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PROPOSAL FOR IN-PILE TEST OF JAERI-DEVELOPED CRUD SEPARATOR SYSTEM IN THE HBWR

January 1989

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JMTR Project has been developing a crud separator system for reducing personnel exposure in the JMTR since 1980. And a proof test of the crud separator system utilizing Halden Project in-pile water loop has been proposed to the Halden Project by the JMTR Project.

In this report, the contents of the test proposed by the JMTR project are described.

Technical calculation and estimation for the crud separator system are also summarized to provide fundamental information for the proof test.

Keywords: Crud Separator System, In-pile Test, HBWR Proof Test

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ＨＢＷＲを用いたクラッド分離装置のインパイル試験計画

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（１９８８年１２月２２日受理）

ＪＭＴＲは，１９８０年から照射施設による運転員の被曝低減化の一環として，クラッド分離装置の開発を行っている。そして，１９８８年からハルデンプロジェクトのインパルループを用いて，本装置の確証試験が予定されている。

本報告書は，ハルデンプロジェクトのインパイルループを用いた。クラッド分離装置の確証試験計画についてまとめたものである。

また，本確証試験を行うための，基礎的な技術計算や推定も行った。

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Crud build-up in the primary circuit of in-pile water loop (Oarai Water Loop No. 2) in the JMTR produces radiation field around the priamry circuits.

The radiation levels continue to increase with operation of loop and the associated increase in occupational radiation exposure prevents operational maintenance and inspection activities.

It is essential to reduce the build-up of crud and increase removing rate of crud in the primary system for radiation exposure reduction. There are several ways to reduce the radiation levels around the primary system, i.e. improvement of purification system, adoption of low corrosive and low cobalt materials in the primary system and periodical decontamination of the primary system.

High temperature and high pressure filtration such as high gradient magnetic filter and an alternative crud separator have been developed in cooperation with IHI (Ishikawajima-Harima Heavy Industries Co., Ltd.) in the JMTR Project since 1980.

The innovative crud separator utilizing a moving alternating magnetic field produced by rotating permanent magnets has been developed under occupational radiation reduction technology program supported by the STA (Science and Technology Agency).

The crud separator consists of cylindrical and annular vessel, and permanent magnets. Out-of-pile tests indicated that the separator was an effective means of removing crud from loop coolant.

As a next step, it is necessary to install the separator in an operating high temperature and high pressure in-pile water loop to demonstrate the ability of the separator to reduce crud concentration in loop coolant.

For this purpose, the actual in-pile test of the separator in Halden Project was proposed by the JMTR Project under a frame of the JMTR/Halden Project Cooperation Program in 1986.

2. Program description of the JMTR/Halden Project joint development

It is proposed that the actual in-pile test JAERI developed crud separator at the Halden Project is performed to assess the effectiveness of JAERI-developed crud asparator.

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The program consists of following three major tasks:

- Evaluation of the advanced crud separator
- Reducing crud concentration in an in-pile water loop
- Recommend subsequent actions such as application to LWRs

Schedule of the joint development on the crud separator system is shown in Table 1. In July 1986, JMTR staffs visited the Halden Project to discuss the separator experiment in the Halden Project in more detail and to exchange information necessary to design the crud separator system. JMTR submitted an proposal document for the actual in-pile test of JAERI-developed crud separator at the meeting and toured the Halden Reactor Hall to confirm that available space to install the separator system can be provided.

The installation of the separator system and an associated sampling line which is essential to evaluate the effectiveness of the system in the Halden Project No. 5 water loop was proposed to the JMTR Project by the Halden Project in March 1987. Current water chemistry of No. 5 water loop was also introduced by the Halden Project.

The firal proposed testing system diagram is shown schematically in Fig. 1. The system consists of following three systems.

(a) Crud separator system

(b) Sampling system

3. Actual in-pile test of the crud separator system

3.1 Introduction

In the JMTR, chemical decontamination of the OWL-1 (Oarai Water Loop No. 1) primary system was carried out to reduce the radiation levels around the primary circuits in 1977[1].

And subsequent investigation of alternative to above removal technique has been initiated in JMTR since 1980. Crud in the primary coolant of OWL-1 loop consists of mainly Fe_3O_4 magnetite which is ferrimagnetic and easily removed by magnetic filtration. Preliminary work designed to test the High Gradient Magnetic Separator (HGMS) contained an amorphous stainless steel foil as filter matrix using OWL-1 loop. The test results showed that considerable amounts of iron, chromium and manganese oxides were trapped from the coolant. However, it was found that the HGMS is not fit for high temperature filter. And then, a new type of

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The separator consists of a cylindrical and annular vessel, and permanent magnets as shown in Fig. 2. Rotation of permanent magnet assembly surrounding the vessel produces moving alternating magnetic field in the vessel. And then, crud can be easily separated from the coolant by moving alternating magnetic force.

