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Reduction of releases of radioactive effluents from light-water-power-reactors in Japan

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1. Introduction

Japan Atomic Energy Commission has established the dose objectives to the population arround the light-water-reactors in May, 1975, based on the "ALAP" concept.

These values are respectively, 5 mrems per year for total body and 15 mrems per year for thyroid of an individual in the critical group in the environs, due to both gaseous and liquid effluents from LWRs in one site.

The present paper describes the implications of the dose objective values, control measures which have been adopted to reduce releases of radioactive materials and related technical developments in Japan.

2. Dose objective values for light-water-power-reactors

In Japan, at present, twelve commercial nuclear power reactors (one magnox reactor and eleven light-water-reactors) are in operation, and twelve light-water-power-reactors are under construction.

For light-water-power-reactors, some of the techniques of reducing the release amount of radioactivities have become practicable based on operational experience and also future reduction techniques are expected as described in the following sections.

Japan Atomic Energy Commission, considering the above situation, has established the dose objectives to the population around the light-water-power-reactors in May, 1975, based on the concept "doses be kept as low as practicable", of ICRP. These values are respectively, 5 mrems per year for total body and 15 mrems per year for thyroid of a typical individual in the critical group in the environs, due to both radioactive gaseous and liquid effluents from light-water-power-reactors at a particular site. Dose objective values for less critical organs have not been given.

Dose objective values should be implemented as a guidance to both design and operational control of light-water-power-reactors. The legal permissible dose outside the restricted area, 500 mrem per year, is not altered.

For the construction permit, doses should be estimated using realistic calculation models with realistic parameters such as in meteorology and food chain for a typical member, especially related to dietary custom, and agricultural and fishery characteristics arround a particular site.

Operational control should be made based on controlling standards of radioactive effluent release such as total yearly releases and average release rates, to meet the above-mentioned dose objectives, depending on the operating mode of releases.

3. Reduction of release amount of radioactivities in effluents

Tsuruga Nuclear Power Station is the first commercial LWR in our country and whose history of construction and operation until now is at the same time the history of typical reduction programme of radioactive effluent from an LWR in our country.

Tsuruga Station is a 357 MWe GE-BWR. Its construction programme started in 1966 and the first generator synchronization was achieved in November 1969. Its radioactive effluent treatment system was originally designed by GE with standard US practices, but several improvements were introduced in the system design or operational management during both construction and operational stages to enable us to reduce radioactivity releases from the station to the environments.

a. Gaseous Effluent Reduction

Tsuruga Station has started its operation in early 1970 with one-day gas hold-up system for main condenser off-gas treatment, but this system was proved to be less reliable than expected after nine months, on account of poor integrity of gas compressor diaphrams.

Efforts to overcome this problem and positive attitude for further reduction of the gaseous releases from the plant to meet the concurrent ALAP guide lines had finally resulted in introduction of a new gas hold-up system, using gas chillers, activated charcoal columns and air-operated eductors. This system started its operation in late 1971 to achieve gas decay of about 40 hours for Kryptons and 30 days for Xenons.

The major components of this new system have no mechanical moving part and this contributes so much to high reliability of this system until today and probably for future services. Owing to this system being in service, the released gaseous radioactivity showed a remarkable reduction down to less than 4% of the former average statistics.

Now that the main condenser ejector off-gas is decayed down to very low value, the remaining sources of gaseous wastes are turbine shaft seal packing steam exhausters and building ventilation including radwaste tank vents. A new shaft packing system using clean steam is under construction for the LP turbine which will be completed in mid 1977. This may accomplish further reduction of gaseous releases to about two-thirds.

For the plants of latest design, a high stack venting of all ventilation exhaust is proposed to eliminate roof venting of turbine building ventilation in order to reduce resulting exposures to the off-site public. Tank vent filtration to remove iodines is also under development for its practicable effectiveness for dilute gases from tank vents and for its cost to run with long term reliability.

b. Liquid Effluent Reduction

As the plant was operated, contaminations in the primary system was increasing, and contamination maintenance was getting more frequent especially during refueling outage which gave rise to higher radioactivities in the laundry drains. In the middle of 1975, an activated charcoal bed filter system was introduced for the treatment of laundry drain to achieve a practical release reduction of 1/2 to 1/10.

For the liquid effluent, however, there still seem to remain some problems to be resolved for future reduction.

