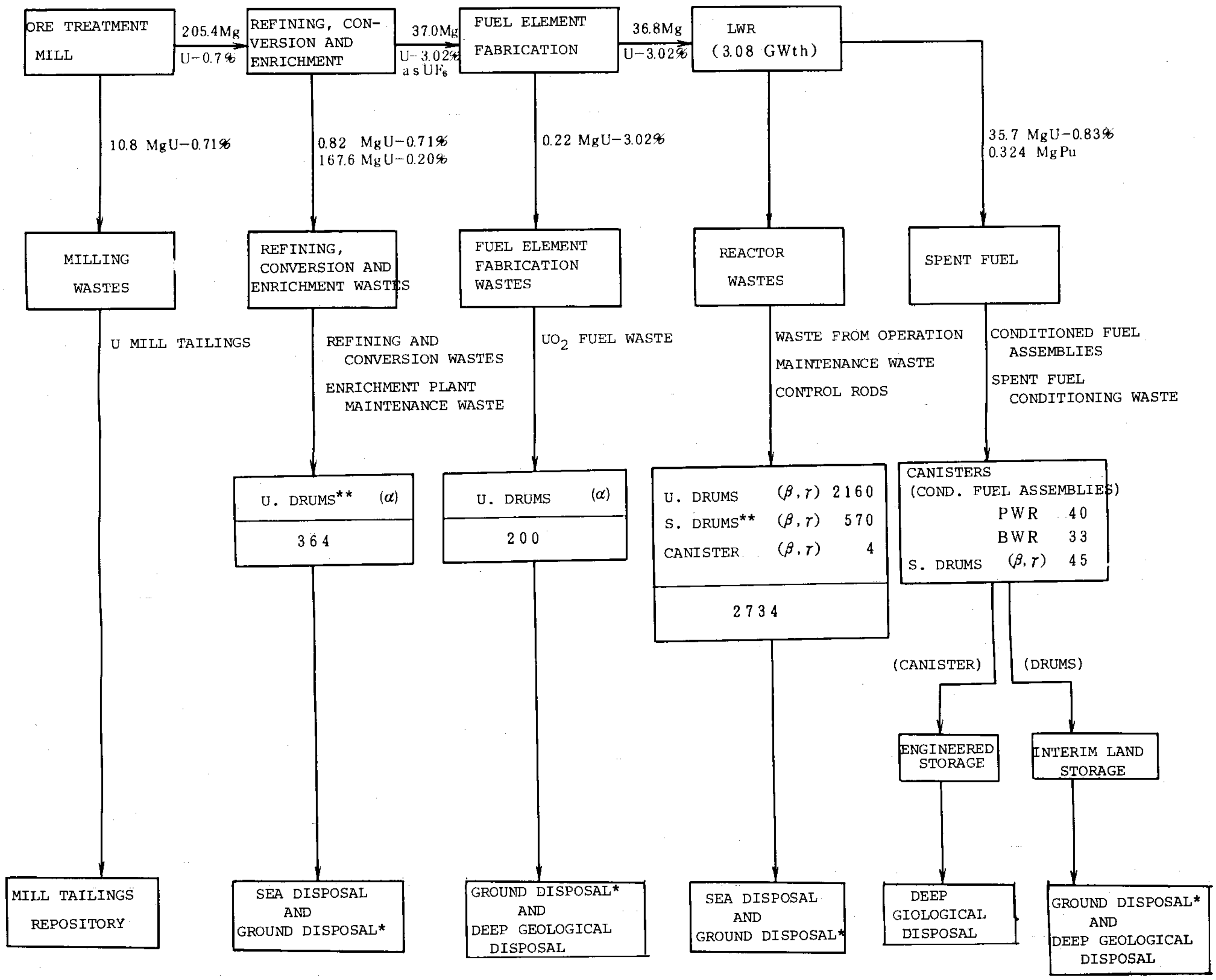
Table 1 ASSUMPTION IN ESTIMATING THE QUANTITIES OF WASTE PRODUCED

1. It is assumed that each fuel cycle is in the steay state over an indefinite period of time. Total fuel mass flow through the fuel cycle per Gigawatt year (GWe-Year) is first obtained and on the basis of this mass flow quantities of waste arised in each step of the fuel cycle are calculated
2. Quantities of waste arised are shown as the number of packages assuming some treating methods. Specification of the container is as follows.

IDENTIFICATION	INNER DIAMETER(CM)	HEIGHT (CM)	MATERIALS	WALL THICKNESS(CM)	VOLUME(M^3)
UNSHIELDED DRUM	VALIABLE		CARBON STEEL	0.16	0.20
SHIELDED DRUM	VARIABLE		CARBON STEEL CONCRETE	0.16 20	0.20
CANISTER(β,γ)	32-41	490	STEEL	1.3	0.4-0.6
CANISTER(HULL)	86	115	STEEL	2.5	0.6
CANISTER(HLW)	20	300	STAINLESS STEEL	1.0	0.077
GAS FLASK			STEEL		0.05

3. In the light water reactor, the ratios of BWR and PWR is assumed to be 1 to 1.
4. In U-Pu cycle,
   (1) Enrichment tailings from U-enrichment process are to be used in blanket of FBR.
   (2) 0.45% depleted uranium from reprocessing process is recycled to enrichment process.

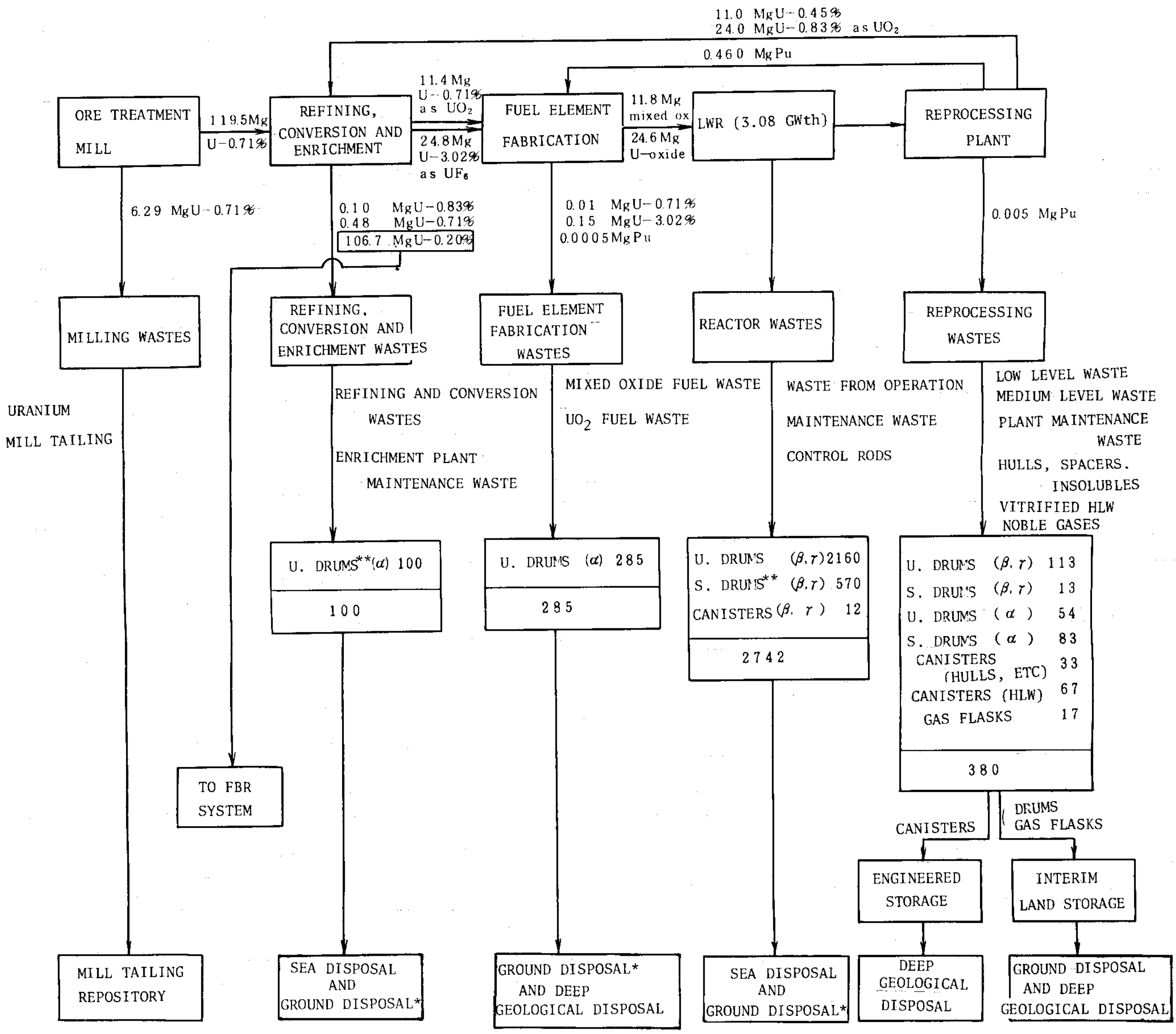
Fig. 1 LIGHT WATER REACTOR ONCE-THROUGH
HEAVY ELEMENT FLOW SHEET PER GIGAWATTYEAR ELECTRICITY
AND WASTE MANAGEMENT LOGISTICS



* LAND STORAGE AND SHALLOW LAND DISPOSAL INCLUDED
** U. DRUMS: UNSHIELDED DRUMS, S. DRUMS: SHIELDED DRUMS

(AFTER INFCE WG.7 DOCUMENT)

Fig. 2 LIGHT WATER REACTOR WITH U-Pu-CYCLE
HEAVY ELEMENT FLOW SHEET PER GIGAWATTYEAR ELECTICITY
AND WASTE MANAGEMENT LOGISTICS



* LAND STORAGE AND SHALLOW LAND DISPOSAL INCLUDED.

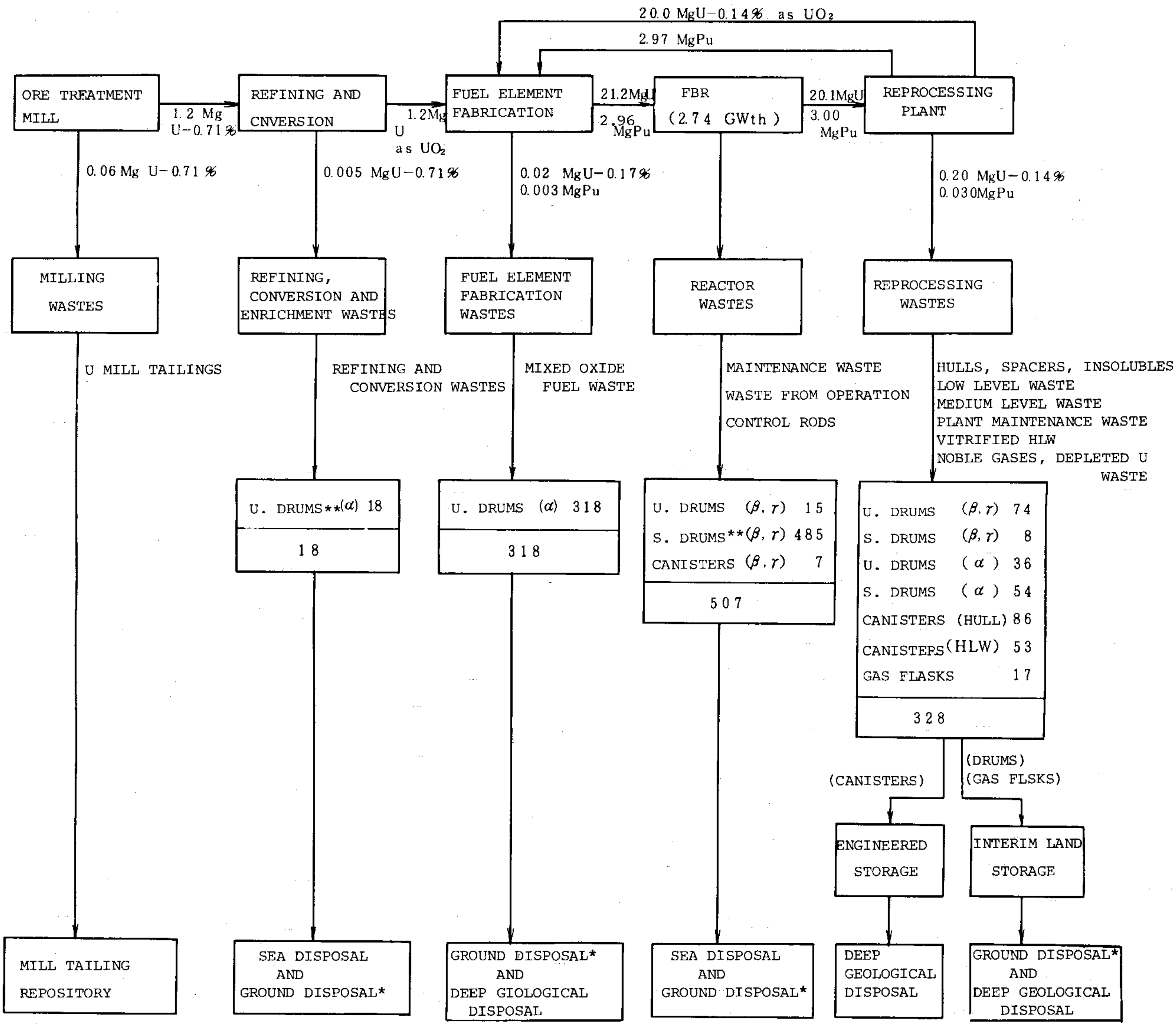
** U. DRUMS: UNSHIELDED DRUMS, S. DRUMS: SHIELDED DRUMS

(AFTER INFCE WG.7 DOCUMENT)

Fig. 3 FAST BREEDER REACTOR WITH U-Pu-CYCLE

HEAVY ELEMENT FLOW SHEET PER GIGAWATTYEAR ELECTRICITY

AND WASTE MANAGEMENT LOGISTICS



* LAND STORAGE AND SHALLOW LAND DISPOSAL INCLUDED

** S. DRUMS: SHIELDED DRUMS, U. DRUMS: UNSHIELDED DRUMS

(AFTER INFCE WG.7 DOCUMENT)

and (iii) the quantity of transuranium elements in the highly radioactive waste in the light water reactor with once through mode is largest, and the difference of hazard indices between once through and U-Pu cycle modes reaches in an order of magnitude after the standing of long duration(See Fig. 4).

b. Estimation of waste arisings in a probable nuclear electricity generating capacity plan

13. In the preceding sub-section, waste arisings are estimated with the selected reference fuel cycles normalized to 1 GWe·Year, and whole features inevitably become somewhat imaginary. It is therefore attempted to apply this methodology to a probable nuclear electricity generating plan and to identify the impacts from various options.

14. As the reference case, Japan's recent plan in line with LWR(U-Pu cycle)-FBR option is chosen(Fig. 5). The annual numbers of various wastes are shown in Table 2 together with the accumulated numbers, in which the decommissioning wastes are not counted. The yearly accumulation of waste packages is illustrated in Fig. 6. It is clear from the table and figure that the contribution of low- and intermediate level wastes is significant in affecting major impacts.

15. The necessary storage capacity for spent fuels depends largely upon the operation of reprocessing plants as shown in Fig. 7. If the reprocessing capacity is lower than the amount of spent fuels produced annually, excess spent fuels are to be stored in the facility. Therefore the amount of wastes produced in a reprocessing plant is decreased, but concurrently the amount of spent fuels stored is increased vis-a-vis depending on the reprocessing capacity as seen in Fig. 7.

16. The amount of spent fuels stored in both cases of reprocessing capacities corresponds to the package numbers given in Table 3 if they can be reprocessed by an imaginary

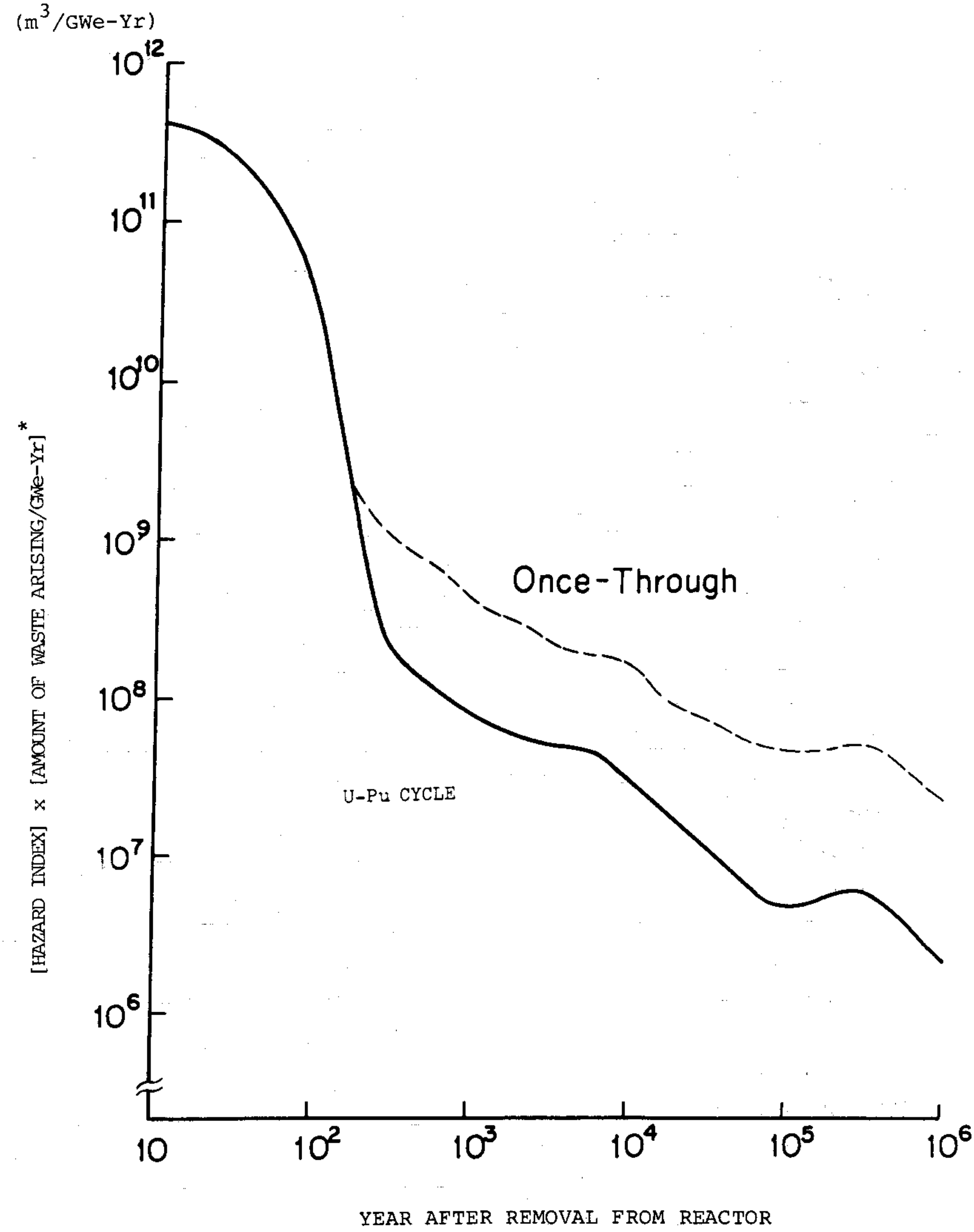


Fig. 4 HAZARD INDEX OF HIGH LEVEL WASTE IN (U-Pu AND ONCE THROUGH) FUEL CYCLE

* AMOUNTS OF WATER TO DILUTE TO A MAXIMUM PERMISSIBLE CONCENTRATION IN WATER THE HIGH-LEVEL WASTE ARISED FROM REACTOR OPERATION OF 1GWe-Yr