Out-of-pile tests to date indicated that the advanced type is an effective means of removing crud.

As a next step, it is necessary to demonstrate the applicability of the separator to LWRs using a high temperature and high pressure in-pile loop.

3.2 Outline of the crud separator system

The crud separator system consists of a crud separator vessel, a permanent magnet assembly, crud size enlarger, a demagnetizer, a crud removal container system, controller and associated piping as shown in Fig. 3 and Photos. 1 and 2.

(1) Crud separator vessel

It is a cylindrical and annular vessel made of non-magnetic materials, usually austenitic stainless steel. Inside the vessel originally designed, there are two free spaces divided isolation wall and several guide vanes as shown in Fig. 4. On the other hand, the advanced type of the vessel has several perforated buffle plates in free spaces as shown in Fig. 5.

The advanced type showed that remarkable improvement in separation factor was obtained even in high flow rate by modifying the vessel as shown in Fig. 6.

(2) Permanent magnet assembly

The separator vessel is surrounded by permanent magnet assembly as shown in Fig. 2. In addition, variable magnet arrangement adjuster is coupled to obtain most satisfactory arrangement by experimental trials. Rotation of the assembly is controlled to generate optimum moving alternating magnetic field by driving motor.

Figure 7 schematically illustrates the separation process of crud by the separator. Rotation of the assembly produces moving alternating magnetic field in the vessel. Crud such as magnetite in the magnetic field is also magnetized. Thus magnetized crud may be transfered to the shifting direction of moving alternating magnetic field. By this process, crud can be easily separated from the coolant. It was confirmed that separation factor depends on applied magnetic field strength and magnets arrangement. The relation of magnetic field strength to separation factors of γ-maghemite and α-hematite is shown in Fig. 7.

(3) Crud size enlarger

The crud size enlarger performs to make crud size larger and give better separation factor because crud grain size affects separation factor.

Crud size enlarger is an electromagnetic separator in a word. Out-of-pile test results showed that crud size in water can be made larger by using electromagnetic separator and thus be obtained better separation factor.

The HGMS will be installed as crud size enlarger before inlet of the separator in order to obtain better separation factor.

Operation procedure with intermittently energizing a coil like a flip-flop makes crud size larger.

(4) Demagnetizer

Demagnetizer works demagnetizing crud leaked out the separator during operation because crud released from the vessel may have residual magnetization.

The used method for achieving demagnetization is to pass crud through an ac solenoid. The demagnetizer consists of a vessel and a copper coil surrounding vessel. The vessel is made of titanium metal to prevent heat generation by eddy current during operation.

The demagnetizer will be installed in down stream line of the separator.

(5) Crud removal container system

Crud removal container system performs disposal of divided crud remotely. The system consists of a crud removal container and an associated evacuation system.

Crud divided from coolant is deposited in sludge at the bottom of the separator vessel as shown in Figs. 4 and 5. Under operating pressure, deposited crud may be pushed out from the separator vessel through remotely operatable isolation valve to sintered stainless steel filter plate inside the container and dried by vacuum process using evacuation system. After drying sludge deposited on the filter plate may be transfered to a waste container. Filtrate can be also wasted to a plant liquid waste pond.

(6) Controller

The control panel shown in Photo. 2 contains power supply, magnet assembly rotation controller, invertor for demagnetizer and DC source for crud size enlarger. The panel is remotely located in general access area.

3.3 Specifications of the crud separator system for proof test

Specifications of the crud separator system to be utilized for the proof test at HBWR are summarized as follows;

Overall system parameter	
Max. flow rate (1/min.) at 350 C, 85 kg/cm^2	5
Temperature (°C)	350
Crud separator vessel	
Number	1
Type	Cylindrical
Pressure (kg/cm^2)	85
Temperature (°C)	350
Pressure drop at max. flow rate (kg/cm^2)	Refer to Fig. 9
material	SUS316
Dimension:	
Outside diameter (mm)	165
Length (mm)	482
Magnet assembly	
Magnetic field intensity at center (Gauss)	2000
Crud size enlarger	
Material	SUS316
Magnet field intensity (Gauss)	2000
Cooling requirement	yes
Magnetic assembly driving motor	
Power source (V)	200
Frequency (Hz)	50
Power requirement (kW)	1.5
Rotating speed controller	
Variable range (rpm)	50-120