1) Radwaste Concentrators: We have succeeded in the concentrator processing of floor drains, however, with the sacrifice of large fuel consumption and relatively frequent corrosion of concentrators. Large fuel consumption is resulted from the higher dependence on the concentrators as a steady operable alternative due to less reliable performance of other process equipment. Corrosion is resulted from the floor drain concentration since floor drains may be often contaminated with calcium, sea water or manganse acid.

2) Laundry Drains: Laundry drains contain residual detergent and suspended solids which make further reduction treatment difficult. Charcoal bed filtration is proved to be only one resort now applied in practice for about 10,000 tons a year

of laundry drains with annual generation of about 50 drums of spent charcoal. Alternative treatment systems with higher DF, less secondary waste generation and easier maintenance are so expected for development in order to meet social concerns on environmental protection today, since laundry drains are now only main source of environmental releases of liquid wastes.

3) Crud production in primary system: Some BWR plants are suffered from high crud generation in the reactor feed water line which gets activated in the reactor and is trapped in the process radwaste system through equipment drains or collected in the laundry effluent by way of worker's contaminated working suit. Very small fraction of these trapped or collected crud is finally released into environment which form considerably larger portion of released activities. The reduction of crud production can surely play a remarkable role in the reduction of liquid effluent from BWR.

4) Solidified Waste: Reduction of liquid effluent into the environment might counterbalance larger accumulation of solidified waste which would give rise to another point to be resolved for the final treatment. Chronological discharge of radioactive effluents from Tsuruga Station is shown in Fig. 3. Annual discharges from all operating LWRs in Japan is shown in Table 1.

Generally speaking, PWRs have essential advantage to BWRs about effluent treatment system. Because the primary coolant system of PWR is of closed system and confined in less extent and liquid waste is generated in smaller volume.

There are some examples.

1) As concentraror load is low, fuel consumption is small.
2) The corrosion problems of concentrator caused by sea water contamination is resolved by introducing intermediate cooling system in the primary containment.
3) Stainless steel and corrosion inhibitors in the primary coolant system contribute to less crud generation.

But, it still remains inpracticable to sense boron in feed-breed cycle of borated water since bred solution is poor in chemical purity.

This is, therefore, one of problems to be resolved in due course of time.

For research reactors, reduction of release of effluents has also been carried out in a similar way to LWRs. For example, in JRR-2 the release amount of ^{41}Ar has been reduced both by adding a decay duct for irradiated air and sealing the irradiation holes.

4. Technical Development

4.1 Techniques for further reduction of radiation exposure

The release amount of radioactive material has been kept within the ALAP guidelines in Japan. Considering the future multi-unit site, however, the following new techniques are being developed for further reduction of radiation exposure. Besides these, valves of leak off and bellows seal types have been applied partly and will be used more widely.

a Reduction of radioiodine leakage

A tank-vent filtration system has been developed to remove such iodine as contained in vent gas from equipments and sampling hoods. It uses a silver impregnated adsorbing agent under consideration for reducing exposure dose rate both to inhabitant around the site and to operators in the power station.

As to iodine removal, activated charcoal including the one impregnated with iodide is widely known for a typical adsorber. However, the activated charcoal has essential disadvantage of very poor performance especially under higher relative humidity.

The effect of silver content on methyl iodide removal efficiency has been examined using various base materials. It was confirmed that activated alumina (8,9) and silicagel can achieve high removal efficiency with less silver content, as shown in Fig. 4.

b Removal of krypton (10-12)

A ^{85}Kr removal system based on cryogenic technique (Fig. 5) has been developed for a part of the off-gas treatment system. Oxygen and hydrocarbon such as acethylene is removed by pre-treatment apparatus composed of platinum and palladium catalyst to prevent potential undesirable detonation due to accumulation of oxygen and hydrocarbon in the distillation column. Carbon dioxide and water moisture is also removed by molecular sieve column to suppress plegging in the succeeding system.

Distillation column is operated at about - 196°C (liquid N_2 temperature). Krypton is finally stored in a cylinder in gaseous phase after purification in batch column.

Decontamination factor of distillation column with 1,000 mm height is more than 10^7.

c Treatment of laundry drain waste

Laundry drain waste treatment systems have been developed by several organizations in Japan. (13)

The system developed by Hitachi is a skid mounted type, consisting of a reverse-osmosis unit and an evapórator in series.