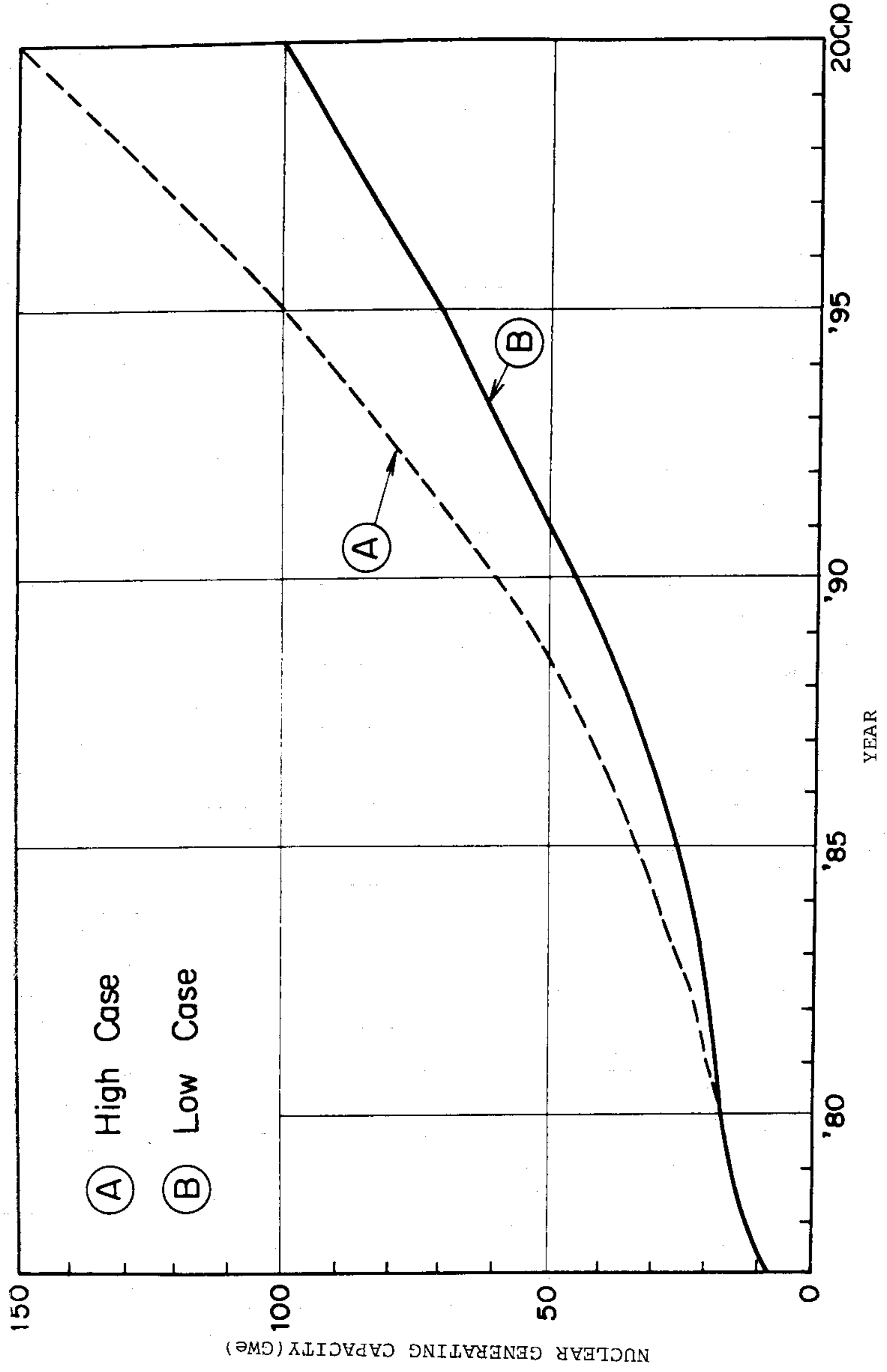


Fig. 5 ESTIMATED GROWTH OF NUCLEAR ELECTRICITY GENERATING CAPACITY IN JAPAN

Table 2 ACCUMULATION OF RADIOACTIVE WASTES GENERATED IN NUCLEAR FACILITIES

PACKAGE TYPE \ YEAR	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1995	2000
N_{GC}* (GWe)	15	17	18	19	21	23	26	29	33	36	41	45	70	100
UNSHIELDED DRUM (β, γ)	34,095	38,641 (72,736)	40,914 (113,650)	43,187 (156,837)	47,733 (204,570)	52,279 (256,849)	59,098 (315,947)	65,917 (381,864)	75,009 (456,873)	81,828 (538,701)	93,193 (631,894)	102,285 (734,179)	159,110 PS** 689,900 (1,416,079)	227,300 PS 1,000,120 (2,416,199)
SHIELDED DRUM (β, γ)	8,745	9,911 (18,656)	104,94 (29,150)	11,077 (40,227)	12,243 (52,470)	13,409 (65,879)	15,158 (81,037)	16,907 (97,944)	19,239 (117,183)	20,988 (138,171)	23,903 (162,074)	26,235 (188,309)	40,810 PS 174,900 (363,209)	58,300 PS 256,520 (619,729)
CANISTER (β, γ)	180	204 (384)	216 (600)	228 (828)	252 (1,080)	276 (1,356)	312 (1,668)	348 (2,016)	396 (2,412)	432 (2,844)	492 (3,336)	540 (3,876)	840 PS 3,600 (7,476)	1,200 PS 5,280 (12,756)
UNSHIELDED DRUM (α)	6,585	7,463 (14,048)	7,902 (21,950)	8,341 (30,291)	9,219 (39,510)	10,097 (49,607)	11,414 (61,021)	12,731 (73,752)	14,487 (88,238)	15,804 (104,042)	17,999 (122,041)	19,755 (141,796)	30,730 PS 131,700 (273,496)	43,900 PS 193,160 (466,656)
SHIELDED DRUM (α)	1,245	1,411 (2,656)	1,494 (4,150)	1,577 (5,727)	1,743 (7,470)	1,909 (9,379)	2,158 (11,537)	2,407 (13,944)	2,739 (16,683)	2,988 (19,671)	3,403 (23,074)	3,735 (26,809)	5,810 PS 24,900 (51,709)	8,300 PS 36,520 (88,229)
CANISTER (HULL)	495	561 (1,056)	594 (1,650)	627 (2,277)	693 (2,970)	759 (3,729)	858 (4,587)	957 (5,544)	1,089 (6,633)	1,188 (7,821)	1,353 (9,174)	1,485 (10,659)	2,310 PS 9,900 (20,559)	3,300 PS 14,520 (35,079)
CANISTER (HLW)	1,005	1,139 (2,144)	1,206 (3,350)	1,273 (4,623)	1,407 (6,030)	1,541 (7,571)	1,740 (9,313)	1,943 (11,256)	2,211 (13,467)	2,412 (15,879)	2,747 (18,626)	3,010 (21,641)	4,690 PS 20,100 (41,741)	6,700 PS 29,480 (71,221)
GAS FLASK	255	289 (544)	306 (850)	323 (1,173)	357 (1,530)	391 (1,921)	442 (2,363)	493 (2,856)	561 (3,417)	612 (4,029)	697 (4,726)	765 (5,491)	1,190 PS 5,100 (10,591)	1,700 PS 7,480 (18,071)

(NOTE) THE VALUE IN THE PARENTHESIS SHOWS THE ACCUMULATED ONE

* NUCLEAR GENERATING CAPACITY ** PARTIAL SUMMATION

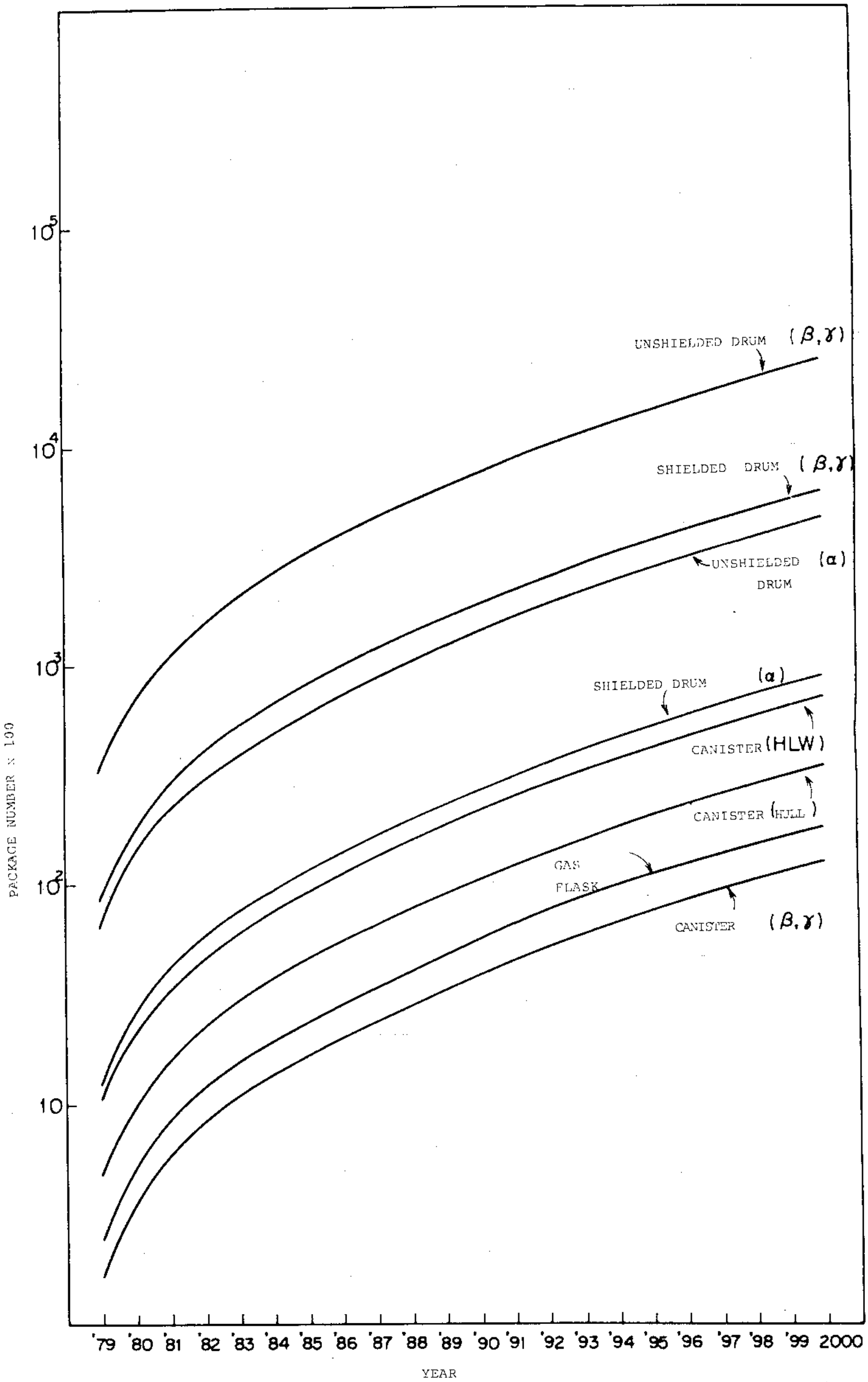


Fig. 6 ACCUMULATION OF RADIOACTIVE WASTES GENERATED IN NUCLEAR FACILITIES

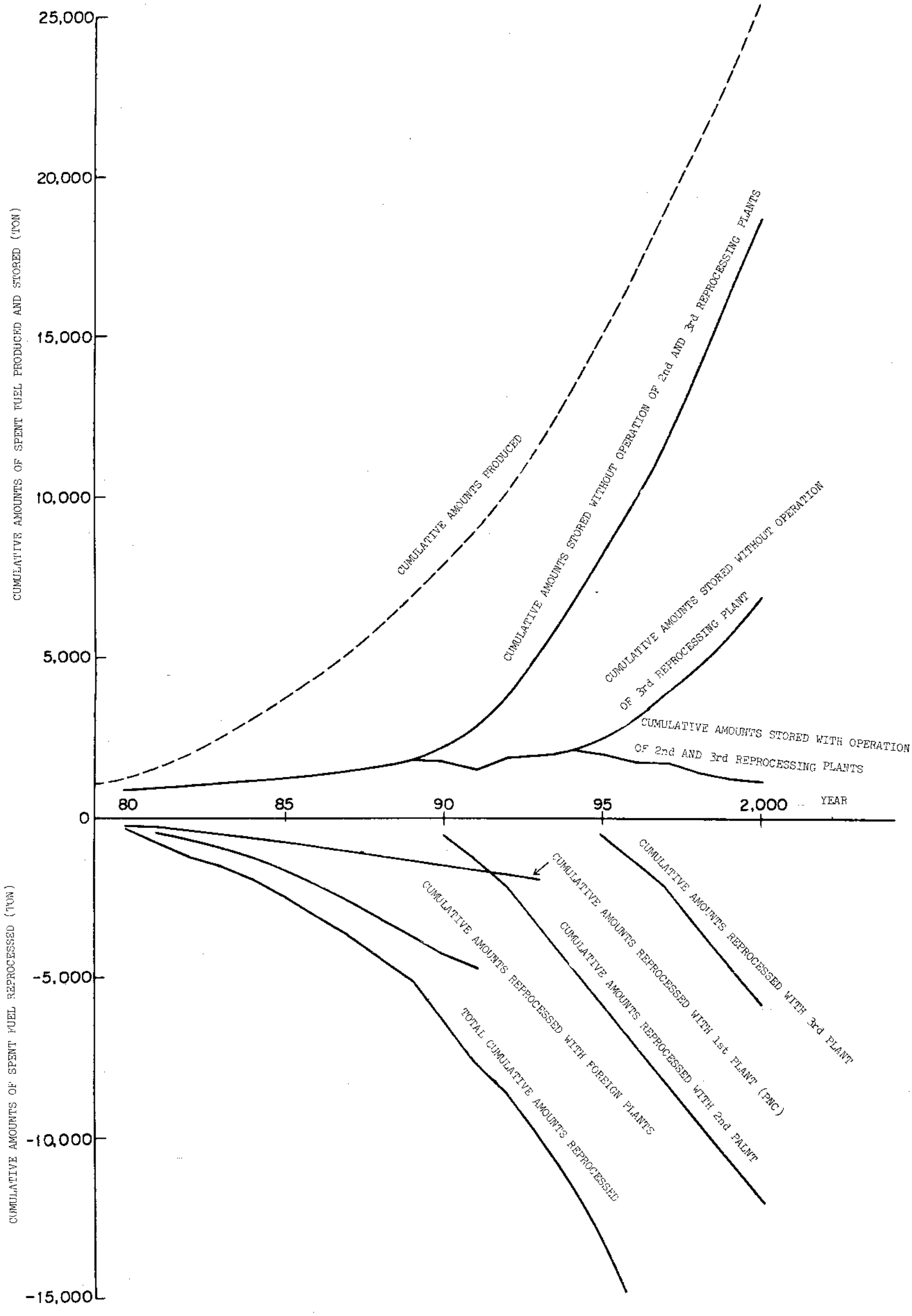


Fig. 7 ACCUMULATION OF SPENT FUEL STORED DEPENDING ON OPERATION OF FUEL REPROCESSING PLANTS

plant. The reprocessing capacity has not significant impact on the package numbers as shown in Fig. 8, because of relatively small numbers of packages from reprocessing.

17. By assuming the mission life of a reactor as 30 years, the decommissioning waste will not arise until 2005 in Japan. But in order to examine the impact from decommissioning on waste management, the arisings of decommissioning wastes are estimated as shown in Table 4 and Fig. 9. It can be seen from the table and figure that decommissiong of reactors does not affect so much on the whole figure.

2.2 Logic of Waste Management

a. Categories of wastes

18. The wastes arisen at each step of nuclear fuel cycle can be categorized into four types according to their characteristics:(i) extremely low-level waste(beta, gamma), (ii) low- and intermediate-level waste(beta, gamma), (iii) alpha-waste(alpha or alpha, gamma) and (iv) high-level waste(beta, gamma, alpha). The suitable isolation period for the respective categories can also be set suggesting the possible disposal method as shown in Fig. 10.

19. The decreasing effects of cooling time on the hazard indices for three types of wastes are given in a three-dimensional expression(Fig. 11). It should be noted that setting of deminimus level brings a large volume reduction of wastes and that decay of radionuclide leads to a desirable effect on waste management.

b. Logic of waste management

20. Even there exist the differences among the categories of wastes according to their characteristics, a generic logic or a flow diagram can be framed by distinguishing the principal points as shown in Fig. 12 .

21. In this logic, the discharge of waste, the control of waste arising(pre-treatment), the storage(tank, silo), and the engineered storage are given their seats differing

Table 3 PACKAGE NUMBER OF RADIOACTIVE WASTES CORRESPONDING TO THE AMOUNTS OF SPENT FUEL STORED

* NUCLEAR GENERATING CAPACITY

	PACKAGE TYPE \ YEAR	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
	NGC* (GWe)	15	17	18	19	21	23	26	29	33	36	41	45	51	56	62	67	70	78	84	89	95	100
PACKAGE NUMBER PRODUCED WITH OPERATIONS OF 2nd AND 3rd REPROCESSING PLANTS	UNSHIELDED DRUM (β, γ)	3,514	509 4,021	373 4,394	497 4,891	463 5,354	350 5,704	520 6,224	588 6,812	667 7,479	644 8,123	961 9,084	−192 8,892	−1,198 7,694	1,684 9,378	396 9,774	983 10,757	−780 9,977	−870 9,107	−192 8,915	−1,492 7,423	−972 6,451	294 6,745
	SHIELDED DRUM (β, γ)	404	59 463	43 506	57 563	53 616	40 656	60 716	68 784	77 861	74 935	111 1,046	−22 1,024	−138 886	194 1,080	46 1,126	113 1,239	−90 1,149	−100 1,049	−22 1,027	−172 855	−112 743	34 777
	CANISTER (β, γ)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	UNSHIELDED DRUM (α)	1,679	243 1,922	178 2,100	238 2,338	221 2,559	167 2,726	248 2,974	281 3,255	319 3,646	308 3,954	459 4,413	−92 4,321	−572 3,749	805 4,554	189 4,743	470 5,213	−373 4,840	−416 4,424	−92 4,332	−713 3,619	−464 3,155	140 3,295
	SHIELDED DRUM (α)	2,581	374 2,955	274 3,229	365 3,594	340 3,934	257 4,191	382 4,573	432 5,005	490 5,495	473 5,968	706 6,674	−141 6,533	−880 5,653	1,237 6,890	291 7,181	722 7,903	−573 7,327	−639 6,688	−141 6,547	−1,096 5,451	−714 4,737	216 4,953
	CANISTER (HULL)	1,026	149 1,175	109 1,284	145 1,429	135 1,564	102 1,666	152 1,818	172 1,990	195 2,185	188 2,373	281 2,654	−56 2,598	−350 2,248	492 2,740	116 2,856	287 3,143	−228 2,915	−254 2,661	−56 2,605	−436 2,169	−284 1,885	86 1,971
	CANISTER (HLW)	2,084	302 2,385	221 2,607	295 2,902	275 3,177	208 3,385	308 3,693	348 4,041	395 4,436	382 4,818	570 5,388	−114 5,274	−710 4,564	998 5,562	235 5,797	583 6,380	−462 5,918	−516 5,402	−114 5,288	−884 4,404	−576 3,828	174 4,002
	GAS FLASK	529	77 606	56 662	75 737	70 807	53 860	78 938	88 1,026	100 1,126	97 1,223	145 1,368	−29 1,339	−180 1,159	253 1,412	60 1,472	148 1,620	−117 1,503	−131 1,372	−29 1,343	−224 1,119	−146 973	44 1,017
PACKAGE NUMBER PRODUCED WITHOUT OPERATIONS OF 2nd AND 3rd REPROCESSING PLANTS	UNSHIELDED DRUM (β, γ)	PACKAGE NUMBER IN THIS COLUMN IS THE SAME AS THE ABOVE VALUE												2,780 11,672	5,673 17,345	6,215 23,560	6,961 30,521	7,515 38,036	8,814 46,850	9,436 56,286	10,057 66,343	10,679 77,022	11,300 88,322
	SHIELDED DRUM (β, γ)													320 1,344	653 1,997	715 2,712	801 3,513	865 4,378	1,014 5,392	1,086 6,478	1,157 7,635	1,229 8,864	1,300 10,164
	CANISTER (β, γ)													—	—	—	—	—	—	—	—	—	—
	UNSHIELDED DRUM (α)													1,328 5,649	2,711 8,360	2,970 11,330	3,326 14,656	3,591 18,247	4,212 22,459	4,509 26,968	4,806 31,774	5,103 36,877	5,400 42,277
	SHIELDED DRUM (α)													2,042 8,575	4,167 12,742	4,565 17,307	5,113 22,420	5,520 27,940	6,474 34,414	6,931 41,345	7,387 48,732	7,844 56,576	8,300 64,876
	CANISTER (HULL)													812 3,410	1,657 5,067	1,815 6,882	2,033 8,915	2,195 11,110	2,574 13,684	2,756 16,440	2,937 19,377	3,119 22,496	3,300 25,796
	CANISTER (HLW)													1,648 6,922	3,363 10,285	3,685 13,970	4,127 18,097	4,456 22,553	5,226 27,779	5,595 33,374	5,963 39,337	6,332 45,669	6,700 52,369
	GAS FLASK													418 1,757	853 2,610	935 3,545	1,047 4,592	1,131 5,723	1,326 7,049	1,420 8,469	1,513 9,982	1,607 11,589	1,700 13,289