Flow meter	
Type	turbine
Flow rate (l/min.)	max. 5
Max. operating pressure (kg/cm^2)	422
Max. operating temperature (°C)	460
Associated piping	
Size (mm)	10.5/7.5
Material	SUS304TP
Valves	
Type	Needle
Maker	Autoclave Eng.
Max. operating pressure (kg/cm^2)	165
Control panel	
Dimension:	
Width (mm)	520
Length (mm)	600
Height (mm)	1800

3.4 Evaluation of the crud separator

The selection of an optimum operating condition is based on the following criteria.

(a) Effective crud concentration reduction
(b) Effective dose reduction
(c) Minimal production of liquid waste
(d) Minimal interference with the operation and maintenance outage of reactor and other facilities
(e) Minimal maintenance outage of the separator
(f) Minimal personnel exposure

An important aspect of evaluation program is crud concentration effectiveness. The measure of crud concentration reduction is Separation Factor (SF) defined as the concentration difference between inlet and outlet of the separator divided by the inlet concentration.

Typical separation factors of the advanced crud separator yielded through a loop test in JMTR are presented in Table 2.

4. Design calculation of the crud separator system for the Halden Project in-pile loop

4.1 Design principle

The JAERI developed crud separator system for the Halden Project in-pile loop is designed to demonstrate the ability of the separator to remove crud from the primary coolant of the loop at operating conditions up to 296°C and 82 kg/cm^2 (80 bars).

All system components are designed in accordance with the Japanese Boiler and Pressure Vessel Code and Japanese Industrial Standard (JIS).

Design principle and construction practices for boiler and pressure vessel of the Japanese Boiler and Pressure Vessel Code are in principle identical with those of the ASME Code Section-III Division-1.

Therefore, the safety factor on tensile strength of the Japanese Boiler and Pressure Vessel Code is same as that of the ASME Code Section-III Division-1, allowable stresses being limited to one-fourth of minimum tensile strength for austenitic stainless steel at temperatures up to 427°C.

4.2 Crud separator vessel

Figure	JM-61-003 or JM-61-005
Specification	
Number	1
Type	Cylinder
Volume	1.3 liter
Design pressure	85 kg/cm^2 (83.4 bar)
Design temperature	350°C
Material	JIS-G-3459, SUS316 TP

4.2.1 Outer wall thickness

Wall thickness under internal pressure loading in the cylindrical outer shell is designed using the Japanese Boiler and Pressure Vessel Code.

$$t = \frac{PD_i}{200\sigma\chi\eta - 2P(1-k)} + \alpha$$

D_i = inside diameter ---------------------- 151 mm

t = wall thickness ---------------------- 7 mm

P = design pressure ---------------------- 85 kg/cm^2

k = constant ------------------------------ 0.4

$\sigma\chi$ = allowable tensile strength at 350°C --- 11.2 kg/mm^2

η = weld efficiency factor --------------- 1

α = corrosion allowance ------------------ 0

Note: Corrosion allowance should be ignored because of neglective small of type 316 austenitic stainless steel under high temperature and high pressure pure water.

from which,

$$t = \frac{85\times151}{200\times11.2+2\times85\times0.6} = 5.5$$

The outer shell is satisfactory since a thickness of 7 mm is provided.

4.2.2 Inner shell wall thickness

Wall thickness under external pressure loading is designed using the same code as the preceeding calculation.

i.e.

$$P = \frac{BC(t-\alpha)}{Do}$$

Do = outside diameter of the inner shell --- 131 mm

t = wall thickness ----------------------- 15 mm

P = design pressure ---------------------- 85 kg/cm^2

α = corrosion allowance ------------------ 0

B = factor depending on L/Do and Do/t determined from the applicable chart in the code for the material used in the shell at the design temperature

C = weld efficiency factor --------------- 1

L = design length of the vessel section taken as the greatest center to center distance between two adjacent stiffing rings -------------- 324 mm

where L/Do = 2.47 and Do/t = 8.7

from the chart read B = 880

The maximum allowable pressure for the shell thickness of 15 mm is;

$$Pa = \frac{880\times1.0\times15}{131} = 100 > 85$$

Since Pa is greater than the design pressure P, the thickness is satisfactory.