Scale deposited inside membrane made of cellulose acetate is periodically cleaned out with sponge ball circulation developed by Hitachi originally. Permeate passing through membrane is recovered for reuse after further purification by mixed bed demineralizer.

Decontamination factor of reverse-osmosis unit tested at an operating Nuclear Power Station has been proved to be very sufficient as high as 10^3 - 10^4. Concentrate from reverse-osmosis unit is further concentrated by evaporator for volume reduction.

Undesirable foaming problem during evaporation process has already been solved by antifoaming agent like silicone oil.

d Plant personnel exposure reduction

The following techniques are being developed for the reducing plant personnel exposure.

1) Reduction of crud in a primary coolant

One of the significant means to decrease plant radiation level is to reduce amount of corrosion products which are carried into the reactor vessel and activated by neutron exposure in the reactor core.

Following two measures are demonstrated promising to reduce corrosion product concentration in the feedwater;

(i) Application of powdered resin type filter-demineralizer as the prefilter of deep-bed type condensate demineralizer, and

(ii) Control of oxygen concentration in the feedwater to reduce crud concentration.

Operational experience demonstrated that the powdered resin type filter-demineralizer was effective to minimize the crud level at the outlet of condensate demineralizer. The filtration efficiency exceeded 90%.

The corrosion inhibition effect in the feedwater line was obtained by injecting oxygen into the feedwater to keep the oxygen concentration at between 20 to 50 ppb. This method had been known through corrosion tests as well as through the experiences in operating BWRs.
Several tests on oxygen injection were performed as means of reducing feedwater crud and obtained the reduction of more than 90%.

For further reduction of the plant dose, studies are being made on (i) alternate materials for cobalt alloy to reduce the cobalt source which significantly contributes to shutdown radiation level and on (ii) new filter without filter aid such as etched disc filter to reduce radioactive waste.

2) Automatic CRD handling machine

An automatic control rod drive (CRD) handling machine (Fig. 6) has been developed for the removal and reinstallation of CRD units to save time required for maintenance working and to make significant reduction of personnel radiation exposure.

This machine has such remarkable advantage that CRD handling time will be reduced to half and personnel radiation exposure will be reduced to one-tenth in comparison with the present method.

3) Eddy current testing system

An engineered eddy current inspection system has been developed and employed for steam generator inspection. Personnel radiation exposure of the inspectors is minimized, while exposure during setting and removal of the machine will be reduced through further development.

4.2 Techniques for monitoring exposure from gaseous effluents

Technical development has been made in JAERI for measuring low-level gamma radiation exposure down to 5 mR per year due to gaseous effluents from nuclear reactors, using an NaI(Tl) scintillation exposure rate meter with flat energy response.[1-3] Following two methods have been studied for measuring environmental radiations from nuclear facilities discriminating the fluctuating natural radiation.

First technique is to employ an equipment [4] of a 2 x 2-inch NaI(Tl) scintillator and two separate electronic units; an exposure rate meter having a pulse height weighting circuit for flattening the energy response and a single channel pulse height analyser. Natural radiation has wide energy spectrum distribution up to 2.62 MeV, and the intensity changes with time rather uniformly in wide energy range.

Therefore, one can measure the environmental radiation from nuclear facilities by taking the differential between total gamma radiation in full energy range and natural gamma radiation in the higher energy channel. Results of the test was satisfactory for measuring increases in exposure less than 1 mR/yr of gamma radiation from ^{41}Ar cloud under natural fluctuation of background and showed a good stability in a long-run operation in the field.

Another technique (5) is to measure selectively gamma radiations from gaseous effluents by directly shielding the natural radiations from the ground. The NaI(Tl) scintillator with lead wall shield on the lower part is mounted above the ground as shown in Fig. 1. Thus, response of the detecter to natural radiations decreases by a factor of 3 or so.

Measurements of the exposure rate from ^{41}Ar clouds during rainfall are shown in Fig. 2 (6) for comparison of the two method described above.

Applying the same technique as described above, a new stack monitor is designed (7) consisting of a NaI(Tl) scintillation head with a specially designed lead shield cap and an electronic circuit for pulse height weighting to measure the photon energy dissipating rate, the photon dissipating rate and the average energy. It is shown that this method is to simplify the procedures and to improve the accuracy in estimating gamma exposure from mixed radioactive gaseous effluents.