(NOTE) THE VALUE OF THE LOWER PARTS OF EACH COLUMN SHOWS THE CUMULATIVE PACKAGE NUMBER

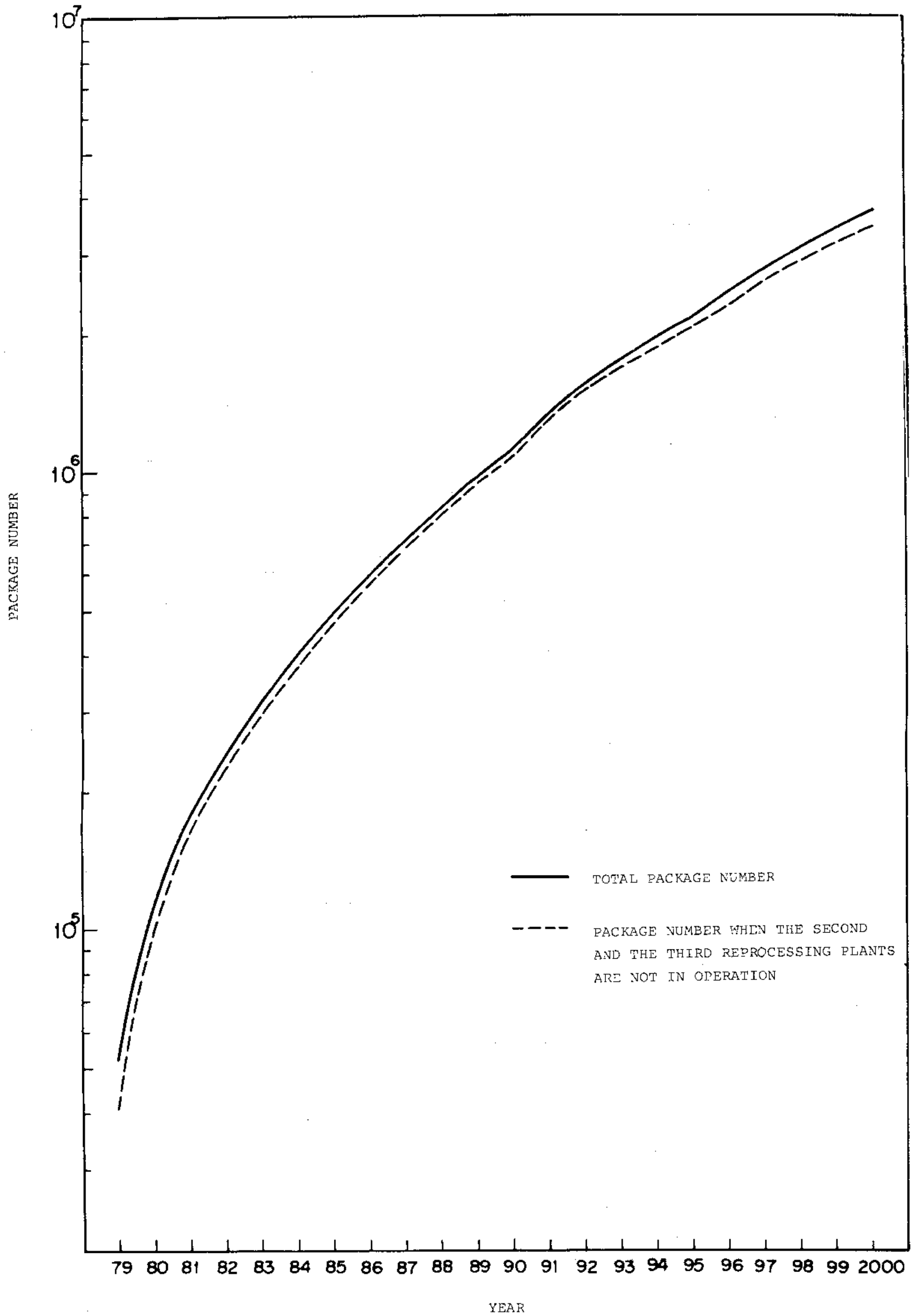


Fig. 8 DECREASE IN WASTE ARISING WITH THE STORAGE OF SPENT FUELS

[NOTE] ACCODING TO LOW ESTIMATION CASE OF NUCLEAR GENERATING CAPACITY

Table 4 DECOMMISSIONING MODE

DECOMMISSIONING MODE	PLANT, SITE USE	
1. DISMANTLEMENT	PLANT-UNRESTRICTED SITE-UNRESTRICTED	After final nuclear facility shutdown, the immediate or deferred removal from the site of all radiomaterials (including nuclear fuel), radioactive fluids and waste, and all other materials having residual radioactivity levels greater than those permitted for unrestricted use of the property. The nuclear facility owner may then have unrestricted use of the site with no requirement for a license. The remainder of the facility may be dismantled and vestiges removed and disposed of if the facility owner so desires.
(1) IMMEDIATE DISMANTLEMENT		Radioactive materials are removed and the station is disassembled and decontaminated during the four-year period following final cessation of power production operations. Upon completion, the property is released for unrestricted use.
(2) DEFERRED DISMANTLEMENT		Radioactive materials and contaminated areas are secured and structures and equipment are maintained as nesessary to assure the protection of the public from the residual radioactivity. During the period of Safe Storage, the facility remains limited to nuclear uses. Dismantlement is deferred until the radioactivity within the station has decayed to lower levels. Upon completion of dismantlement, the property is released for unrestricted use.
2. SAFE STORAGE		Those activities required to place and maintain a nuclear facility in such a condition that future risk from the facility to public safety is within acceptable bounds and that the facility can be safely stored for as long a time as desired.
(1) ENTOMBMENT OR HARDEND SAFE STORAGE	PLANT-CONDITIONAL NON-NUCLEAR SITE-CONDITIONAL NON-NUCLEAR	The comprehensive cleanup and decontamination is coupled with the construction of barriers around areas containing significant quantities of radioactivity. These barriers are of sufficient strength to make accidental intrusion impossible and deliberate intrusion extremely difficult. Surveillance requirements are limited to detection of attack upon the barriers and maintenance of the integrity of the structures.
(2) MOTHBALLING OR PASSIVE SAFE STORAGE	PLANT-NUCLEAR ONLY SITE-CONDITIONAL NON-NUCLEAR	A more comprehensive cleanup and decontamination effort is performed initially, sufficient to permit deactivation of the active protective (ventilation) systems during the continuing care period. The structures are strongly secured and electronic surveillance is provided to detect accidental or deliberate intrusion. Maintenance of the integrity of the structures is required.
(3) LAY AWAY OR CUSTODIAL SAFE STORAGE	PLANT-NUCLEAR ONLY SITE-NUCLEAR ONLY	A minimum cleanup and decontamination effort is made initially, followed by a period of continuing care with the active protection systems (principally the ventilation system) kept in service throughout the storage period. Full time onsite surveillance by security forces is required to prevent accidental or deliberate intrusion into the facility and the subsequent exposure to radiation or the dispersal of radioactivity beyond the confines of the facility.

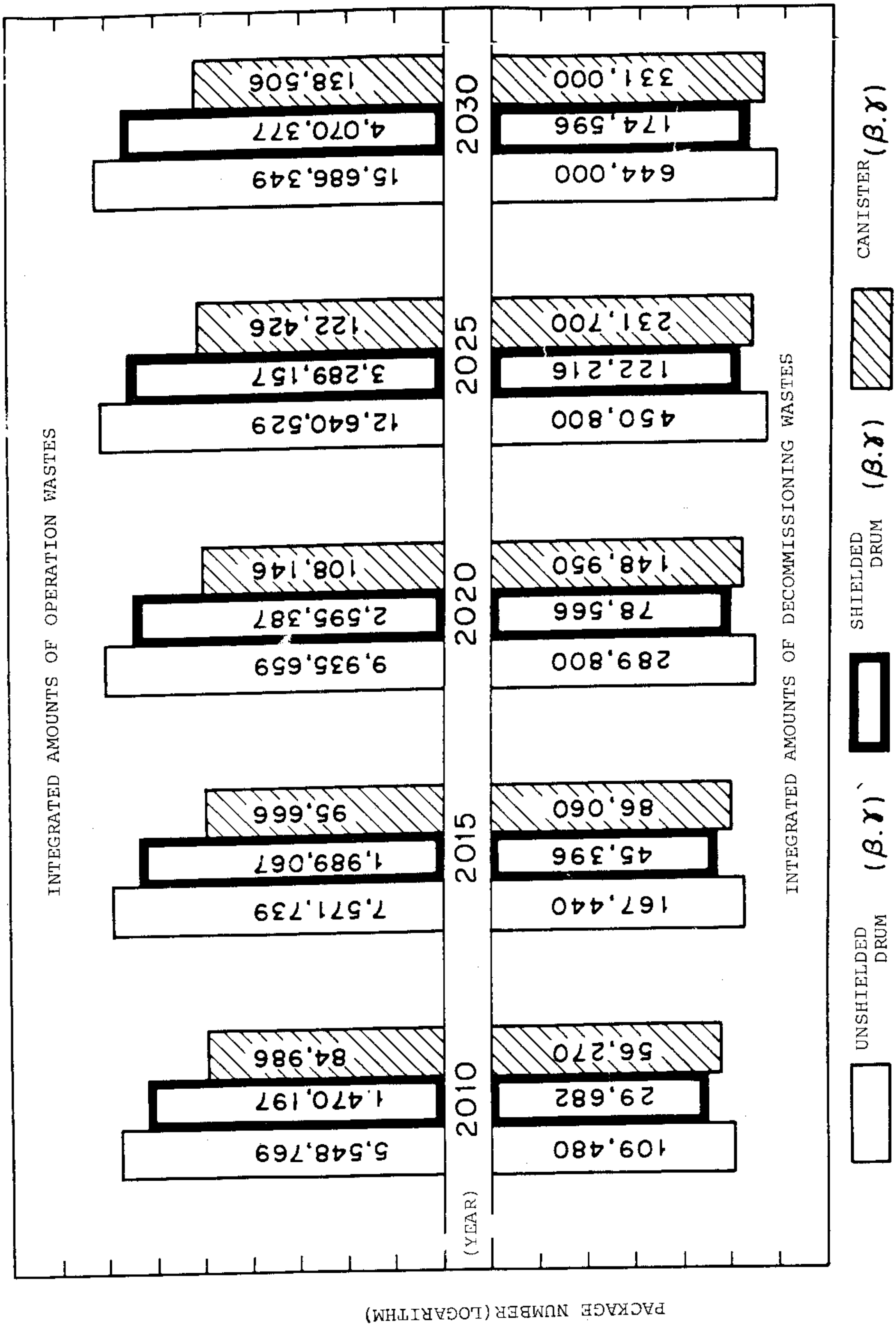


Fig. 9 COMPARISION OF INTEGRATED AMOUNTS OF WASTE GENERATED FROM OPERATION AND DECOMMISSIONING

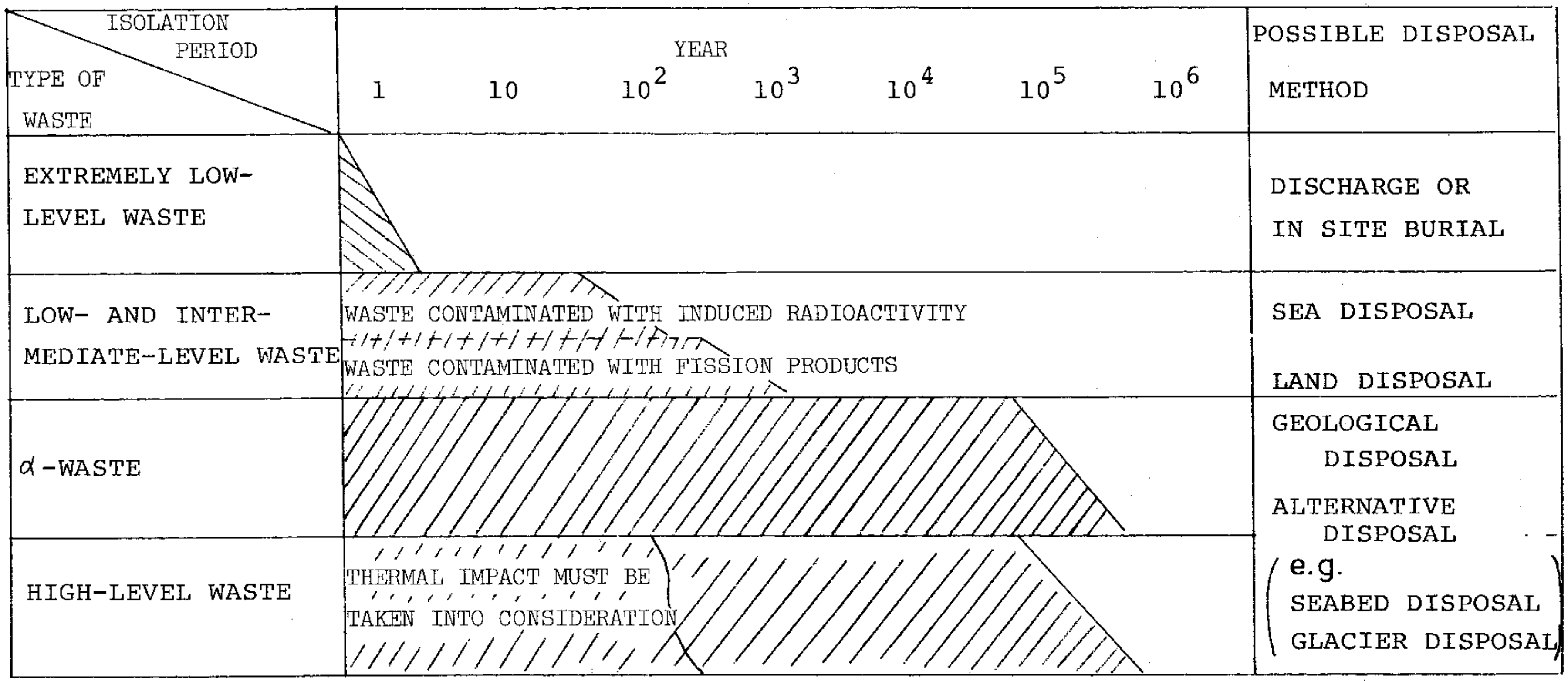


Fig. 10 CATEGORY AND THEIR SUITABLE ISOLATION PERIOD

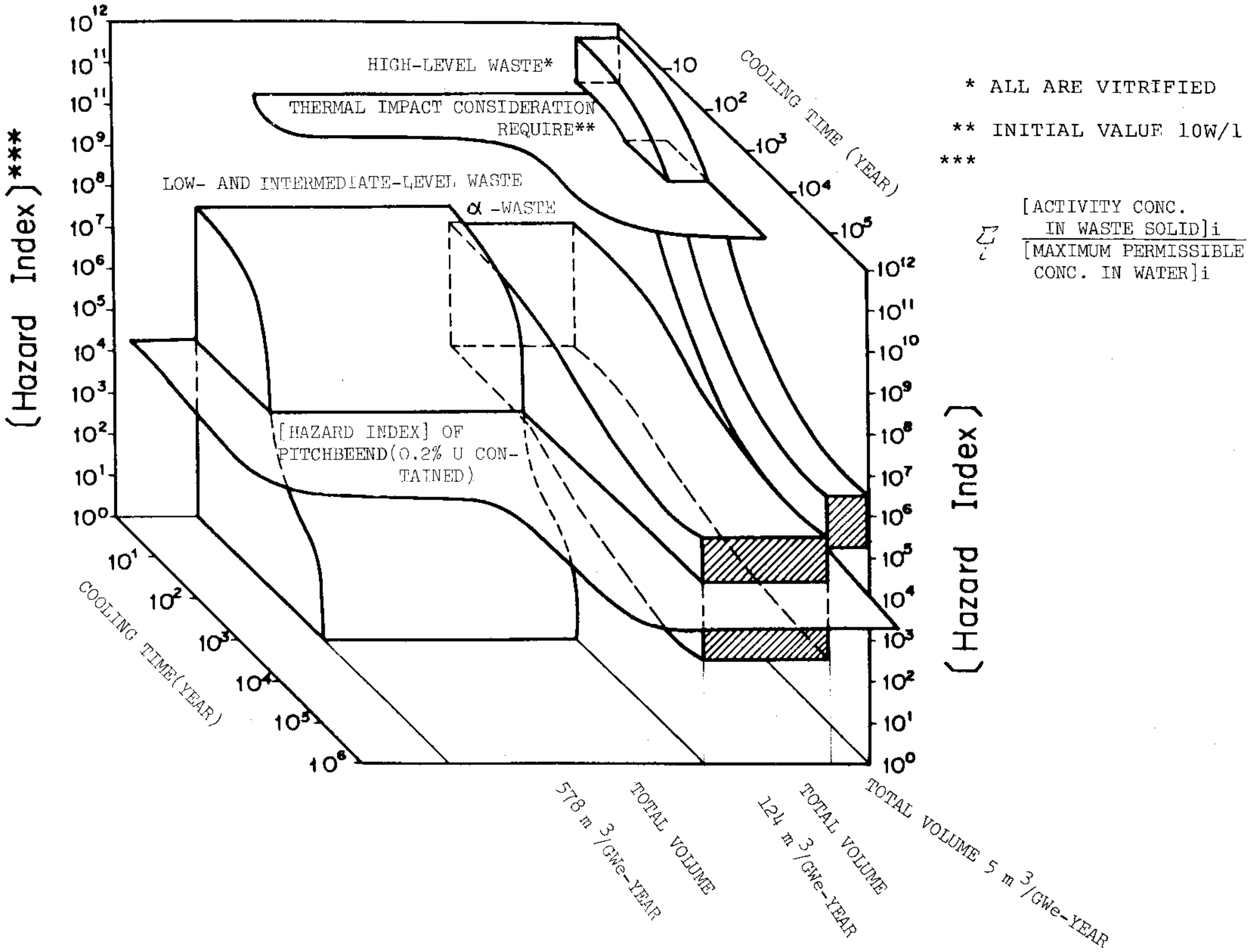


Fig. 11 GROUPING AND PROPERTIES OF RADIOACTIVE WASTES LWR (U-PuCYCLE)

Explanation for Fig.11

1. Vertical axis of the figure represents the product of (Hazard Index) and amount of high level waste per GWey, m^3/GWey.

2. Horrizontal axis of the figure represents time after removal of the fuel from a reactor.

3. Comparing the hazard of high level waste from LWR (U-P_u cycle) and that from LWR (Once-through), the figure shows that they have almost equal hazard in early age of several hundred years, in which fission products are main hazardous component, but the hazard of waste from LWR (Once-through) becomes higher after thousand years because of relatively high α content.