4.2.3 Thickness of end plates

The thickness of the end plates of the cylinder are designed in accordance with the code.

i.e. $$t = \sqrt{\frac{6Wl}{\pi D \sigma \chi}}$$

, where $W = \frac{\pi}{400} D^2 P$ and the thickness should not be less than twice of the outer shell thickness.

D = inside diameter of the outer shell ---- 151 mm

l = flow path width of the separator vessel ---------------------------------- 10 mm

P = design pressure ----------------------- 85 kg/cm^2

= the maximum allowable bending stress of type 316 austenitic stainless steel at 350°C --- 16.8 kg/cm^2

t = thickness of the end plates ----------- 22 mm

from which $W \frac{\pi}{400} \times 151^2 \times 85 = 15213.9$

$$t = \sqrt{\frac{6\times15213.9\times10}{\times151\times16.8}} = 10.7$$

The end plates of the cylinder are satisfactory since a thickness of 22 mm is provided.

4.3 Demagnetizer

Figure	JM-61-002
Specification	
Number	1
Type	Tube
Volume	17.3 cm^3
Design pressure	85 kg/cm^2
Design temperature	350°C
Material	Titanium (JIS-H-4630 TTP-49)

4.3.1 Tube wall thickness

Minimum wall thickness under internal pressure loading in the tube is designed as the preceeding design calculations.

i.e. $t = \frac{PDo}{200\sigma\chi\eta + 0.8P} + \alpha$

Do = outside diameter of the tube ---------- 13.8 mm

t = wall thickness ------------------------ 2.2 mm

P = design pressure ----------------------- 85 kg/cm^2

$\sigma\chi$ = allowable tensile strength at 350°C --- 4.4 kg/mm^2

η = weld efficiency factor ---------------- 1

α = corrosion allowance ------------------- 0

from which $t = \frac{85 \times 13.8}{200 \times 4.4 + 0.8 \times 85} = 1.23$

The demagnetizer tube is satisfactory since a thickness of 2.2 mm is provided.

4.4 Crud size enlarger

Figure	JM-61-001
Specification	
Number	1
Type	Flanged vessel
Volume	58 cm^3
Design pressure	85 kg/cm^2
Design temperature	350°C
Material	JIS-G-3459, SUS316 TP

4.4.1 Tube wall thickness

Wall thickness under internal pressure loading is designed using the same code as the preceeding design calculations.

i.e. $t = \frac{PDo}{200\sigma\chi\eta + 0.8P} + \alpha$

Do = outside diameter --------------------- 34 mm

P = design pressure ----------------------- 85 kg/cm^2

α = corrosion allowance ------------------- 0

η = weld efficiency factor ---------------- 1

$\sigma\chi$ = allowable tensile strength ------------ 11.2 kg/cm

t = wall thickness ------------------------ 4.5 mm

from which $t = \frac{85 \times 34}{200 \times 11.2 + 0.8 \times 85} = 1.3$

Therefore, use 1" sch. 80 Type SUS316 pipe.

4.4.2 Design of flange

Flange is designed in accordance with the ANSI B16.5 Steel Pipe Flanges and Flanged Fittings.

From the code, class 1500 flange is applied to the vessel and Number R 16 is selected for octagonal ring-joint gaskets and grooves.

4.4.3 End plate stress calculation

The required thickness of end plate should be calculated,

i.e. $$t = d\sqrt{\frac{ZCP}{100}} + \alpha$$

d = inside diameter of the tube ----------- 25 mm

P = design pressure ---------------------- 85 kg/cm^2

α = corrosion allowance ------------------ 0

$\sigma\chi$ = allowable tensile strength at 350°C --- 11.2 kg/mm^2

Z = a factor of noncircular heads and covers that depends on the short span to long span -------- 1

C = a factor depending on the method of attachment of head --------------------------------- 0.5

from which $$t = 25\sqrt{\frac{1\times0.5\times85}{100\times11.2}} = 4.9$$

The required thickness of 4.9 mm is obtained.

4.4.4 Size of weld required

By the requirement for circular plate welded to the end of shell in the case C = 0.5, actual thickness of shell t_s is at least 1.25 × (minimum design thickness of shell) and the weld details should be comfirmed to fulfil the requirements as shown in Fig. 10.

t_s of 4.5 mm is greater than $1.25t_r$ (= 1.25×1.3).

Since the actual plate thickness of 14 mm is greater than the a+b of 9 mm, weld size is satisfactory.

4.5 Summary

The JAERI developed crud separator is expected to instell in a in-pile water loop at the Halden Project and to be operated at a maximum pressure of 80 bar. The mechanical analysis performed to comfirm the structural integrity of the JAERI made separator system at the maximum operating condition in accordance with Japanese Boiler and Pressure Vessel Code.