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Table 1 Radioactivity discharged in effluents from LWR's in Japan

Type	Reactor	Fiscal Year	Electricity generated MW(e)h	Airborne Effluents: Noble Gases (Ci)	Airborne Effluents: Iodine-131 (Ci)	Liquid Effluents: Gross Activity excluding Tritium (Ci)
BWR	Tsuruga	1970	$2.4x10^6$	$1.3x10^5$	0.38	1.8
		1971	$2.2x10^6$	$4.2x10^4$	1.06	0.17
		1972	$2.3x10^6$	$4.9x10^3$	0.24	0.21
		1973	$2.5x10^6$	$5.2x10^3$	0.20	0.20
		1974	$1.5x10^6$	$5.6x10^3$	0.28	0.29
		1975	$1.4x10^6$	$1.2x10^3$	0.02	0.46
	Fukushima 1	1970	$6.6x10^4$	$1.2x10^3$	-	1.2
		1971	$2.7x10^6$	$7.0x10^4$	0.06	3.0
		1972	$2.6x10^6$	$9.7x10^4$	0.25	0.26
		1973	$2.0x10^6$	$4.9x10^3$	0.79	0.22
	Fukushima 1	1974	$1.1x10^6$			
	2		$3.2x10^6$	$1.4x10^4$	0.34	0.18
	1	1975	$6.6x10^5$			
	2		$1.1x10^6$	$1.6x10^4$	0.05	0.16
	Fukushima 3	1975	$9.4x10^4$	7.3	0.0	< 0.1
	Shimane	1974	$3.0x10^6$	ND	ND	< 0.1
		1975	$3.1x10^6$	ND	ND	< 0.1
	Hamaoka	1975	$2.6x10^6$	8.7	$6.7x10^{-5}$	< 0.1
PWR	Mihama 1	1970	$7.0x10^5$	$9.0x10^2$	-	1.6
		1971	$2.2x10^6$	$1.4x10^3$	-	0.15
		1972	$1.1x10^6$	$6.2x10^2$	-	< 0.1
		1973	$8.2x10^5$	$5.1x10^2$	-	< 0.1
		1974	$2.2x10^5$	$7.0x10^1$	-	< 0.1
		1975	-	$1.4x10^1$	< 0.1	< 0.1
	Mihama 2	1972	$2.1x10^6$	$2.6x10^2$	-	< 0.1
		1973	$2.4x10^6$	$3.4x10^2$	-	< 0.1
		1974	$2.8x10^6$	$3.4x10^2$	-	< 0.1
		1975	$1.2x10^6$	$2.9x10^2$	< 0.1	< 0.1
	Takahama 1	1974	$2.3x10^6$	$7.1x10^1$	ND	< 0.1
		1975	$3.9x10^6$	$1.3x10^2$	< 0.1	< 0.1
	Takahama 2	1975	$2.1x10^6$	$8.1x10^1$	< 0.1	< 0.1
	Genkai 1	1975	$2.9x10^6$	$5.0x10^1$	ND	< 0.1

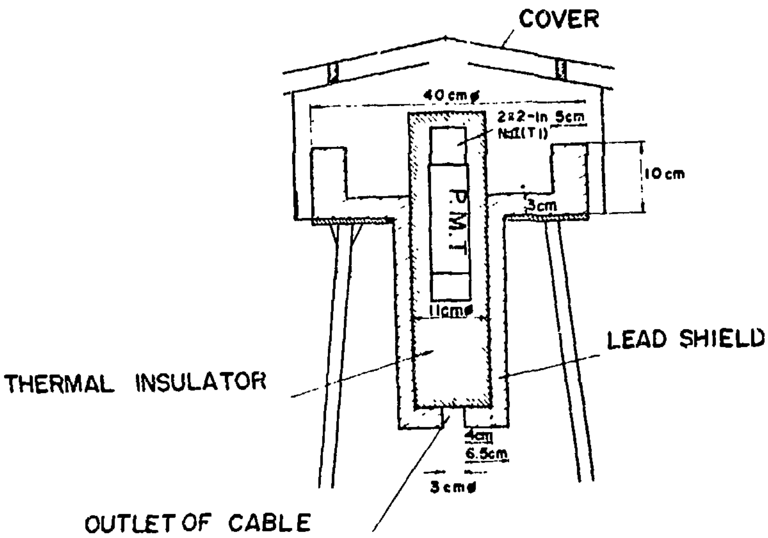
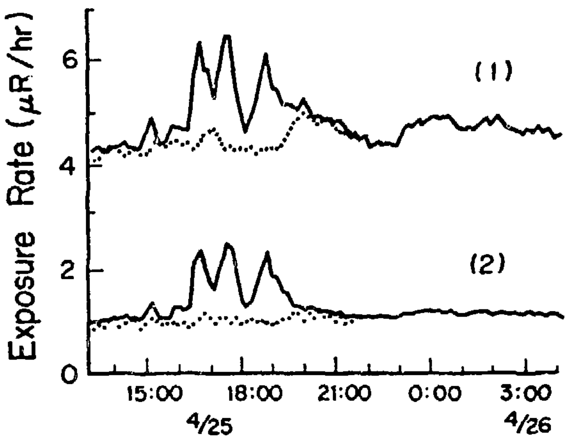