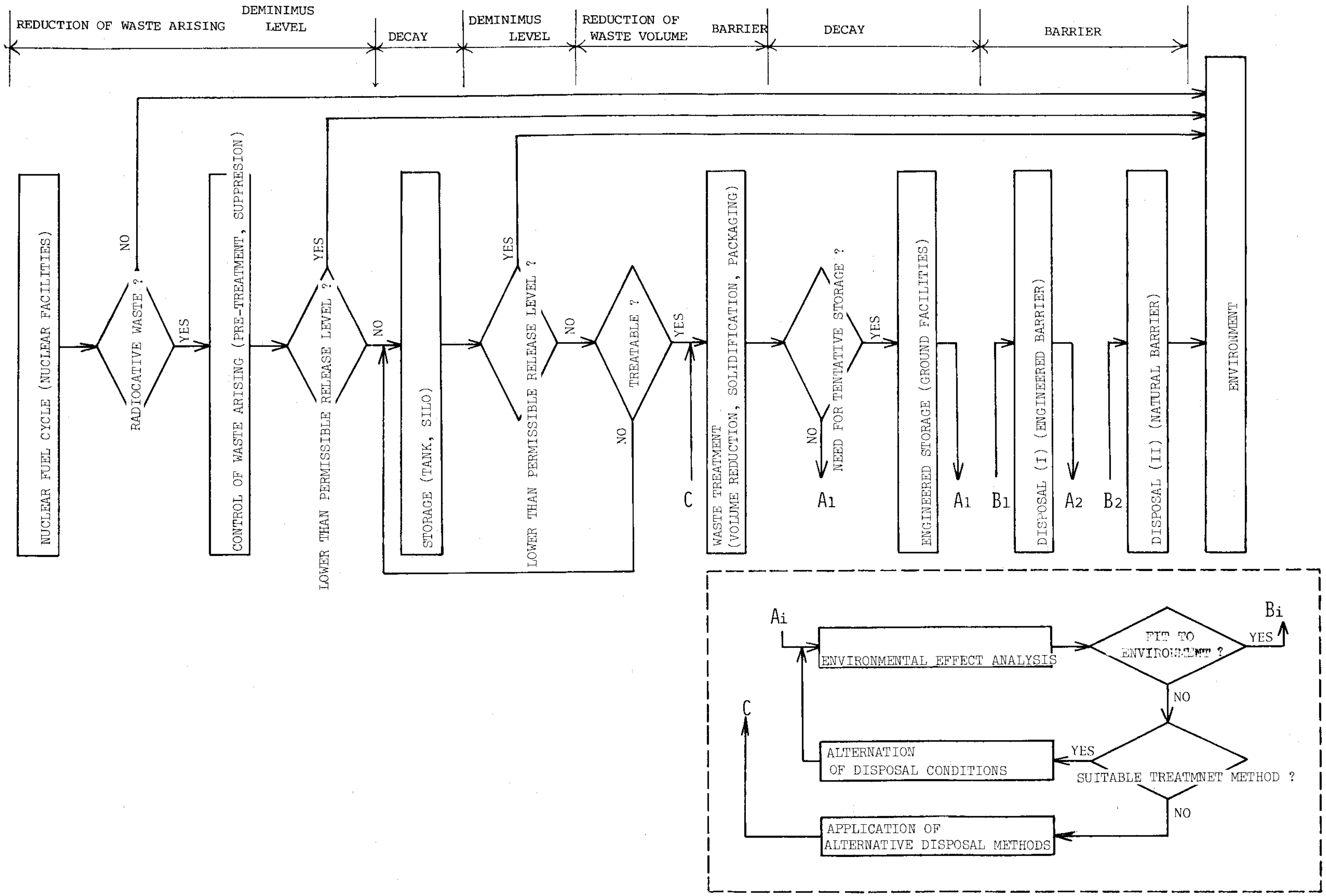


Fig. 12 RADIOACTIVE WASTE MANAGEMENT FLOW DIAGRAM FOR A NUCLEAR FUEL CYCLE

from the conventional logics.

22. The section boxed by dotted line in the figure is also an unique attempt in this logic. By following this procedure, one can assess the effect of combination of artificial and natural barriers.

2.3 Items to be solved and Directions of Approach

23. In order to adjust the items of R&D on waste management, the scenarios for the respective waste categories are established as shown in the tops of Figs. 13, 14 and 15.

24. The principal logic is common through whole three scenarios, but there are some modifications corresponding to the differences of their characteristics.

25. As seen in the figures, the items concerned to the respective categories can be divided into three:(i) items for establishment of management system, (ii) items for safety assessment covering also verification of technology and system, and (iii) items for regulation.

26. And one can easily draw the roles of the respective institutions as the operator, the verificator and the regulator.

a. Low- and intermediate-level wastes

27. The storage of low- and intermediate-level wastes produced in a large amount contributes to reduce the efficiency of a repository, resulting in unfavorably affecting the public acceptance of nuclear energy. It is urgently required that an adequate waste management system covering from the control of waste arising up to the final waste disposal should be set up earlier(as seen in Fig. 13).

(1) Sea disposal

28. Various preparations including survey and evaluation for sea disposal have been in progress. In an attempt to bring about earlier realization of the routine operation of sea disposal, it is essential that the methodology to highten the reliability in the environmental safety analysis

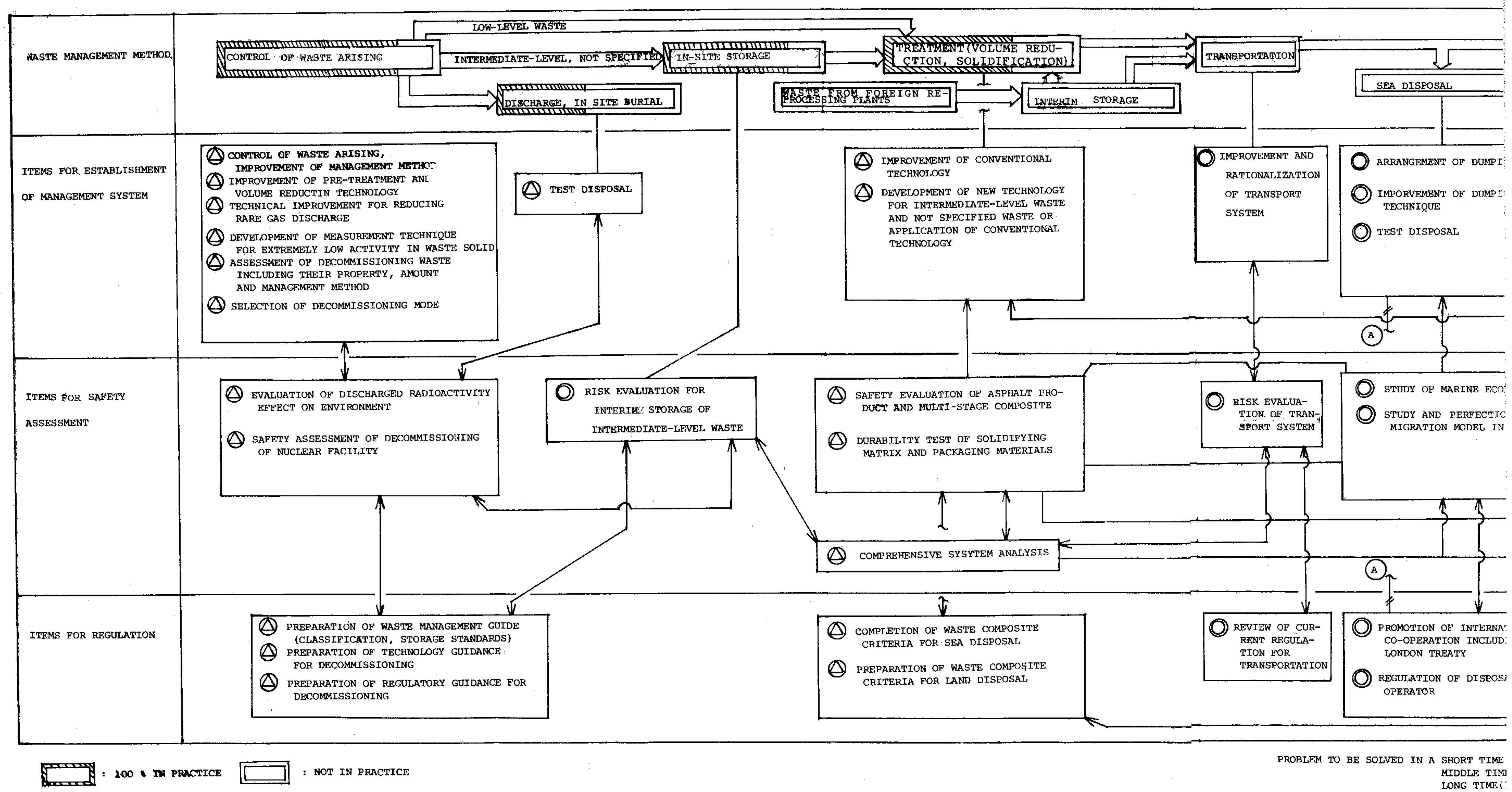
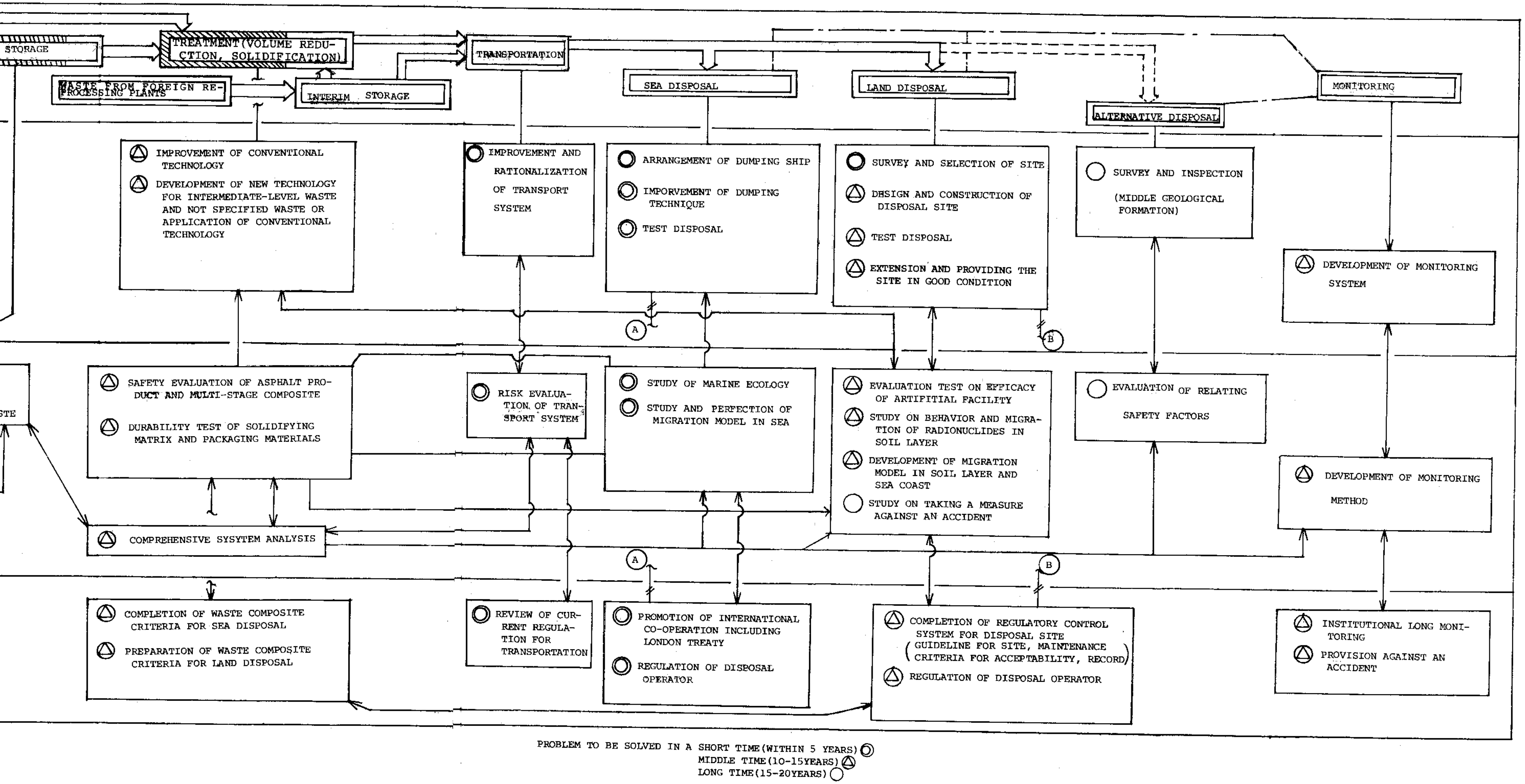


Fig. 13 SUPPOSED WASTE MANAGEMENT METHODS AND RESEARCH ITEMS TO BE DEVELOPED 1. LOW- AND INTERMEDIATE-LEVEL WASTES



W- AND INTERMEDIATE-LEVEL WASTES

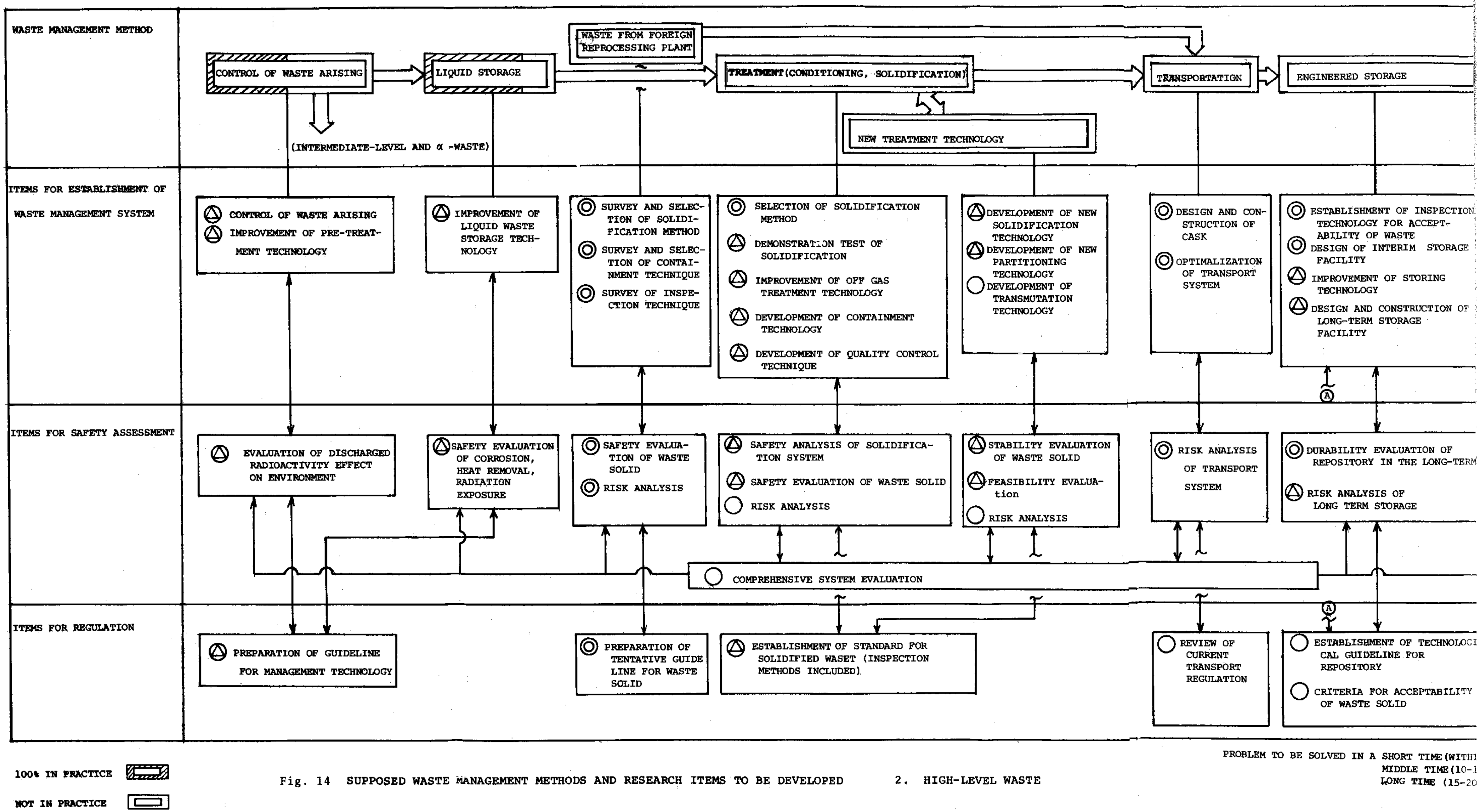
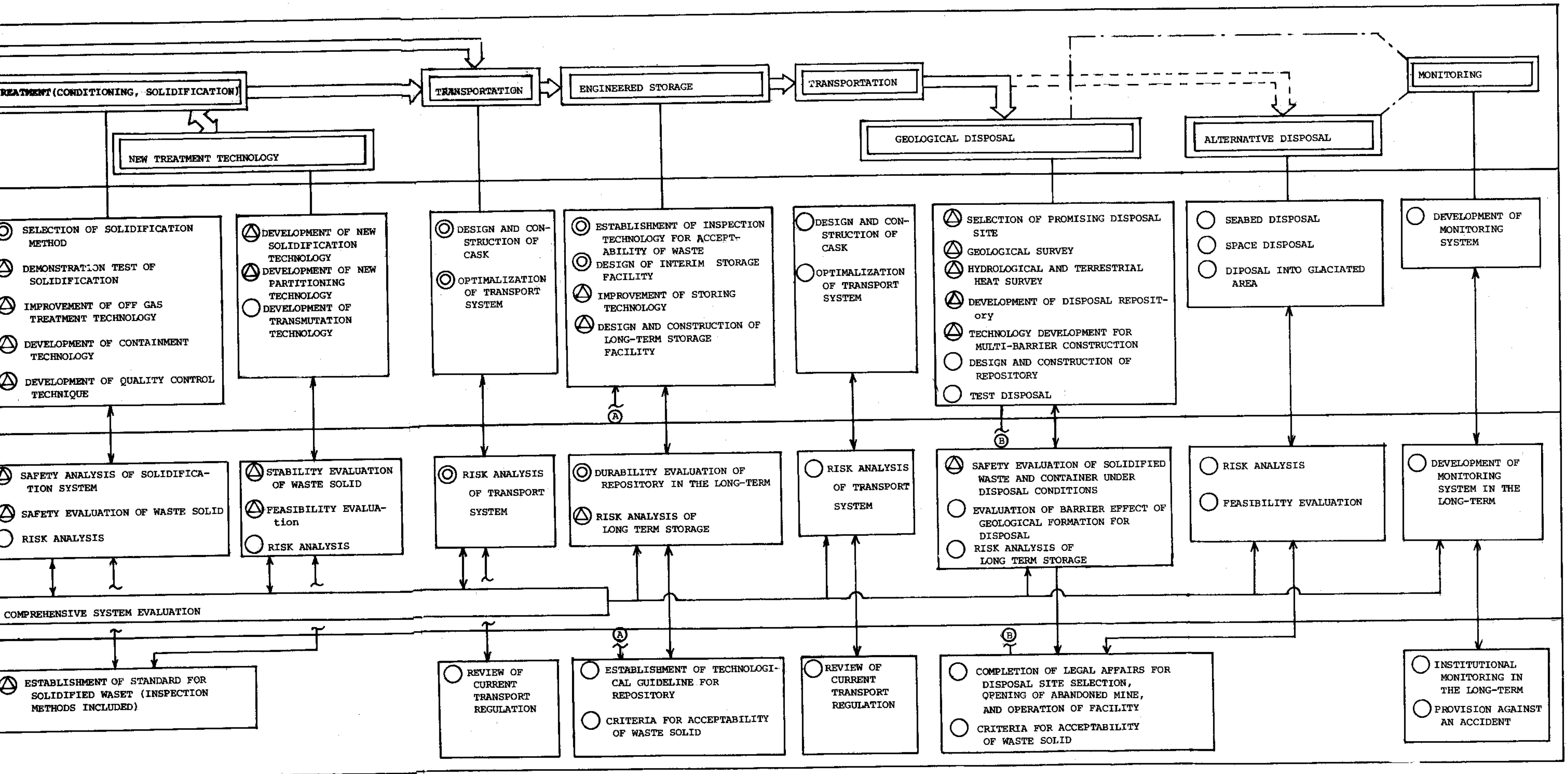