Table 3 summarizes the vessel data and calculated stresses comparing with code limit to ensure standard integrity.

The results of stress analysis indicate that design for pressure retaining vessels in the system are adequate for the maximum operating condition.

Therefore, the system must be safely operated without any difficulties in an operating HBWR loop and performing irradiation tests.

In addition, special care should be taken to ensure that the system properly and reliably design, fabricate and assemble for reasons of operating safety. The system components are designed, machined and welded, and all final assembly work is performed under Quality Assurance Program for Nuclear Power Plant at Ishikawajima-Harima Heavy Industries Co. certificated by MITI (Ministry of International Trade and Industry) and ASME for nuclear reactor vessels fabricator.

5. Performance estimation of the crud separator system for the Halden Project in-pile loop

5.1 Introduction

To provide quantitative bases for assessing the effectiveness of installing the crud separator in a Halden Project in-pile loop, for evaluating the suitable measure to determine the efficiency of the separator and for designing shield against gamma dose from the separator for safe operation, the following calculations are provided.

5.2 Performance estimation of the crud concentration reduction

From the material balance in a primary circuit, concentration variation of crud in the coolant is defined approximately by equation (1).

$$\frac{dC}{dt} = \frac{R}{V} - \varepsilon \cdot \frac{\nu}{V} C \qquad (1)$$

where, C is the concentration of crud in primary coolant, R the net production rate of crud, V the volume of water in primary circuit, ε the crud removal efficiency of the separator and ν the flow rate in the separator.

This equation allows a rough estimation of crud concentration condition in accordance with Japanese Boiler and Pressure Vessel Code.

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This equation allows a rough estimation of crud concentration reduction by the separator.

Assuming that the net production rate of crud in the coolant is unchangeable, this equation may be integrated with the boundary condition,

$C = C_o$ at $t = 0$ to give

$$C = \frac{R}{\varepsilon\cdot\nu} + \left(C_o - \frac{R}{\varepsilon\cdot\nu}\right)e^{-\frac{\varepsilon\nu}{\nu}t} \tag{2}$$

The equation describes the concentration variation of crud in the coolant at any time.

At steady state ($t\to\infty$), equation (2) reduces to

$$C = \frac{R}{\varepsilon\cdot\nu} \tag{3}$$

With the separator in operation, the lowest limit of the saturation concentration of crud becomes $C_{sat}=R/\varepsilon\nu$.

Figure 11 and 12 illustrate concentration variation of crud in the coolant due to the crud separator for different operational conditions. In reference calculations, following parameters are used.

ν; Crud separator flow rate ----------------------- 300 l/hr.
V; Volume of primary circuit of a in-pile loop ----- 60 liter
(equivalent to the volume of the Halden Project corrosion loop)

The effectiveness of the installation will be higher with a higher efficiency of the separator (ε) and a higher flow rate through the separator (ν) for a given system volume (V).

5.3 Estimation of the crud accumulation rate at the separator

The accumulation rate of crud may be described by equation (4).

$$\frac{dn}{dt} = \varepsilon\nu C \tag{4}$$

where, n is the amount of crud divided by the separator.

The substitution of equation (2) in equation (4) yields equation (5).

$$\frac{dn}{dt} = R + (\varepsilon\nu C_o - R)\ e^{-\frac{\varepsilon\cdot\nu}{V}t} \tag{5}$$

The equation may be integrated with the boundary condition, n=0 at t=0 to give

$$n = Rt + V(C_o - \frac{R}{\varepsilon\nu})(1 - e^{-\frac{\varepsilon \cdot \nu}{V}t}) \tag{6}$$

The amount of crud removed from the coolant for a time can be expressed as equation (6).

$$n = Rt + V(C_o - \frac{R}{\varepsilon\nu}) \tag{7}$$

Figure 13 and 14 illustrate the accumulation variation of crud as a function of time for different values of the separator.

The typical accumulation change for long term operation is shown in Fig. 15 comparing with the buildup of activity by divided crud.