Fig. 1 The detector with lead wall



(1) without lead wall

(2) with lead wall

_________ both from gaseous effluent and natural radiation

--------- from natural radiation only

Fig. 2 Measurement of exposure rates from gaseous effluent during rainfall

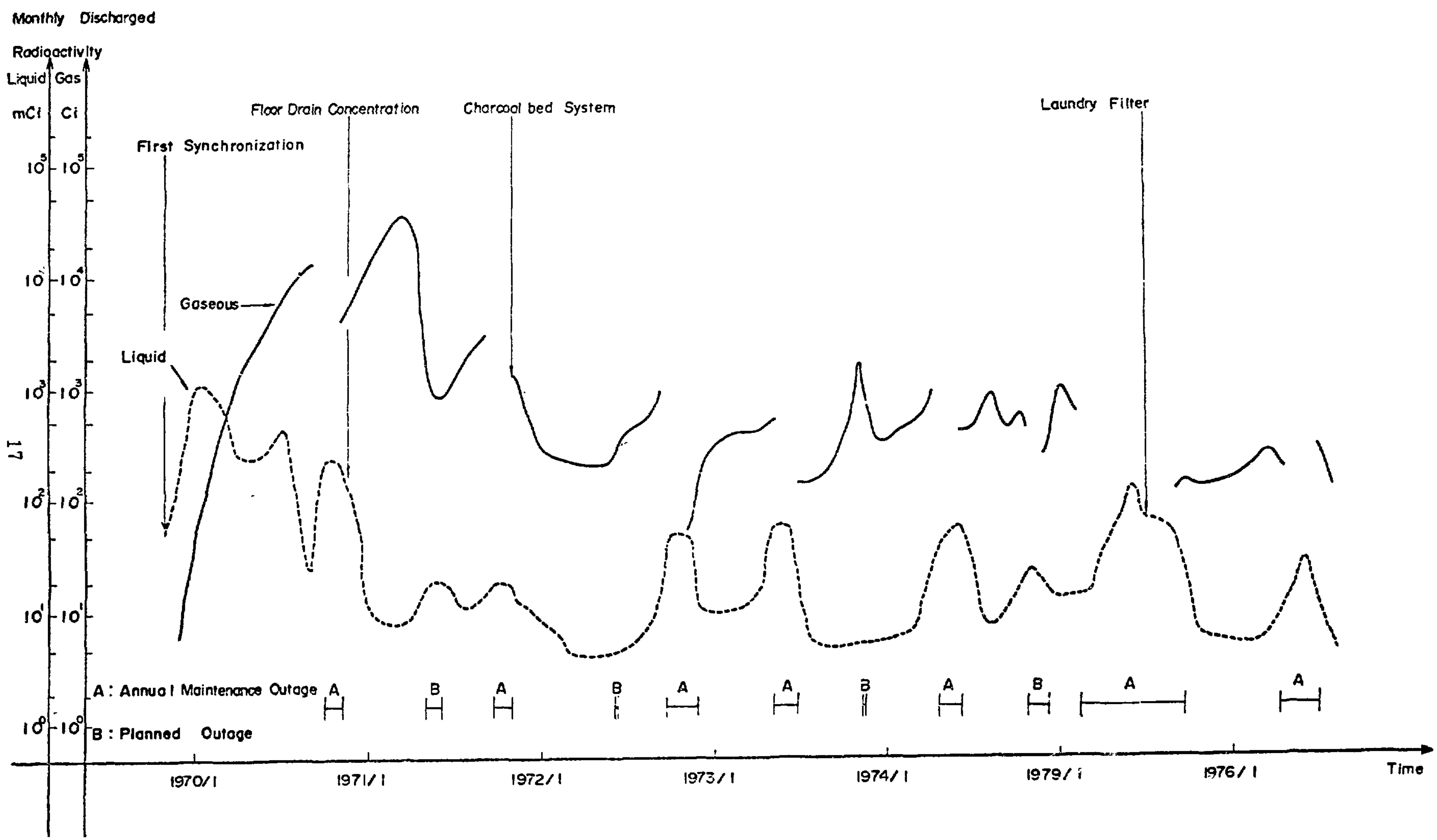