Fig. 14 SUPPOSED WASTE MANAGEMENT METHODS AND RESEARCH ITEMS TO BE DEVELOPED 2. HIGH-LEVEL WASTE



PROBLEM TO BE SOLVED IN A SHORT TIME (WITHIN 5 YEARS) ◎
MIDDLE TIME (10-15 YEARS) △
LONG TIME (15-20 YEARS) ○

TO BE DEVELOPED 2. HIGH-LEVEL WASTE

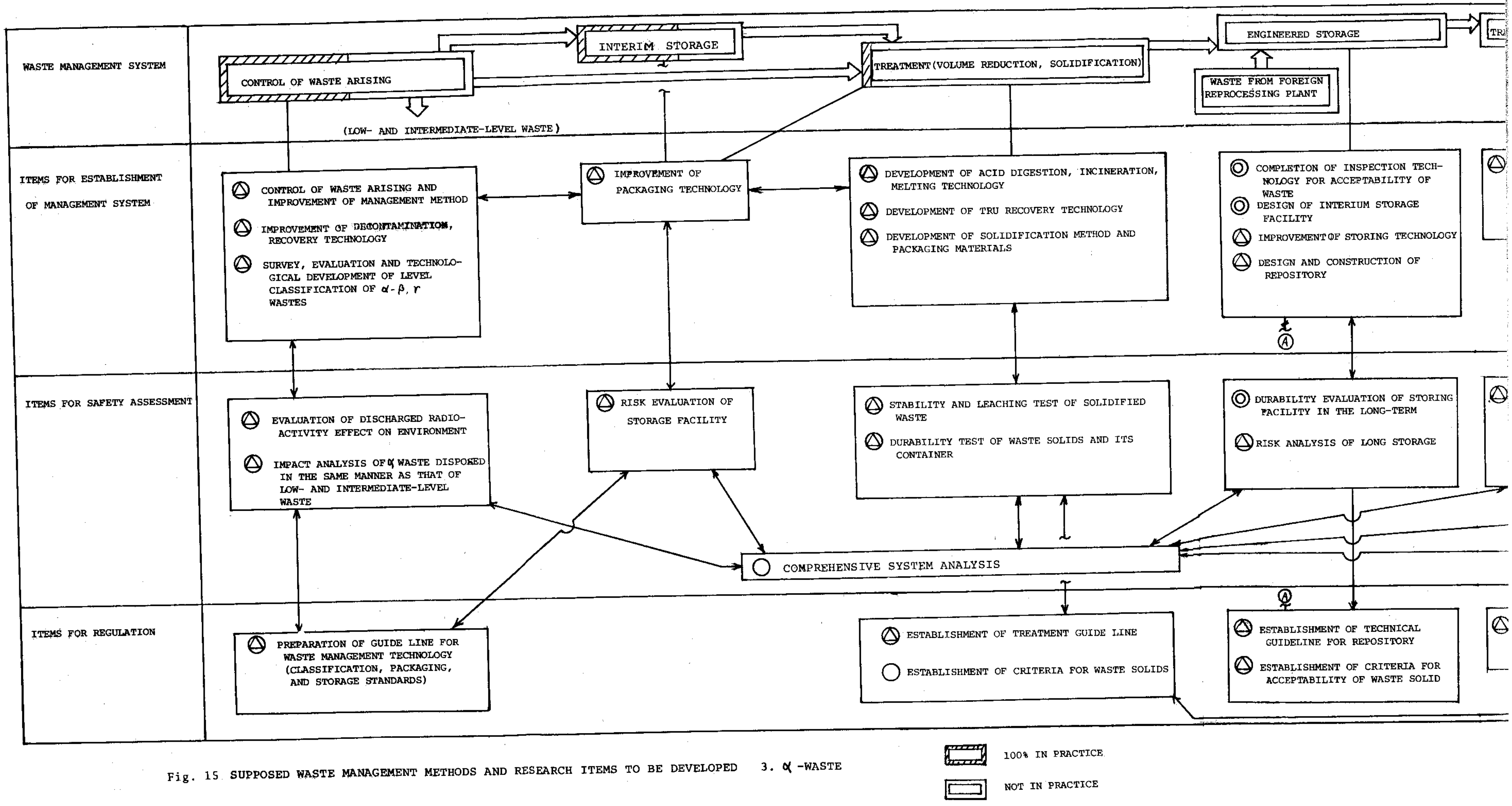
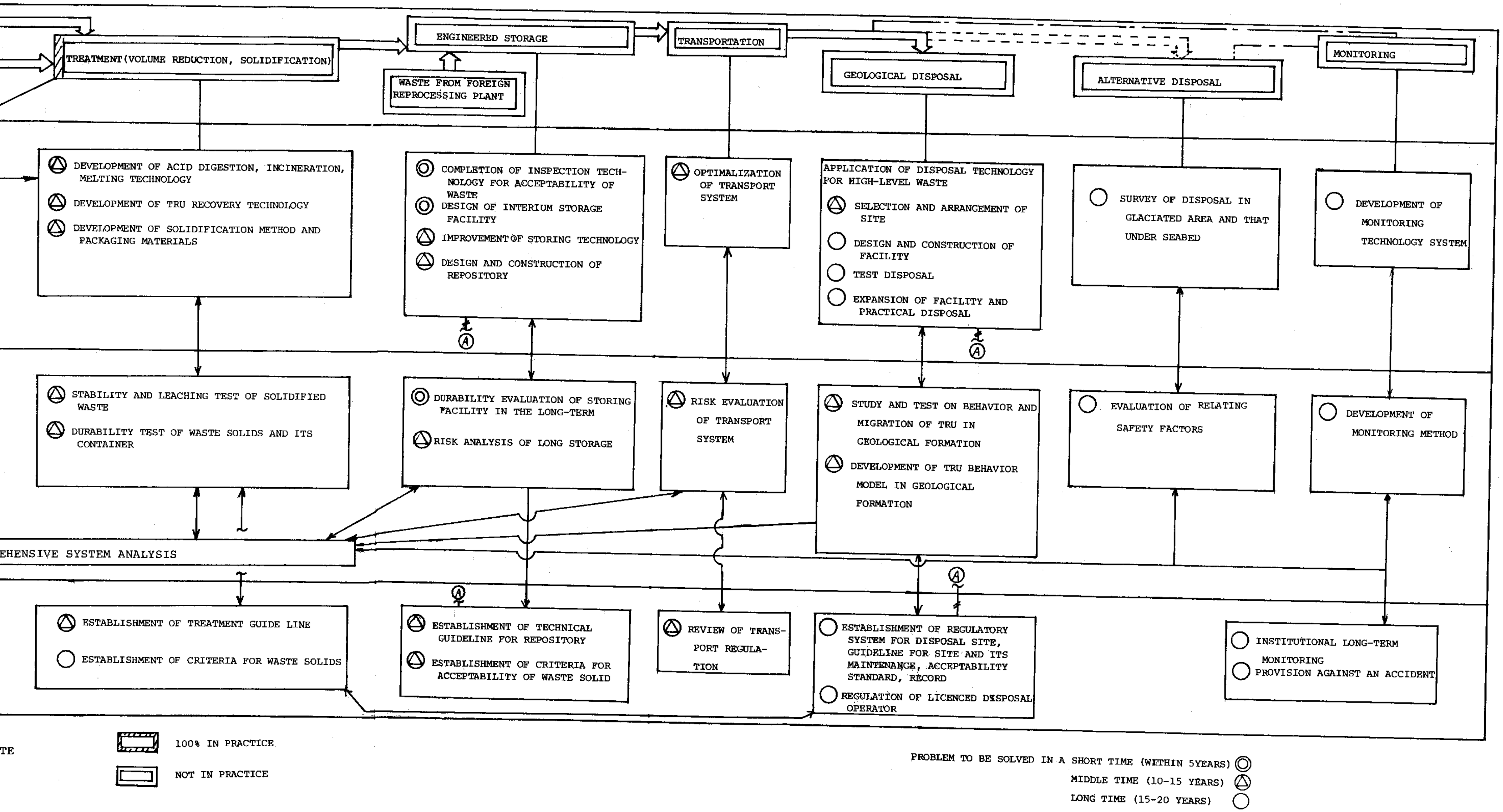


Fig. 15 SUPPOSED WASTE MANAGEMENT METHODS AND RESEARCH ITEMS TO BE DEVELOPED 3. α -WASTE


TREATMENT (VOLUME REDUCTION, SOLIDIFICATION)
ENGINEERED STORAGE
WASTE FROM FOREIGN REPROCESSING PLANT
TRANSPORTATION
GEOLOGICAL DISPOSAL
ALTERNATIVE DISPOSAL
MONITORING
DEVELOPMENT OF ACID DIGESTION, INCINERATION, MELTING TECHNOLOGY
DEVELOPMENT OF TRU RECOVERY TECHNOLOGY
DEVELOPMENT OF SOLIDIFICATION METHOD AND PACKAGING MATERIALS
COMPLETION OF INSPECTION TECHNOLOGY FOR ACCEPTABILITY OF WASTE
DESIGN OF INTERIUM STORAGE FACILITY
IMPROVEMENT OF STORING TECHNOLOGY
DESIGN AND CONSTRUCTION OF REPOSITORY
OPTIMALIZATION OF TRANSPORT SYSTEM
APPLICATION OF DISPOSAL TECHNOLOGY FOR HIGH-LEVEL WASTE
SELECTION AND ARRANGEMENT OF SITE
DESIGN AND CONSTRUCTION OF FACILITY
TEST DISPOSAL
EXPANSION OF FACILITY AND PRACTICAL DISPOSAL
SURVEY OF DISPOSAL IN GLACIATED AREA AND THAT UNDER SEABED
DEVELOPMENT OF MONITORING TECHNOLOGY SYSTEM
STABILITY AND LEACHING TEST OF SOLIDIFIED WASTE
DURABILITY TEST OF WASTE SOLIDS AND ITS CONTAINER
DURABILITY EVALUATION OF STORING FACILITY IN THE LONG-TERM
RISK ANALYSIS OF LONG STORAGE
RISK EVALUATION OF TRANSPORT SYSTEM
STUDY AND TEST ON BEHAVIOR AND MIGRATION OF TRU IN GEOLOGICAL FORMATION
DEVELOPMENT OF TRU BEHAVIOR MODEL IN GEOLOGICAL FORMATION
EVALUATION OF RELATING SAFETY FACTORS
DEVELOPMENT OF MONITORING METHOD
EHENSIVE SYSTEM ANALYSIS
ESTABLISHMENT OF TREATMENT GUIDE LINE
ESTABLISHMENT OF CRITERIA FOR WASTE SOLIDS
ESTABLISHMENT OF TECHNICAL GUIDELINE FOR REPOSITORY
ESTABLISHMENT OF CRITERIA FOR ACCEPTABILITY OF WASTE SOLID
REVIEW OF TRANSPORT REGULATION
ESTABLISHMENT OF REGULATORY SYSTEM FOR DISPOSAL SITE, GUIDELINE FOR SITE AND ITS MAINTENANCE, ACCEPTABILITY STANDARD, RECORD
REGULATION OF LICENCED DISPOSAL OPERATOR
INSTITUTIONAL LONG-TERM MONITORING
PROVISION AGAINST AN ACCIDENT
A
TE
100% IN PRACTICE
NOT IN PRACTICE
PROBLEM TO BE SOLVED IN A SHORT TIME (WITHIN 5YEARS)
MIDDLE TIME (10-15 YEARS)
LONG TIME (15-20 YEARS)

should be intensively studied in parallel with making required arrangements for the facility and ship for disposal operation. Furthermore, it is necessary to initiate the developmental experiments to diversify the waste composite to be disposed into the sea.

(2) Land disposal

29. For expecting its realization in a decade or so, a land disposal, which allows considerable diversity with respect to the type of package and radioactivity contained therein, requires intensive survey and selection of a site and the construction of related facilities as well as strengthened analytical study on the migration behavior of radionuclides in the geosphere in parallel with or prior to the forestated actions.

30. The feasibility study on the disposal of wastes into a middle geological formation and on alternative disposal methods should also be carried out to make the waste disposal more reliable and to expand the disposal alternatives to be selected as required.

(3) Improvement of treatment method

31. As the disposal operation materialized, the current conditioning technology has to be improved applicable to various types of wastes. In this regards, in addition to the safety study on a waste composite, technologies for volume reduction and solidification of the intermediate-level wastes especially spent ion-exchange resins and degraded solvents should be developed and introduced in a timely mode.

(4) Review of waste management system

32. The comprehensive review of low- and intermediate-level waste management system consisting of the control of waste arisings, treatment and disposal can afford the optimization of management system as well as the minimization of the environmental impact involved. The essential

issues to be solved in a middle-term stage are; the reduction of waste arisen in nuclear facilities, improvement of the technology for minimization of released rare gases, establishment of the deminimus level for solid waste, demonstration and environmental impact analysis of the waste management system for solid wastes near the deminimus level, and comprehensive management system analysis.

(5) Institution and regulation

33. In addition to technical development mentioned above, it is indispensable for the realization of the total management system to establish the institutional mechanism and regulatory system, both of which specify the course of nuclear industry in Japan. In these aspects, governmental authorities concerned have been making perpetual efforts, but it is urgently required that the regulatory roles and resposibilities of the disposal undertakers should be defined and that a keen attention be paid upon the institutional methods for long-term control and surveillance as well.

b. High level waste

34. High level waste must be isolated from biosphere infinitely and managed safely. Method of management is based on what described in the first column of Fig. 14.

(1) Engineered storage and geological disposal

35. Technological guideline should first be set forth for engineered storage. Repository should be then designed and constructed in accordance with the established guideline. Durability evaluation and risk analysis have to be done before construction(see Fig. 14). Inspection technology for waste acceptability should also be developed.

36. As for geological disposal, geological, hydrological and terrestrial heat survey are needed for site selection. In advance to the design and construction of repository, evaluation of barrier effect of geological formation and risk analysis should be made as shown in Fig. 14.

(2) Conception of disposal

37. It is important to introduce the conception of multi-barrier effect to ensure the safety of final disposal under the conditions of geography, geology and climate in the nation. Greater barrier effect may be expected by constructing many powerful layers of artificial barrier where natural barrier effect is small. Consequently, selection scope of the site probably becomes wider even in the nation where the land is small and conditions are not favorable as in Japan.

(3) Advancement of R&D programmes

38. Research and development programmes for high level waste management should be progressed by giving priorities on the items shown by the symbol ◎ in the following table. New and alternative technologies should also be developed.

Process / Effect	Reduction of waste arising	Liquid storage	Treatment	Engineered storage	Geological disposal
Volume reduction	◎		◎		
Barrier			○	○	◎
Decay		◎		◎	○

(4) Progress in resolving research problems

(i) Research problems to be solved promptly (~ 3 years)

39. The receipt of the returned waste solid from overseas based on the reprocessing contract is expected to start in 1990, while examination of the specifications of the solid is required to complete by 1982. Examination and selection of the returned waste solid plus containment and inspection technologies are also needed. Safety evaluation on waste

solid properties and risk analysis thereof have to be conducted and tentative guidelines for solidified waste have to be set forth.

40. Returned waste are to be transferred to engineered storage. In relation to the transportation, reviews on the design and construction of cask, optimalization of transport system are required, while in safety assessment, risk analysis of the transport system, and the current transport regulations become necessary to be examined. Concerning engineered storage, inspection technology for waste acceptability should be developed and design of interim storage facility be promptly pushed forward. Safety assessment on durability of storage is also required to be done.

(ii) Research problems to be solved in short term(~ 5 years) or middle term(5 to 15 years)

41. It is necessary for the completion of the solidification technology to determine the specifications of waste solid as soon as possible. In reducing waste arisings, improvement of management and pretreatment method are of great importance. Safety evaluation of dispersed radioactivity effects on environment and setting-up of the guide for management technology are necessary. Relating to liquid state storing, improvement for storing technology of waste solution and safety assessment on corrosion, heat removal, and radiation exposure are required. As far as treatment is concerned, among numerous requirements are; demonstration test of solidification, improvement of off gas treatment technology, development of containment technology and quality control technology, safety assessment of solidification system, stability evaluation of waste solid, and establishment of standards for solidified composites.

42. Concerning engineered storage, development of better storage technology, design and construction of long-term storage facility, risk analysis thereof, setting of tech-

nical guide for storage and establishment of criteria for acceptability of waste solid are requested. In respect of geological disposal, choice of candidate site, geological survey, hydrological survey, terrestrial heat survey, development of disposal repository, construction technology of multi-barrier and integrity assessment of packages containing solidified waste are essential.

(iii) Research problems to be solved in a long term period (more than 15～20 years)

43. Development of transmutation technology and risk analysis thereby of waste solid with and without transmutation should be carried out. As for transportation between engineered storage and geological formation, design of cask, optimalization of transport system, risk analysis of the system and review on the current transport regulations are necessary to be done. With regard to geological disposal, design and construction of disposal facility, test disposal, evaluation of barrier effect necessary for disposal formation and risk analysis should be made. Along with these requirements, legal provisions associated with site selection, opening of abandoned mine, operation of repository, and criteria for acceptability of waste solid become necessary to determine. Investigation on other disposal options such as seabed, space and glaciated area disposals should be moved towards full-fledged research and development. In accordance with these activities, risk analysis and feasibility evaluation are needed. In addition, development of long-term monitoring system and counter provisions against abnormalities are required.

44. It will be necessary to make comprehensive system analysis throughout the tasks stated above.

c Alpha-waste

45. The managemental methods and research items suggested for alpha-waste are given in Fig. 15, which might be solved.

46. The waste contaminated with alpha-nuclides having extremely long half-lives does not afford decay effect,

but gives possibility of realization of disposal easier than that of high-level waste because of its smaller volume. The management system basically consists of the control of waste arising, interim storage, treatment, transportation and geological disposal. The research and development items are required to be undertaken in a middle-term, besides the geological disposal of the waste is subjected to as such an item in a long-term. The most parts of items concerning alpha-waste can be derived from items for high-level wastes.

47. The characteristic RD&D items for alpha-waste are of the improvement of technology for decontamination, classification, recovery and packaging, furthermore, of analysis on migration behavior of TRU in a geological formation and related safety assessment.

d. Partitioning

48. Effectiveness of partitioning and its technical problems are shown in Figs. 16 and 17.

(1) Effectiveness

49. High-level waste contains Sr-90, Cs-137 being as main part of the activity and TRU having ultimate long half-lives. The waste characterizes relatively fast leaching rate when solidification is applied to it with glass. In separation of Sr-90, Cs-137 and TRU using partitioning technique, it can be expected to increase safety in high-level waste disposal.

50. Leachability of radionuclides from vitrified solid can be extremely lowered by removal of Sr-90 and Cs-137. Therefore, stringent management including heat removal may not be required for the waste.

51. Sr-90 and Cs-137 separated may be frozen into minerals such as titanate and aluminosilicate, respectively, which exist stable for a long time in nature.