Fig. 3 Discharged Radioactivity From Tsuruga Power Station

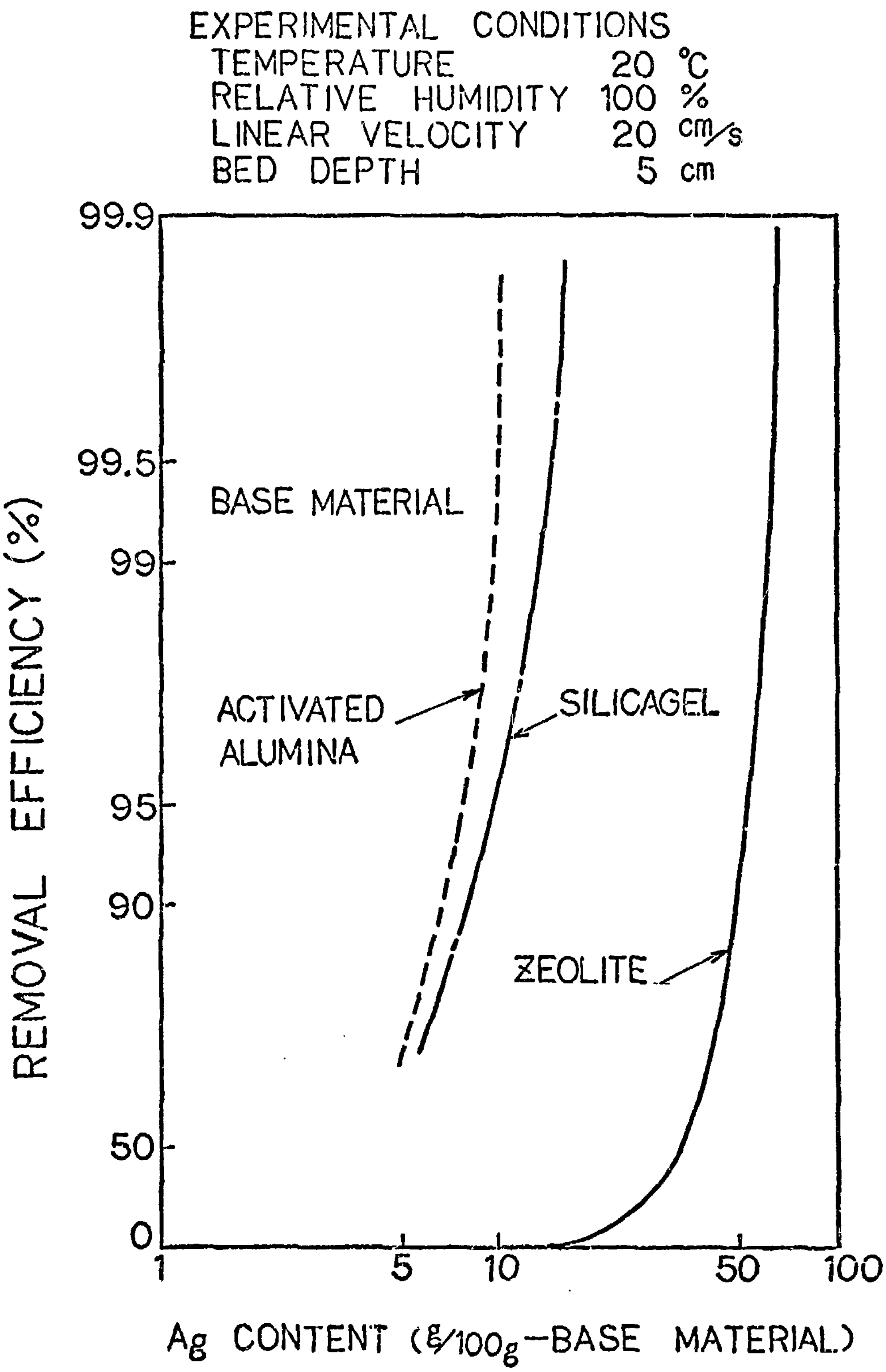


Fig. 4 PERFORMANCE OF Ag IMPREGNATED ADSORBERS

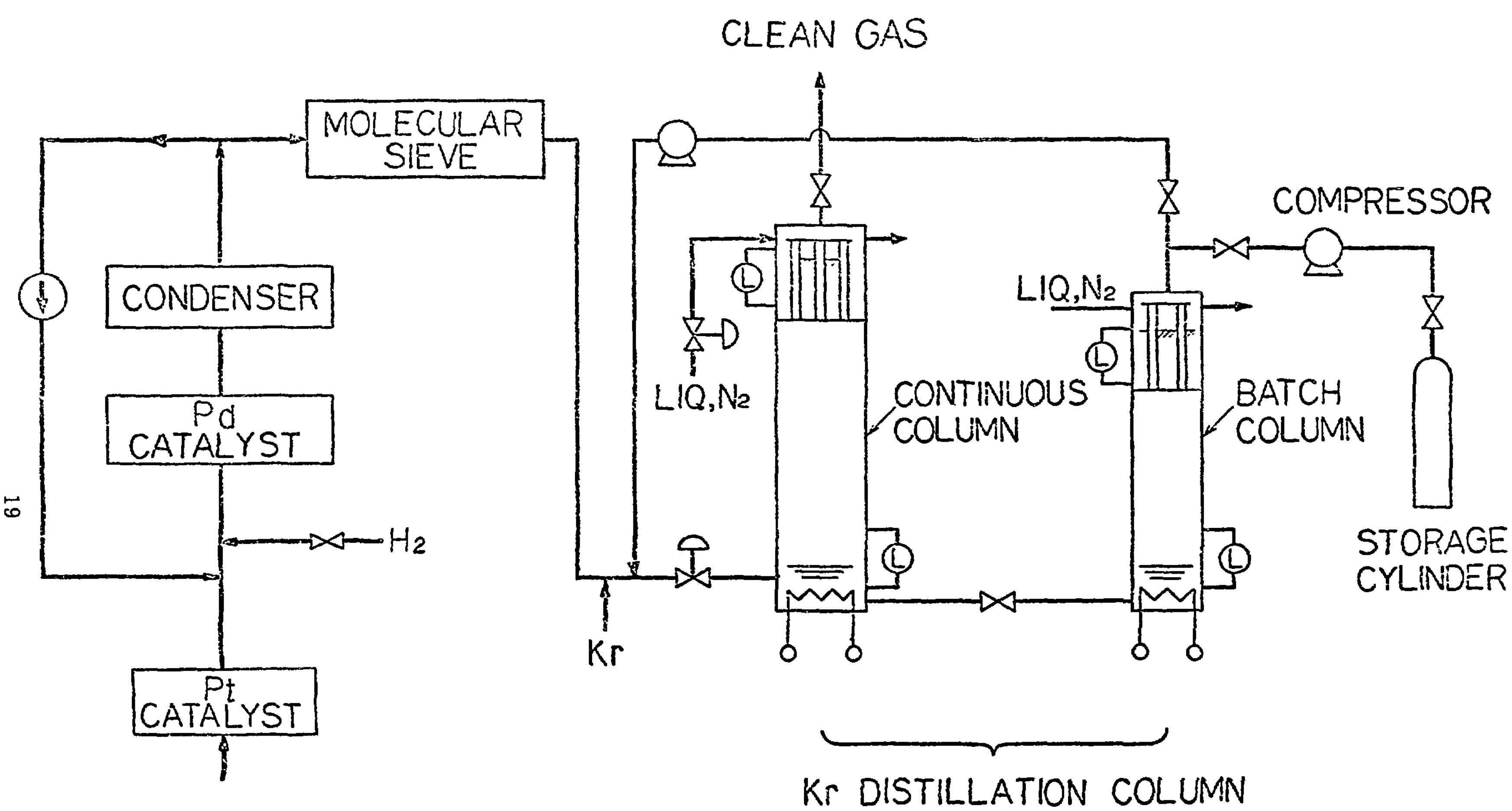


Fig 5 SCHEMATIC FLOW SHEET OF THE Kr REMOVAL PILOT PLANT

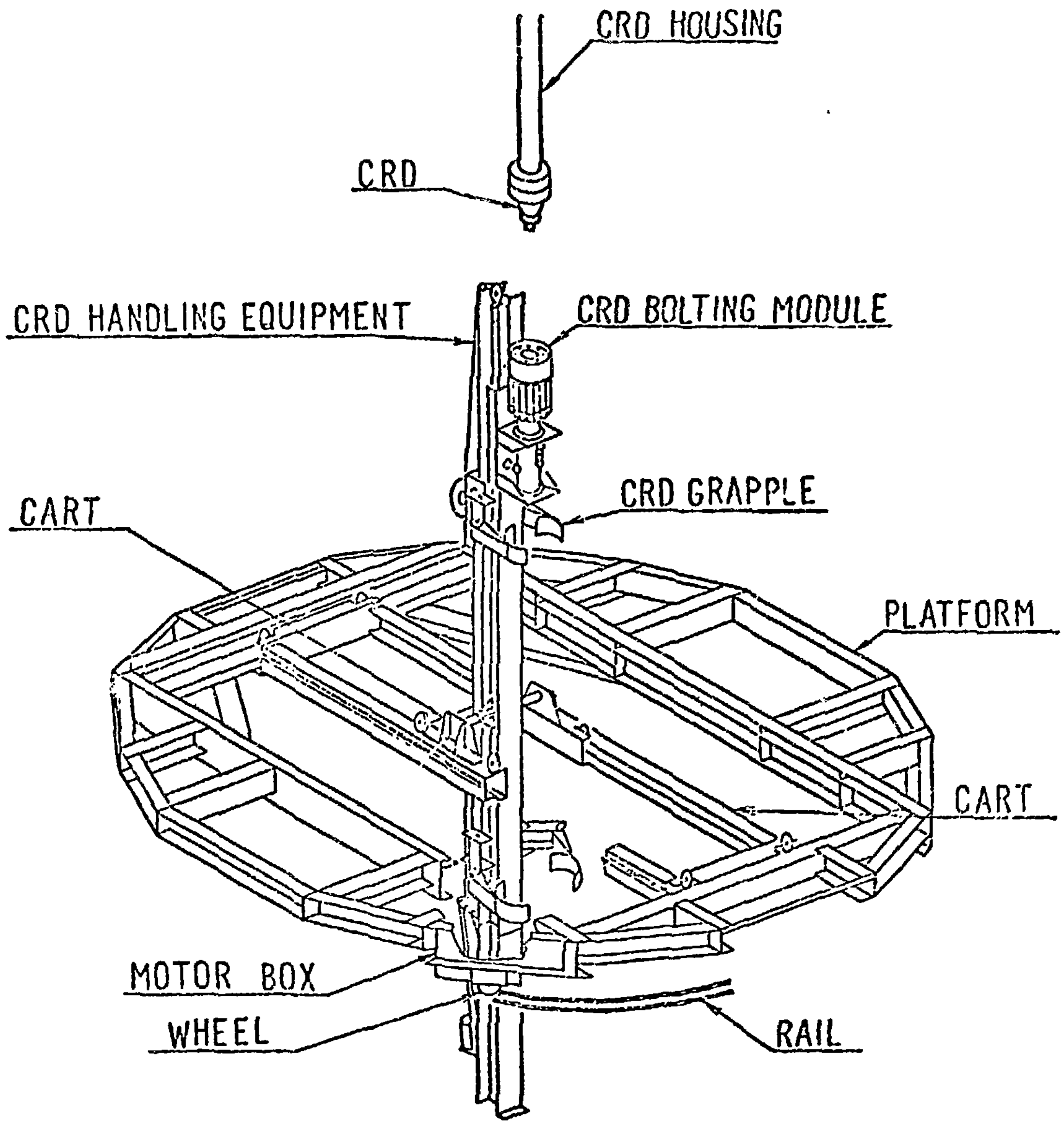


Fig. 6 CRD HANDLING MACHINE