52. Isolation period of vitrified waste under geological disposal may be reduced to about 1000 years by removal of TRU.

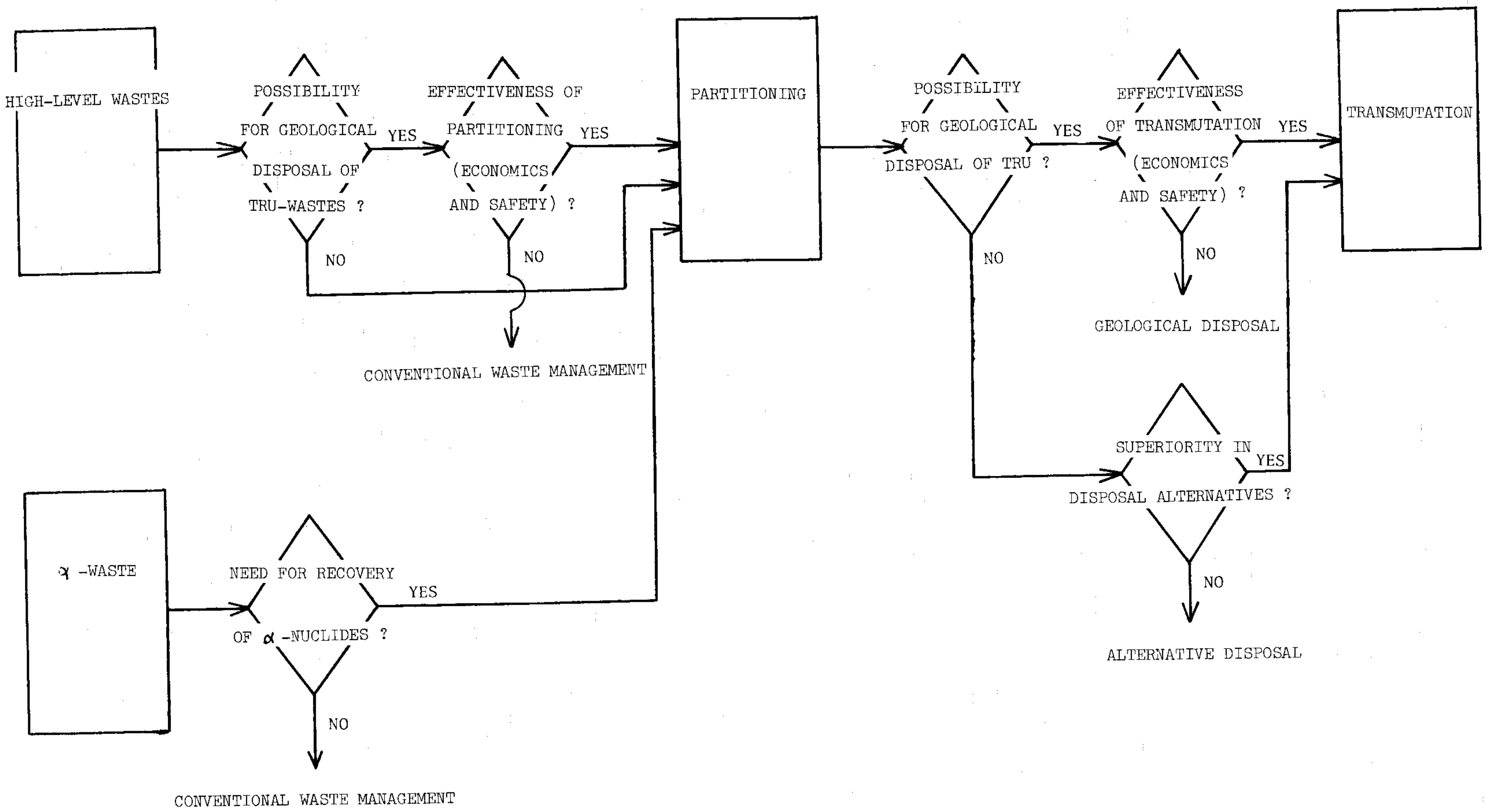
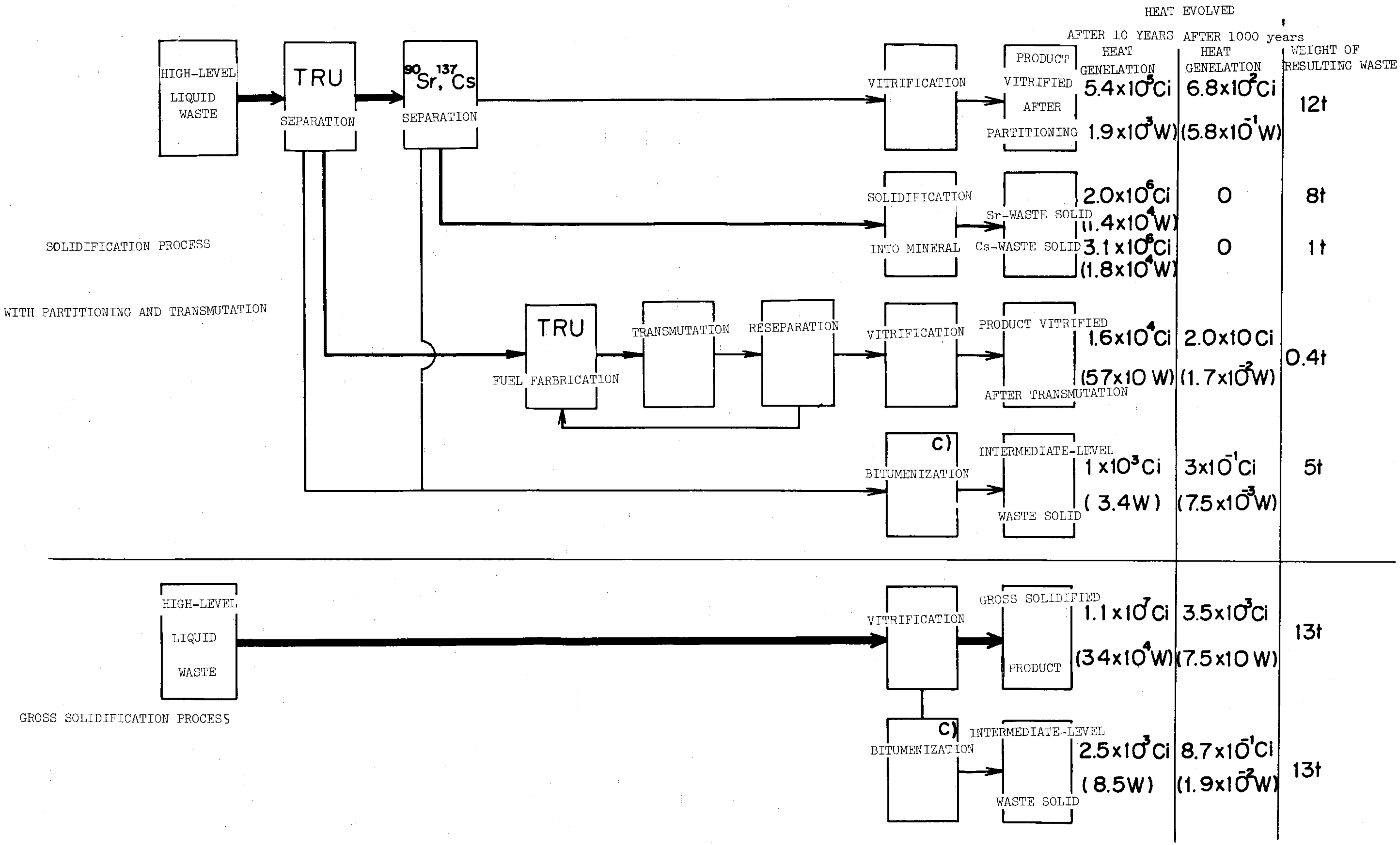


Fig. 16 LOGIC DIAGRAM FOR ASSESSING EFFECTIVENESS OF PARTITIONING AND TRANSMUTATION IN REPROCESSING WASTES MANAGEMENT



a) 33 TONS OF FUEL ARE TO BE REPROCESSED (BURN-UP: 33,000MWD/t, THERMAL POWER OF FUEL: 30MW/t, EFFICIENCY: 0.33)

b) 0.15 m^3 OF VITRIFIED WASTE IS GENERATED WHEN 1 TON OF FUEL IS REPROCESSED AND THE DENSITY OF VITRIFIED WASTE IS 2.7.

c) BITUMINIZATION IS TO BE APPLIED.

Fig. 17 COMPARISON OF SOLIDIFICATION AFTER PARTITIONING-TRANSMUTATION AND DIRECT GROSS SOLIDIFICATION (CORRESPONDS TO 1GWe-YEAR)[a]

53. Separated TRU can be converted into another nuclides having shorter half-lives by means of transmutation.

54. Alpha-wastes contain TRU such as Pu. It may be possible to handle these as low- or intermediate-level wastes, provided that TRU is separated from these wastes by partitioning.

(2) Technical problems to be solved

55. When waste solid containing partitioned TRU is kept in engineered storage, it is needed to develop the following techniques.

56. Shielding and heat removal must be taken into consideration when separated TRU includes 10% of fission products. Therefore, separation technique must be improved so as to get as higher decontamination factor as possible.

57. Stringent management may be required against degradation of waste solid due to the formation of He gas produced from TRU contained and leaching of alpha-nuclide in the concentrated form. In order to prevent it, technology of stabilization for the waste solid must be developed.

(3) Time target

58. When partitioning is to be built in the waste management system, then time target is regarded as follows: Provided that the operation is to start in 1995 of the solidification plant of high-level waste from 2nd reprocessing plant scheduled to operate in 1990, detailed design of solidification plant is probably initiated in 1990. Comprehensive evaluation of partitioning should be completed within 1989 at the latest if partitioning is adopted in the waste management system.

e. Decommissioning

59. The decommissioning mode as shown in Table 5 for nuclear facilities retired may be determined taking into account the intention of owner and social needs for a site, i.e., the balance between benefit of site reuse and decommissioning cost. The basic policy for decommissioning

Table 5 COMPARISON OF ANNUAL AND ACCUMULATED AMOUNTS[d] OF OPERATION AND DECOMMISSIONING[a] WASTES GENERATED

PACKAGE TYPE[c]	WASTE TYPE \ YEAR	1980	1985	1990	1995	2000	2005[b]	2010	2015	2020	2025	2030
	NUCLEAR GENERATING CAPACITY (GWe)	17	26	45	70	100	130	160	190	220	250	280
UNSHIELDED DRUM (β, γ)	OPERATION WASTES	72,736	243,211	418,232	681,900	1,000,120	1,341,070	1,682,020	2,022,970	2,363,920	2,704,870	3,045,820
	DECOMMISSIONING WASTES							109,480	57,960	122,360	161,000	193,200
	(INTEGRATED)		(315,947)	(734,179)	(1,416,079)	(2,416,199)	(3,757,269)	(5,548,769)	(7,629,699)	(10,075,979)	(12,941,849)	(16,180,869)
SHIELDED DRUM (β, γ)	OPERATION WASTES	18,656	62,381	107,272	174,900	256,520	373,652	476,816	518,870	606,320	693,770	781,220
	DECOMMISSIONING WASTES							29,682	15,714	33,170	43,650	52,380
	(INTEGRATED)		(81,037)	(188,309)	(363,209)	(619,729)	(993,381)	(1,470,197)	(2,004,781)	(2,644,271)	(3,381,621)	(4,215,221)
CANISTER (β, γ)	OPERATION WASTES	384	1,284	2,208	3,600	5,280	7,080	8,880	10,680	12,480	14,280	16,080
	DECOMMISSIONING WASTES							56,270	29,790	62,890	82,750	99,300
	(INTEGRATED)		(1,668)	(3,876)	(7,476)	(12,756)	(19,836)	(84,986)	(125,456)	(200,826)	(297,856)	(413,236)

a) NUCLEAR REACTOR IS ASSUMED TO BE IMMEDIATELY DISMANTLED WITH A COOLING TIME OF A YEAR AFTER REACTOR OPERATION PERIOD OF 30 YR. NUCLEAR REACTORS CONSTRUCTED BEFOR 1980 ARE ASSUMED TO BE DISMANTLED IN 2010.

b) THE INCREASE RATE OF NUCLEAR GENERATING CAPACITY DURING 1995 - 2000 YR IS ASSUMED TO BE UNCHANGED UP TO 2030.

c) ALL OF DECOMMISSIONING WASTES ARE ASSUMED TO BE PACKAGED INTO SHIELDED AND UNSHIELDED DRUMS (β,γ), AND CANISTER (β,γ).

d) AMOUNTS OF DECOMMISSIONING WASTES GENERATED ARE ESTIMATED BASED ON THE REPORT OF NIS (Nucll Eng. Design, 45, 1 (1978)), AND THESE VALUES DO NOT CONTAIN WASTES BELOW THE DEMINIMUS LEVEL.

UNSHIELDED DRUM (β,γ)	6440/GWe
SHIELDED DRUM (β,γ)	1746/GWe
CANISTER (β,γ)	3310/GWe

should be established in advance to promote the nuclear power generation in the long-term version.

60. The first item in establishing the policy is determining decommissioning modes. The modes involve potentially Lay away, Mothballing, Entombment, Immediate dismantlement and Deferred dismantlement, and also their combinations(see Fig. 18).

61. The methodology for selecting the time and mode of decommissioning should be developed in advance by considering such factors as the radioactivity inventory, current state of the decommissioning technology, manual limit of surveillance, needs for the reuse of a site, environmental impact and cost.

62. Upon establishment of the policy, the activity involves the preparation of regulatory guide of decommissioning and promotion of technical development required. R&D programme contains development of decommissioning technology especially in a high radiation area, storage technology, decontamination method, radiation protection technology, measurement of extremely low radioactivity and transportation technology.

63. A vast amount of radioactive wastes produced in the decommissioning activity belongs essentially to low- and intermediate-level waste categories, and these consist mainly of reactor components and biological shield concrete.

64. The wastes which do not give high volume reduction with treatment might be subjected to establish for reasonable waste management system. To reduce the decommissioning waste to be handled being as radioactive waste, the deminimus level for solid wastes should be defined as in case of the liquid and gaseous waste.

2.4 Impact on Environment from Disposed Radioactive Wastes

a. Effects of artificial and natural barriers

65. The waste disposal gives the environmental impact through dispersion and migration of nuclides contained in

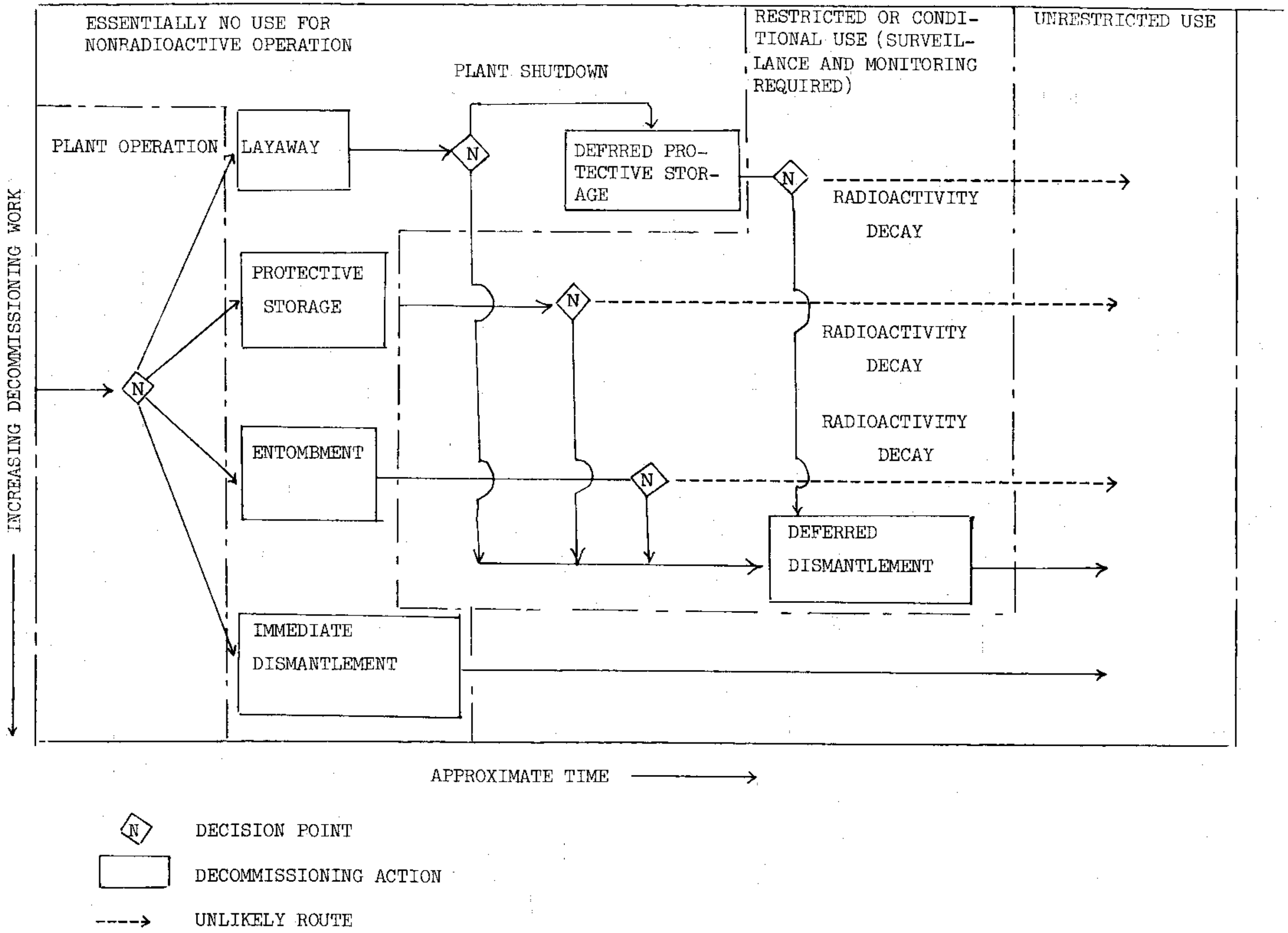


Fig. 18 **GENERALIZED DECOMMISSIONING PATHWAY AND ALTERNATIVES**

wastes into atmosphere, geosphere and hydrosphere. The wastes packaged into a container which provides the artificial barrier are disposed into land, deep geological formation, deep sea and sea bed, whole of which have a role as the natural barriers, shown in Fig. 19.

66. The combination of artificial and natural barriers potentially lengthen the migration path by which the concentration of nuclides in the environmental media is lowered significantly.

b. Estimation of dose commitment

67. The nuclides dispersed and migrated into the environment are uptaken by men through food chains, shown in Table 6. To evaluate the dose commitment accompanied by waste disposal, it is necessary to estimate various parameters given in the table, however most of parameters required are not obtained to date.

68. In Fig. 20, the methodology for calculating the cumulative numbers of radionuclides, which is necessary to obtain collective dose commitment by deposited waste, is developed.

2.5 International Cooperation

a. International standards

69. Because of its almost infinite continuance, the problem from radioactive wastes becomes a gloval concern, whether one likes or not. Therefore, the relevant standards, specifically to be applied to the disposal practice, should be best met by an international consensus. The agreeable standards may be established internationally in a manner which is based on a mutual understanding in respect to the specific conditions of individual nations.

b. Technology exchange

70. Except for geographic specificity, there are many common technologies appropriate to international use. In order to effectively promote the technological development of waste management, the efforts may be shared in a technology exchange base with individual development of allotted tasks.

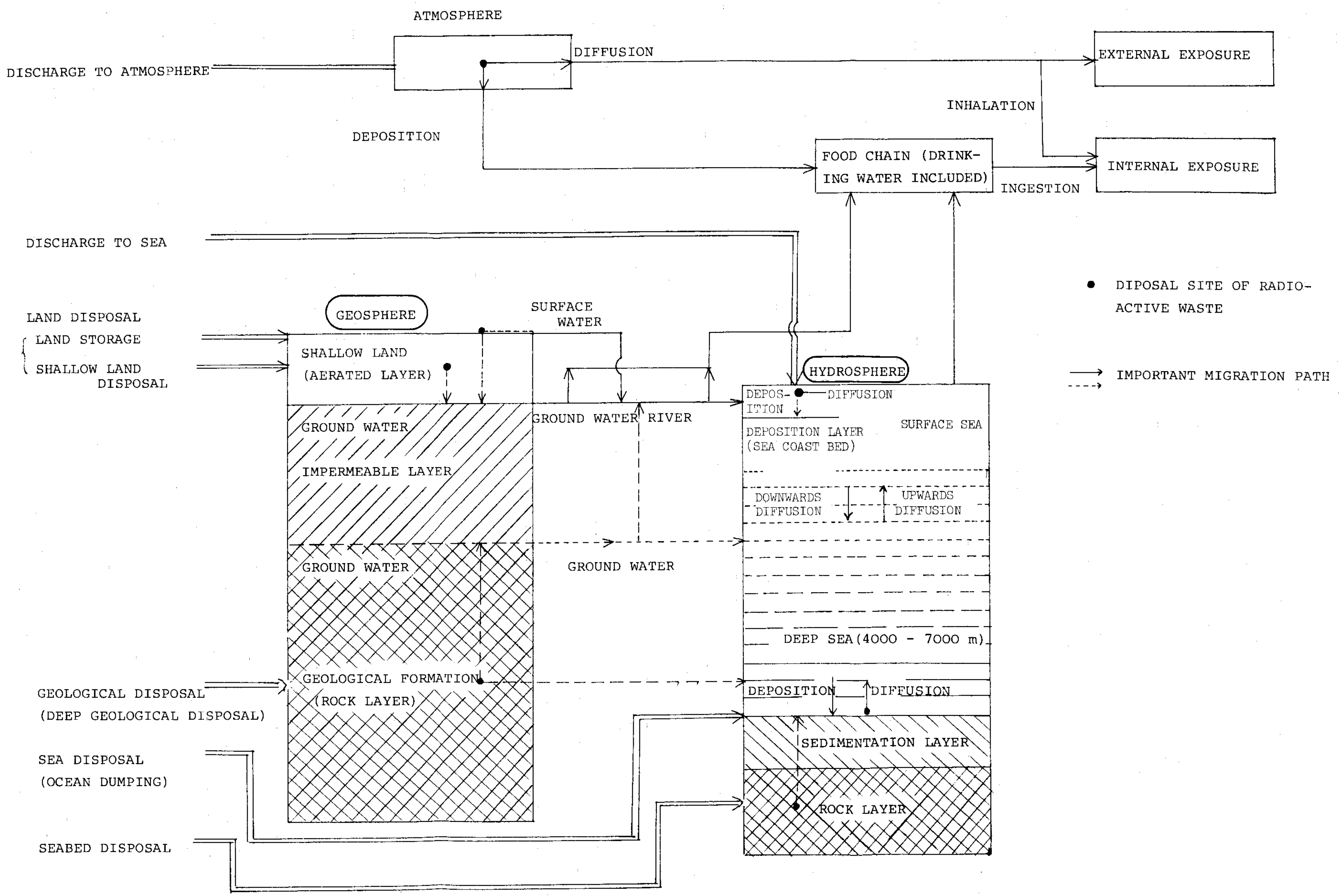


Fig. 19 IMPORTANT MIGRATION PATHS OF RADIOACTIVITY INVOLVED IN WASTE DIPOSAL

Table 6 CONCENTRATIONS OF RADIONUCLIDES IN THE ENVIRONMENTAL MEDIA WHICH GIVE DOSE COMMITMENT OF 1 mrem TO INDIVIDUALS OF GENERAL PUBLIC (I)

DISPOSAL METHOD AND IMPORTANT NUCLIDE	AMOUNT DISPOSED (Ci, Ci/y)	ABILITY OF ARTIFITIAL BARRIER	DEEP GEOLOGICAL LAYER	DEEP SEA (5000 m)	DEEP GROUND WATER (μCi/cm³)	AERATED LAYER	SURFACE GROUND WATER (μCi/cm³)	RIVER (μCi/cm³)	IRRIGATION (μCi/cm³)	POTABLE WATER (μCi/cm³)	SURFACE SEA (μCi/cm³)	AIR ABOVE GROUND (μCi/cm³)	ANNUAL INTAKE VIA INHALATION (μCi)	ANNUAL INTAKE VIA INGESTION (μCi)	CRITICAL ORGAN
DISCHARGE TO ATMOSPHERE															
H-3												3×10^{-10}	8×10^{-1}	2	TOTAL BODY
I-129												8×10^{-17}	4×10^{-5}	3×10^{-5}	THYROID
I-131												2×10^{-15}	2×10^{-4}	2×10^{-4}	"
I-133												7×10^{-14}	8×10^{-4}	6×10^{-4}	"
COASTAL DISCHARGE															
H-3											3×10^{-5}			2	TOTAL BODY
Co-60											2×10^{-10}			4×10^{-3}	(LLI)
Sr-90											5×10^{-11}			7×10^{-6}	BONE
Ru-106											8×10^{-11}			1×10^{-3}	(LLI)
I-131											2×10^{-10}			2×10^{-4}	THYROID
Cs-137											3×10^{-9}			5×10^{-3}	TOTAL BODY
LAND DISPOSAL INCLUDING SHORT-TERM AND LONG-TERM STORAGE ON LAND															
Co-60						○	○	○	4×10^{-8}	9×10^{-9}	2×10^{-10}			4×10^{-3}	(LLI)
Sr-90						○	○	○	6×10^{-11}	2×10^{-11}	5×10^{-11}			7×10^{-6}	BONE
Cs-137						○	○	○	1×10^{-8}	1×10^{-8}	3×10^{-9}			5×10^{-3}	TOTAL BODY
Pu-239						○	○	○	○	6×10^{-10}	3×10^{-11}			2×10^{-4}	BONE
Np-237						○	○	○	○	4×10^{-10}	3×10^{-10}			1×10^{-4}	"
Cm-245						○	○	○	○	5×10^{-10}	5×10^{-12}			2×10^{-4}	"
Am-241						○	○	○	○	6×10^{-10}	6×10^{-12}			2×10^{-4}	"

Table 6 CONCENTRATIONS OF RADIONUCLIDES IN THE ENVIRONMENTAL MEDIA WHICH GIVE DOSE COMMITMENT OF 1 mrem TO INDIVIDUALS OF GENERAL PUBLIC (II)

DISPOSAL METHOD AND IMPORTANT NUCLIDES	AMOUNTS DISPOSED (Ci, Ci/y)	ABILITY OF ARTIFITIAL BARRIER	DEEP GEOLOGICAL FORMATION	DEEP SEA (5000m) (μCi/cm³)	DEEP GROUND WATER (μCi/cm³)	AERATED LAYER	SURFACE GROUND WATER (μCi/cm³)	RIVER (μCi/cm³)	IRRIGATION (μCi/cm³)	POTABLE WATER (μCi/cm³)	SURFACE SEA (μCi/cm³)	AIR ABOVE GROUND (μCi/cm³)	ANNUAL INTAKE VIA INHALAT. (μCi)	ANNUAL INTAKE VIA INGESTION (μCi)	CRITICAL ORGAN
SEA DISPOSAL					DILUTION FACTORS (*)										
Co−60				1×10³	2×10⁻¹³						2×10⁻¹⁰			4×10⁻³	(LLI)
Sr−90				3×10	1×10⁻¹²						5×10⁻¹¹			7×10⁻⁶	BONE
Cs−137				2×10³	1×10⁻¹²						3×10⁻⁹			5×10⁻³	TOTAL BODY
U−238				5×10⁻⁶	6×10⁻⁵						3×10⁻¹⁰			3×10⁻⁴	BONE
Pu−239				1×10⁻¹	3×10⁻¹⁰						3×10⁻¹¹			2×10⁻⁴	BONE
DEEP GEOLOGICAL DISPOSAL															
Sr−90			○	○	○	○	○	○	6×10⁻¹¹	2×10⁻¹¹	5×10⁻¹¹			7×10⁻⁶	BONE
Cs−137			○	○	○	○	○	○	1×10⁻⁸	1×10⁻⁸	3×10⁻⁹			5×10⁻³	TOTAL BODY
Pu−239			○	○	○	○	○	○	○	6×10⁻¹⁰	3×10⁻¹¹			2×10⁻⁴	BONE
N_p−237			○	○	○	○	○	○	○	4×10⁻¹⁰	3×10⁻¹⁰			1×10⁻⁴	BONE
Cm−245			○	○	○	○	○	○	○	5×10⁻¹⁰	5×10⁻¹²			2×10⁻⁴	BONE
Am−241			○	○	○	○	○	○	○	6×10⁻¹⁰	6×10⁻¹²			2×10⁻⁴	BONE

EXPLANATION OF TABLE "CONCENTRATION OF RADIONUCLIDES IN THE ENVIRONMENTAL MEDIA WHICH GIVE DOSE COMMITMENTS OF 1 mrem TO INDIVIDUALS OF GENERAL PUBLIC"

1. Definition of figures in the Table

(1) "Annual intake via inhalation" and "Annual intake via ingestion"

Each figure in these columns is defined as the annual intake of a radionuclide which gives 50-year dose commitment to man on an assumptin that he lives 50 years. Since the most nuclides have short biological half-lives if some of them are radiologically long lived, it is likely that he is assumed to receive annual dose of 1 mrem; it would be overestimated by a smaller factor than 2. These figures are defined for children as the most important exposure group. The word "annual dose" is used instead of "dose commitment" in the following.

(2) "Concentrations in air above ground"

This column shows concentration in air above the ground of a nuclide which, transferring to a child through inhalation, ingestion of leafy vegetables and of cow's milk, gives the annula dose of 1 mrem to his critical organ. Tranfer models used here are provided in the Japan Atomic Energy Commission's guide for evaluating environmental dose from routine releases of LWRs effluents to meet the Criterion "As low as is practicable(ALAP)". If the milk pathway is ignored, the figures would be about 10 times larger than these.

(3) "Concentration in surface sea"

When fish, invertebrates and seaweeds produced in the sea with these concentrations are taken by a child for a year, he receives the annual dose of 1 mrem. The calculational models are given also in the guide mentioned above.

(4) "Concentration in potable water"

The figures correspond to a child's annual dose of 1 mrem when he always drinks this water. The evaluation is based on the model by the committee 2 of the ICRP.

(5) "Concentration in irrigation water"

A pathway of ground water-soil-rice is accounted for. The figures correspond to a child'annual dose of 1 mrem taking this rice for a year.

(6) "Concentration in deep sea"

These concentrations are applied to disposal of radioactive solid wastes both into deep ocean and into deep rock. For the former case, the figures are concentrations in packages defined as follows: Annual dumping rates of radioactivity resulting to the concentrations shown in column (3) can be estimated using diffsuion models discussed in "Assessment on Environmental Safety of Test Ocean Dumping of Wastes" by Nuclear Safety Bureau, Science and Technology Agency.

Co-60	2×10^6 Ci/y
Sr-90	6×10^4 Ci/y
Cs-137	1×10^6 Ci/y
U-237	1×10^{-2} Ci/y
Pu-239	3×10^2 Ci/y

Assuming dumping of 1×10^4 packages of 200-l volume per year, the average concentrations in a package are calculated to be those in this column, "Dilution Factors" are defined to be the ratios of concentrations in the surface sea to those in the deep sea. Though the wastes are not continuously disposed of in case of deep geological formation, the leaching rate of radioactivity from the package is usualy defined, which gives a transfer rate ($Ci/y/m^2$) at the bottom of the deep sea. Consequently, this case can be evaluated by the same way as the case of ocean-dumping. The concentration in the surface sea can not be said theoretically to reach the stationary state, but an approximately stationary concentrations can be considered as all the nuclides are long-lived and, furthermore, they leach very slowly through the rock.

(7) "Critical organ"

The organ in this column are those defined as the critical organ by the ICRP.

2. Symbols

(1) Disposal region

(●→) shows the region where the radioactive wastes are disposed of.

(2) Transfer pathway of radioactive materials from the wastes

(⟶) shows transfer paths of radioactive materials leached from the disposed wastes which correspond to those drawn in the Figure. (---) means that the radioactive materials do not transfer through this medium.

3. Discussion of the figures in the Table

(1) Certainty of values

The values shown in the left column in the table are in general more uncertain than those in the right columns.

(a) "Annual intakes"
These values are obtained from the ICRP models and biological parameters which are based on a lot of knowledges and scientific information.

(b) "Concentration in air"
Environmental transfer models and included parameters on which these values are based are very confident because the JAEC discussed them for the provision of the ALAP guide.

(c) "Concentration in surface sea"
The transfer model applied here dose not contain many uncertain parameters which influence the values in this column. The most important parameter is the bioaccumulatin factor of marine food, and there are, at present, lots of investigation and studies on this parameter.

(d) "Concentrations in irrigation water"
There are neither available models nor good transfer parameters for the pathway adapted here. The transfer factors from soil to rice are obtained only for Cs-137 and Sr-90 from the fallout investigations. Some data are found for Co-60 in laboratory experiments, but there is very little for the TRU isotopes.

(e) "About columns without figures"
The columns each of which a circle is attached to are the part where it is impossible to prepare any values at present. Site-specific conditions may be able to give values to some of them when a repository site is chosen, but it shoould be noticed that most of them can not be filled without more researches.

(2) Effects of the multinuclide condition of the wastes

It is emphasized that the resultant effects of all the nuclides invloved in the wastes should be considered, in practice, on the basis of these values in the table which are introduced on the assumption that the wastes involve only a nuclide of interest.

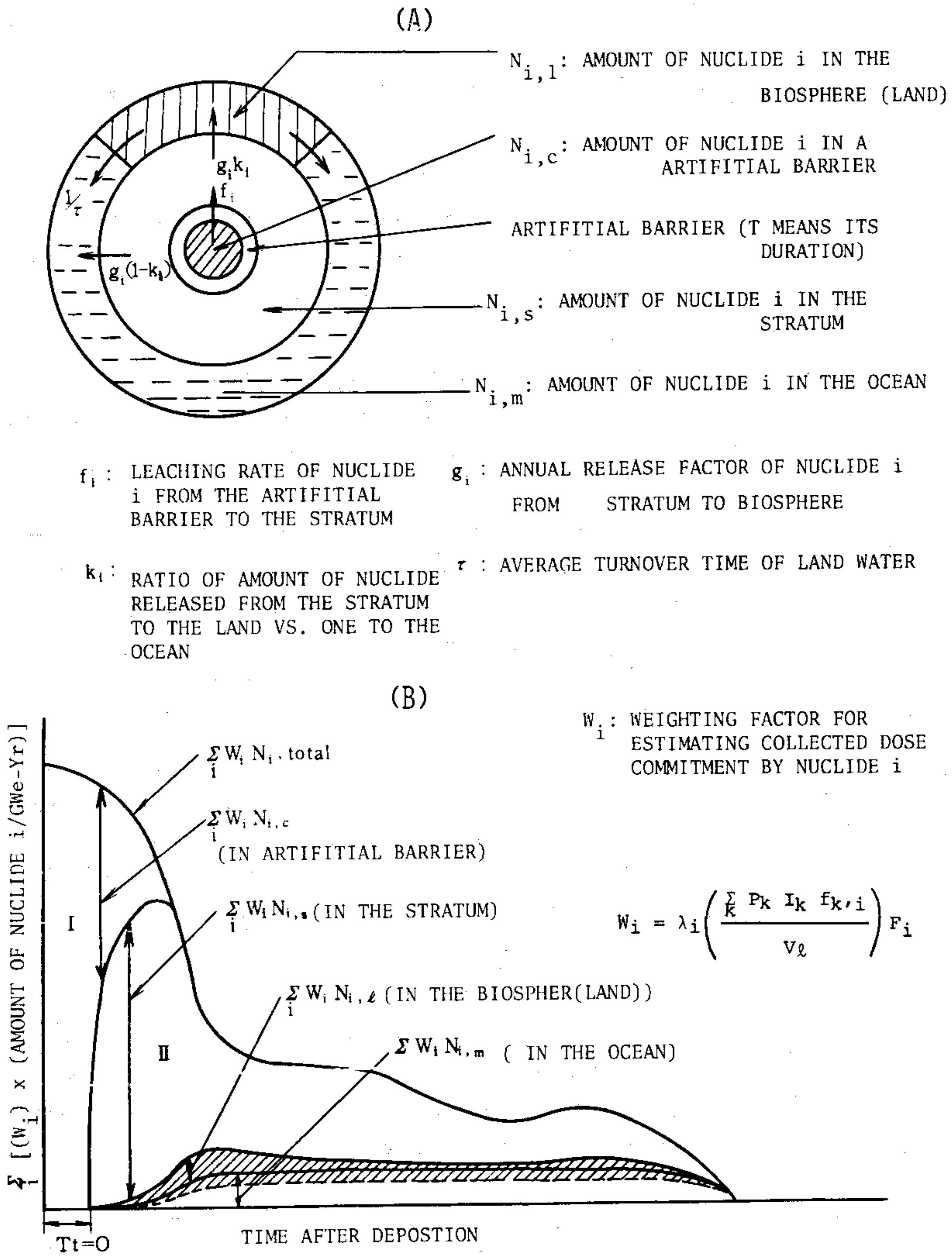


Fig. 20 COLLECTIVE DOSE COMMITMENT BY DEPOSITED RADIOACTIVE WASTE IN THE STRATUM

Explanation for Fig. 20

1 According to the definitions given in the upper figure, number of nuclide i which is contained in each region is calculated by following equations.

in the artificial barrier

$$\frac{dN_{i,c}}{dt} = \underbrace{-N_{i,c}\cdot\lambda_i}_{\text{decay}}\ \underbrace{-N_{i,c}\cdot f_i}_{\text{leaching out}}\ \underbrace{+N_{i-1,c}\cdot\lambda_{i-1}}_{\text{decay of the parent nuclide}}$$

in the stratum

$$\frac{dN_{i,s}}{dt} = \underbrace{-N_{i,s}\cdot\lambda_i}_{\text{decay}}\ \underbrace{-N_{i,s}\cdot g_i}_{\text{leak to biospher}}\ \underbrace{+N_{i-1,s}\cdot\lambda_{i-1}}_{\text{decay of the parent nuclide}}\ \underbrace{+N_{i,c}\cdot f_i}_{\text{supply from the artificial barrier}}$$

in the biosphere(land)

$$\frac{dN_{i,l}}{dt} = \underbrace{-N_{i,l}\cdot\lambda_i}_{\text{decay}}\ \underbrace{-N_{i,l}\cdot\frac{1}{T}}_{\text{move to the ocean}}\ \underbrace{+N_{i-1,l}\cdot\lambda_{i-1}}_{\text{decay of the parent nuclide}}\ \underbrace{+N_{i,s}\cdot g_i\cdot k_i}_{\text{leak from the stratum}}$$

in the ocean

$$N_{i,m} = N_{i,total} - (N_{i,c} + N_{i,s} + N_{i,l})$$

2. Collective dose commitment can be estimated using $N_{i,l}$ and $N_{i,m}$ by following equation considering several food path ways.[1)]

$$S_E^C = \sum_i \int_0^\infty \left(\frac{N_{i,l}\cdot\lambda_i}{V_l} \sum_k P_k I_k f_{k,i} + \frac{N_{i,m}\cdot\lambda_i}{V_m} \sum_k P_k I_k f_{k,i} \right) F_i dt$$

where

V_l is the volume of receiving waters in the land.

V_m is the volume of the diluting water in the ocean.

P_k is the number of individuals exposed by pathway K.

I_k is the individual consumption rate of pathway K.

$f_{k,i}$ is the concentration factor for the consumed item in pathway k for nuclide i.

F_i is the collective effective dose equivalent per unit activity ingested collectively by the exposed group.

3. To express the total collective dose commitment for every nuclide in one figure, " weighting factor for estimating collective dose commitment" , W_i was used which is defined as following expression

$$W_i = \lambda_i \frac{(\sum_k P_k I_k f_{k,i})_l}{V_l} F_i$$

4. The change of the value is shown by the lower figure, the value being obtained by summing the product of W_i and number of nuclide contained in each region. In this case, total erea($\int_0^\infty \sum_i W_i N_{i,total} dt$) represents the potential hazard of total nuclide originated from 1 GWey electric generation.
The area I and II ($\int_0^\infty \sum_i W_i N_{i,c} dt$ and $\int_0^\infty \sum_i N_{i,s} dt$, respectively) means reduced hazard by the decay of nuclides in the artificial barrier and in the stratum, respectively.
The effect of nuclides in the ocean was assumed one thousandth of that of nuclide of equal number in the land.
The hatched area corresponds to the collective dose commitment per GWey waste after deep geological isolation.

3. RECOMMENDATIONS

71. Considering the safety and environmental objectives of nuclear waste management such as:(i) to comply with radiological protection principles for present and future generations derived from the ICRP recommendations;(ii) to preserve the quality of the natural environment; and (iii) to minimize any impact on future generations to the extent practicable, and notably the present status of waste management techniques and the likely development of nuclear energy programmes, the Group presents the following conclusions and recommendations:

72. In order to achieve these objectives, it should be noted that waste management has to be undertaken within satisfactory systems of control, with due attention to the minimization of waste arisings through the selection of appropriate processes, and to the strategic siting and planning of nuclear operations.

73. To realize the satisfactory systems of control, the respective, responsible and central organization should be clearly established in the nation for investigating, designing and administrating the management and operation of the systems. This athourized organization may provide the best guarantee for adopting the most appropriate solutions and maintaining administrative control and possible surveillance as required over the steps of waste treatment and disposal.

74. The following functions should be provided for executing investigation and design undertaken by the organization:

1. to consolidate relevant technical informations on waste treatment and disposal in national and international regimes, and examine them systematically;
2. to build up strategies taking into account the evaluated technical informations, then to design working plan of each task derived from strategies;

3. to classify the working plan into three strata by such tasks concerning for establishment of management system, safety and environment assessment, and regulation, with clarified targets in time;
4. to clarify tasks in short-, intermediate- and long-term items taking into account technical evolution with time, and to assess necessary funds, manpowers and legal arrangements corresponding to each evolution for the government, industry and the third party, respectively.

75. It is important that the periodic check and review of the systems are undertaken, and some corrections on either strategies or working plans, if necessary, might be required to avoid misleading the way in finding better systems.

76. The most important plan but being difficult to set up related to establish the systems is how can we find the approach to acquire public acceptance against waste treatment and disposal. Some analyses made by the Group on socio-ecological problems are illustrated in Fig. 21. It seems to the Group that a train of trustworthy operations of tasks in the manner of accumulating results obtained step by step will be one of the key issues for public people. Simultaneously, the survey of public-opinion should be taken periodically on the waste management in order to develop the better approach and procedure to ensure in obtaining public acceptance.

77. From the detailed technical analysis made by the Group of Experts, it can be concluded that:

1. Reduction of waste arisings and discharge of radioactive effluents into the environment

   Necessary research , development and demonstration work should be pursued on control and accounting techniques for improvement of material balance at any nuclear facility and on improvement of waste treatment techniques to reduce waste arisings. Some measures will have to

1. SOCIAL STRUCTURE AND PUBLIC ACCEPTANCE

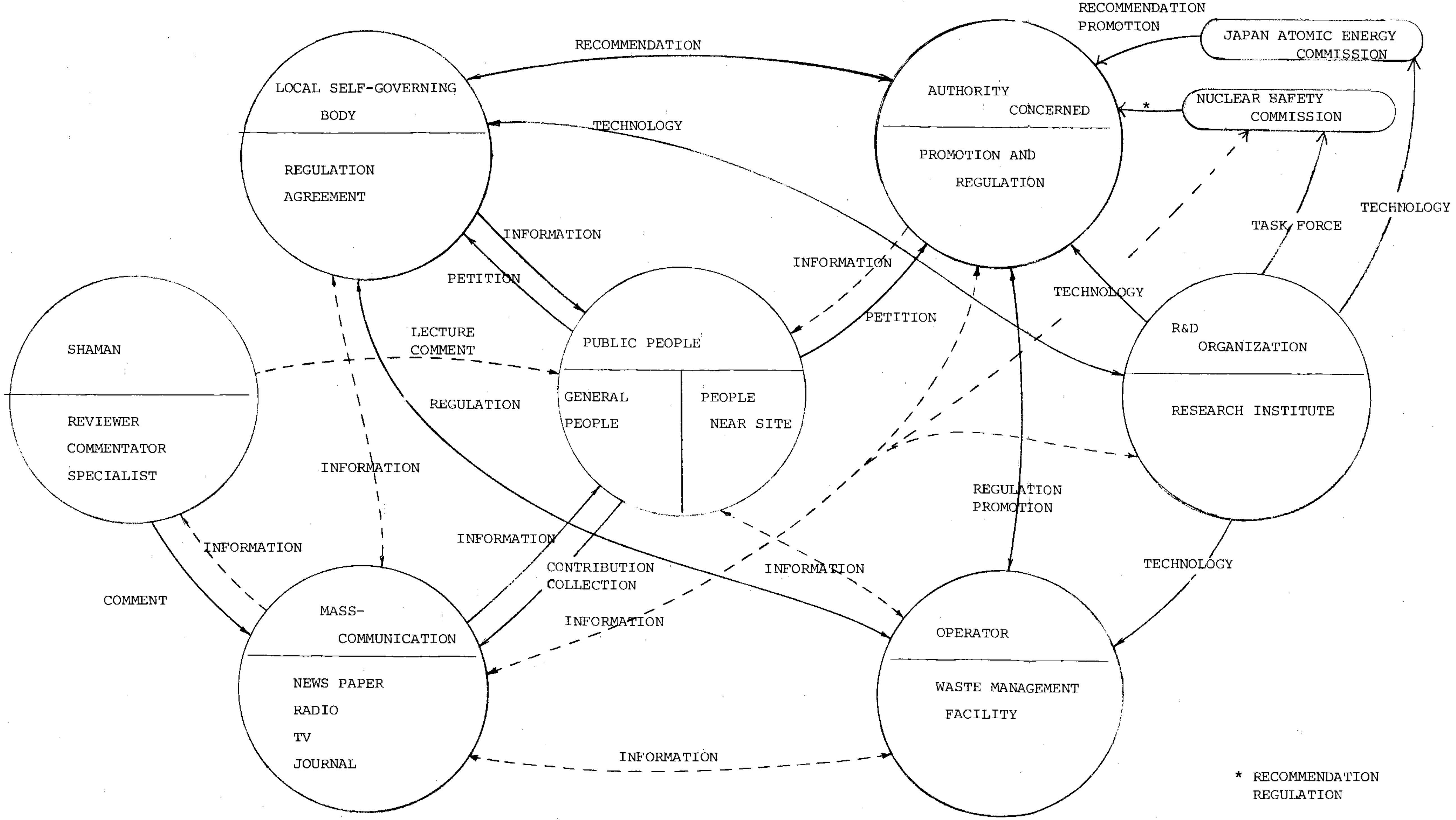
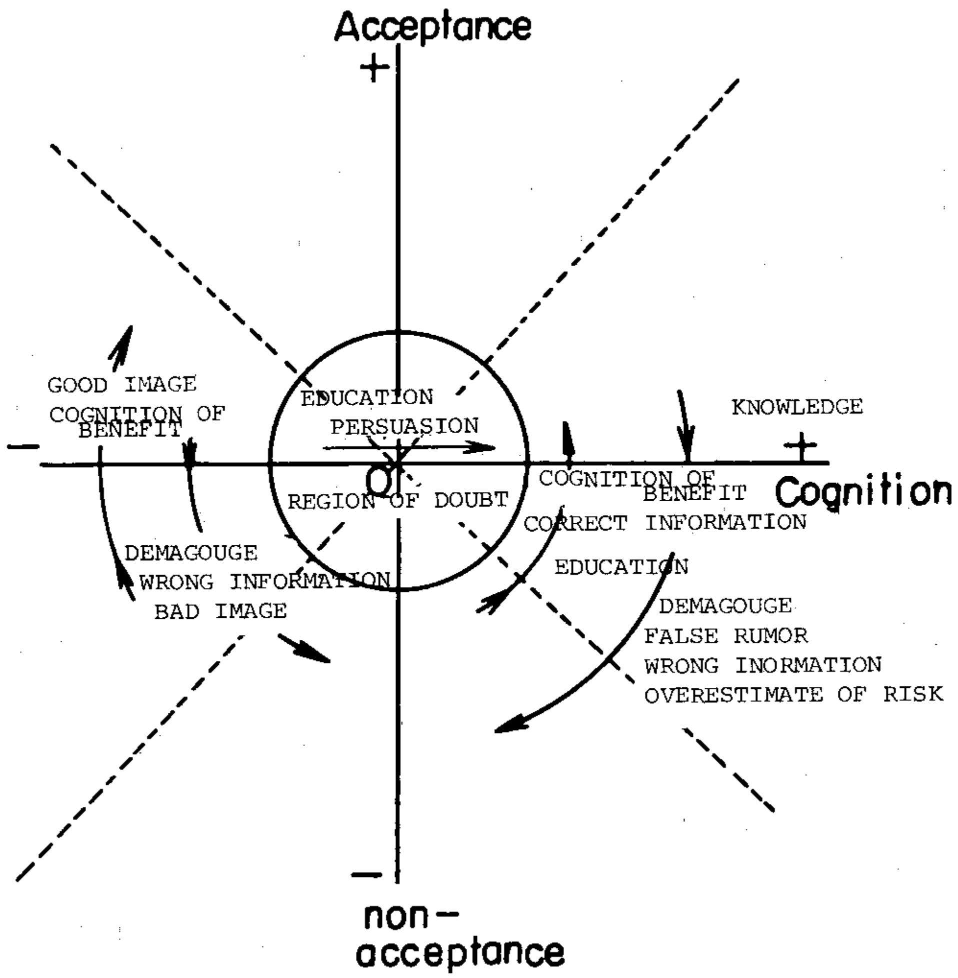


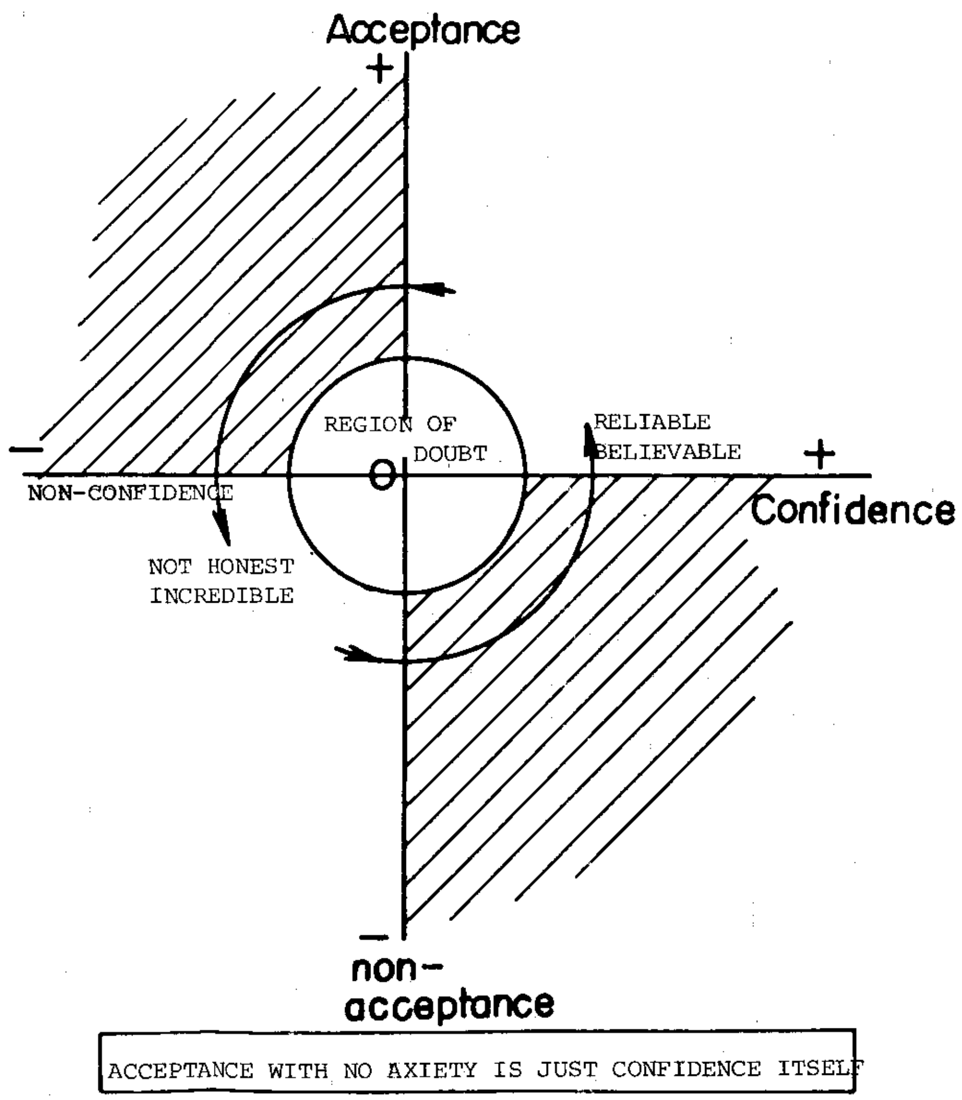
Fig. 21 SOCIAL ENVIRONMENTAL CONSIDERATION ON RADIOACTIVE WASTE MANAGEMENT AND ITS PUBLIC ACCEPTANCE (I)

2. STRUCTURE OF HUMAN ENVIRONMENT

A. RELATION BETWEEN ACCEPTANCE AND COGNITION



B. RELATION BETWEEN ACCEPTANCE AND CONFIDENCE



C. STRUCTURE OF COGNITION

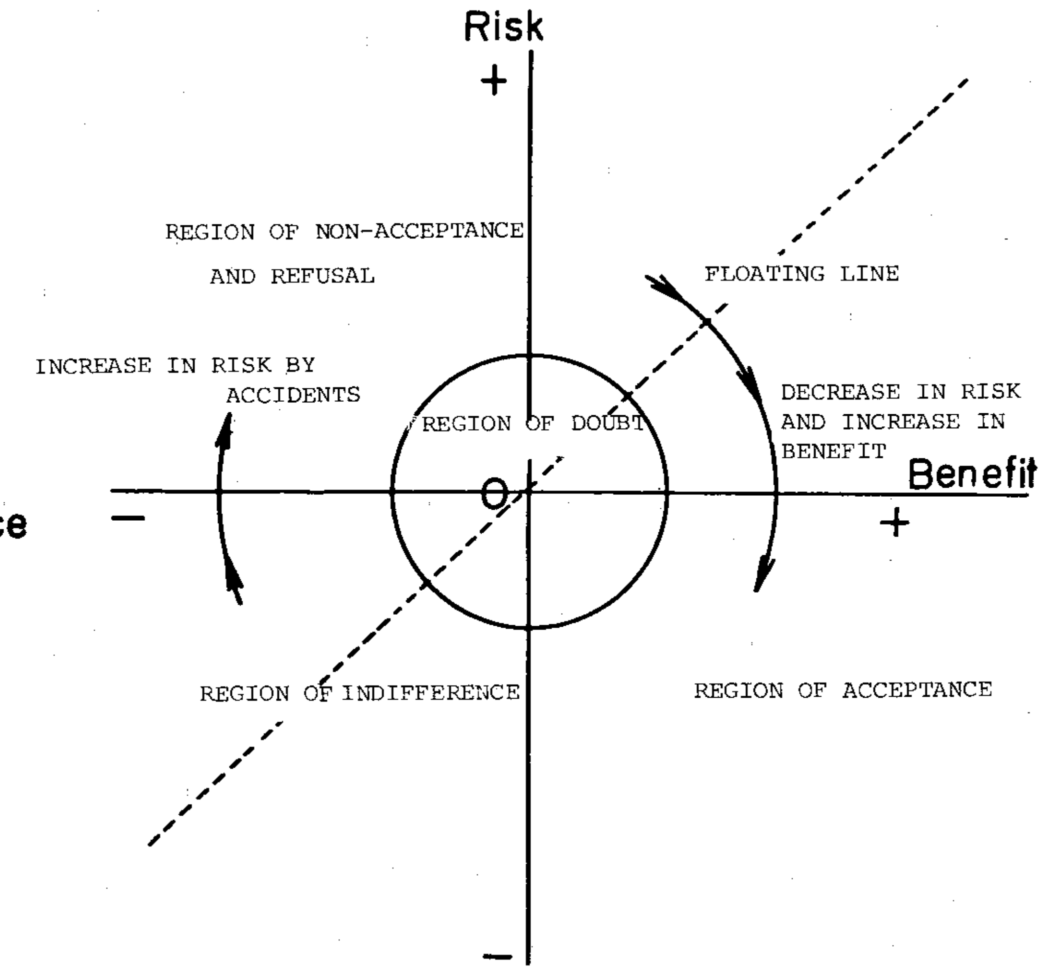


Fig. 21 SOCIAL ENVIRONMENTAL CONSIDERATION ON PUBLIC ACCEPTANCE CONCERNING WASTE MANAGEMENT (II)

be taken in due course on the basis of additional R&D to limit the release of some gaseous and volatile radionuclides particularly from reprocessing facility. Nuclear facilities have been designed essentially for operational safety and performance, without much regard to their subsequent decommissioning. It appears desirable to minimize the complications which can arise, by taking the decommissioning at a nuclear facility into account at its design stage.

2. RD&D on waste treatment and disposal

a. Safe waste disposal practices, such as shallow burial on land, disposal into geological formations on land and sea dumping, are already in use for less radioactive types of waste which do not require long-term containment. Land barrier possibilities depend on local geographical and hydrological conditions. For sea dumping the international legal framework such as London Convention adopted assures that radioactive containment of the marine environment will be kept within the limits required for radiological protection purposes. If sea dumping is preferred as a solution for low-level waste disposal, then it has to be implemented in conformity with international protocols and agreements. For large volume wastes free from significant alpha contamination, disposal solution might be sought preferably in a national framework by such a way of a land burial.

b. For high-level waste, solidification techniques have been developing and demonstration facilities on an industrial scale is planned. For cladding hulls and alpha-bearing waste, the period of storage on site will depend, as for high-level waste, on the availability of longer-term storage and disposal facilities. The objective of nuclear waste management for long-lived wastes is to ensure the required degree of isolation from people over a time scale which precludes completely any form of reliance on long-term surveillance. It is essential to be assured that the safety and reliability of disposal method are sufficient for the type of waste and amounts involved before it is implemented. Meanwhile, the current practice of storing long-lived wastes in engineered facilities provides an adequate degree of safety.

Therefore, the following management scheme is recommended as a result:

(1) Cascade system

The system proposed here is as follows: a 30 years period in time for engineered storage is regarded as one unit, and, for the time being, the intensive RD&D work should be pursued on the most promising long-lived wastes disposal techniques with a view to confirming the validity of the proposed solutions. If above activities are not enough to confirm the solutions, then the work will be continued to pursue still next 30 years. Thus, the RD&D work for establishing management system on long-lived wastes can be performed with sufficient practical experience to obtain public acceptance.

(2) Multi-barrier system

It seems that the dependence on natural barrier only will not be sufficiently reliable for practice of storing long-lived wastes. Therefore, strengthening artificial barrier using multiple layers can be effective. The effectiveness of the barrier system such as a combination measure of natural and artificial barriers should be assessed and developed to reach a high degree of safety without unnecessary costs for establishment of the management.

(3) Geologic disposal on land

Geologic disposal on land is a primary candidate for above works, and disposal into geological formations under ocean floor should be also investigated and evaluated.

78. Taking into account the nature and long-term character of nuclear waste management, and the relative uncertainties

about final cost of disposal, the possible delays between waste arising and implementation of management scheme, it is highly desirable to set forth specific provisions for resources such as funds and manpower.

JAERI-M 8592 正誤表

頁	行	誤	正
(2)	上 5行	verfication	verification
(3)	下 15行	人類に与える影響	人類に与える影響
(7)	下 3行	Comparision	Comparison
(9)	上 13行	accomodation	accommodation
2	下 5行	establised	established
5～(6)	上 2行	steay	steady
〃	上 5行	arised	arisen
〃	上 7行	arised	arisen
〃	Table	VALIABLE	VARIABLE
11～12	Fig. 3 2列目上	CNVERSION	CONVERSION
〃	〃 3列目下	GIOLOGICAL	GEOLOGICAL
14	Fig. 4 最後の行	ARISED	ARISEN
21～(22)	上 8行	Table 4	Table 5
25～(26)	NOTE	ACCODING	ACCORDING
27～28	Table 4 1列目8行	HARDEND	HARDENED
29	Fig. 9 タイトル	COMPARISION	COMPARISON
31	Fig. 11 タイトル	(U-PuCYCLE)	(U-Pu CYCLE)
〃	Fig. 11 上部	REQUIRE**	REQUIRED**
〃	〃 中部	PITCHBEEND	PITCHBLENDE
32	上 1行	Fig. 11	Fig. 4
〃	上 4行	Horrizontal	Horizontal
〃	上 7行	figure shows	figures show
33～34	Fig. 12 2列目	RADIOCATIVE	RADIOACTIVE
〃	〃 3列目	SUPPRESION	SUPPRESSION
35～(36)	下 1行	highten	heighten
37～38	Fig. 13 右3列 上3行	ARTIFITIAL	ARTIFICIAL
〃	〃 右4列 下1行	LONDON TREATY	LONDON CONVENTION
〃	〃 右4列 上2行	IMPORVEMENT	IMPROVEMENT
〃	〃 左2行 上2列	REDUCTIN	REDUCTION
39～40	Fig. 14 左4列 下1行	WASET	WASTE

JAERI－M 8592 正誤表(続)

頁	行	誤	正
41～42	Fig. 15 右5行 上2列	INTERIUM	INTERIM
51～52	Fig. 17 右5行 下3列	BITUMENIZATION	BITUMINIZATION
〃	〃 右5行 下1列	〃 〃	〃 〃
〃	〃 右3行 上4列	GENELATION	GENERATION
〃	〃 右2行 上4列	〃 〃	〃 〃
53～(54)	下 5行	Table 5	Table 4
55～56	下 5行	NIS (Nucll. Eng. ……)	NIS (Nucl. Eng. ……)
58	Fig. 18 中央上部	DEFRRED	DEFERRED
63～64	Table 6 左3列	ART-IFITIAL	ART-IFICIAL
65～66	〃 〃	〃 〃	〃 〃
67	上 6行	assumptin	assumption
〃	上 16行	annula	annual
68	上 6行	diffsuion	diffusion
〃	上 12行	U-237	U-238
〃	上 19行	usualy	usually
69	上 16行	bioaccumulatin	bioaccumulation
〃	下 7行	shoould	should
70	上 4行	ARTIFITIAL	ARTIFICIAL
〃	上 5行	〃 〃	〃 〃
〃	(A)図 fiの説明	〃 〃	〃 〃
〃	(B)図 中 央	〃 〃	〃 〃
〃	〃 横 軸	DEPOSTION	DEPOSITION
71	上 8行	biospher	biosphere
〃	〃	artifitial	artificial
〃	下 10行	$\cdots\int_0^\infty(\cdots\cdots)F_{idt}$	$\cdots\int_0^\infty(\cdots\cdots)F_i dt$
72	上 7行	erea	area
73	下 14行	athourized	authorized
77～78	左 図	WRONG INORMATION	WRONG INFORMATION
〃	中央下	NO AXIETY	NO ANXIETY