5.4 Estimation of the activity buildup in the separator

The activity buildup rate corresponding to accumulating crud in the separator may be described by equation (8).

$$\frac{dNi}{dt} = \varepsilon\nu Ci - \lambda iNi \tag{8}$$

where, Ni: atoms of nuclide i present in suspended crud (n)

Ci: radioisotopic concentration of nuclide i suspended in the coolant (n/m^3)

$$Ci = \frac{Cai \times 3.7 \times 10^{13}}{\lambda i}$$

C : concentration of crud in the coolant (kg/m^3)

ai: specific activity of nuclide i in crud (Curie/g crud)

Now,

$$\frac{3.7 \times 10^{13} ai}{\lambda i} \equiv Pi$$

activity buildup rate of nuclide i in the separator is given by

$$\frac{dNi}{dt} = \varepsilon\nu PiC - \lambda iNi \tag{9}$$

Combining equation (2) and (9),

$$\frac{dNi}{dt} = PiR + Pi(\varepsilon\nu C_o - R)\ e^{-\frac{\varepsilon\cdot\nu}{V}t} - \lambda iNi \qquad (10)$$

The solutions for differential equation (10) is obtained by assuming:

(1) Pi and R are constant during separator operation

(2) t=0 and Ni=0,

$$Ni = Pi\left(\frac{R}{\lambda i}+\frac{\varepsilon\nu C_o-R}{\lambda i-\frac{\varepsilon\nu}{V}}\ e^{-\frac{\varepsilon\cdot\nu}{V}t}\right) - Pi\left(\frac{R}{\lambda i}+\frac{\varepsilon\nu C_o-R}{\lambda i-\frac{\varepsilon\nu}{V}}\right) e^{-\lambda it}$$

$$= \frac{ai\times3.7\times10^{13}}{\lambda i}\left(\frac{R}{\lambda i}+\frac{\varepsilon\nu C_o-R}{\lambda i-\frac{\varepsilon\nu}{V}} e^{-\frac{\varepsilon\cdot\nu}{V}t}\right) - \frac{ai\times3.7\times10^{13}}{\lambda i}\left(\frac{R}{\lambda i}+\frac{\varepsilon\nu C_o-R}{\lambda i-\frac{\varepsilon\nu}{V}}\right) e^{-\lambda it} \qquad (11)$$

Therefore, activity builup rate by isotope i in the separator can be calculated using equation (12).

$$Ai = \frac{Ni\lambda i}{3.7\times10^{10}}$$

$$= 1000ai\left\{\frac{R}{\lambda i}+\frac{\varepsilon\nu C_o-R}{\lambda i-\frac{\varepsilon\cdot\nu}{V}}\ e^{-\frac{\varepsilon\cdot\nu}{V}t} - \left(\frac{R}{\lambda i}-\frac{\varepsilon\nu C_o-R}{\lambda i-\frac{\varepsilon\nu}{V}}\right) e^{-\lambda it}\right\} \qquad (12)$$

The activity buildup rates for nuclides ^{51}Cr, ^{59}Fe and ^{60}Co may be calculated for estimating activity buildup trends using water chemistry data presented by the Telefax dated 1986-11-27. Because major nuclides responsible for the activity buildup are ^{60}Co, ^{51}Cr and ^{59}Fe, calculations for those nuclides are illustrated in Fig. 15 using equation (12).

In the calculation, following parameters are used;

Specific activity of ^{51}Cr 1.9×10^{-4} curie/g crud

Specific activity of ^{59}Fe 2.6×10^{-3}

Specific activity of ^{60}Co 5.4×10^{-4}

(Note; chemical form of crud is estimated as Fe_3O_4 and ^{60}Co concentration is assumed to be 1/200 of Fe from the data of the JMTR OWL-1 in-pile loop.)

5.5 Summary

The estimated reduction of crud concentration in the primary loop coolant due to installation of the crud separator system are illustrated in Fig. 11.

Analysis indicates that the reduction of crud concentration by a factor of an order of magnitude can be achieved if the system performs satisfactorily in extremely low concentration of crud. In order to maintain good performance even such low concentration, a crud size enlarger is applied to the crud separator system.

It is well known that a reduction of radiation field will be achieved by reduction of crud deposition using high temperature filtration such as a magnetic filter in power reactors.

The estimated activity buildup trends are shown in Fig. 15. There appears to be good correlation between the accumulation of crud and the activity build-up of ^{60}Co.

This suggests that the separator performance could be evaluated by means of an in-situ gamma monitor. Shielded gamma monitor to measure the activity of ^{60}Co is now under consideration.

6. Sampling and analysis for evaluation of the crud and separation factor

6.1 Sampling system

To determine separation factor (crud separation efficiency), a sampling system which provides for sampling the inlet and the outlet of the separator will be installed.

The system should be designed and will be installed to provide representative samples of purification system coolant of No. 5 water loop at operation conditions. The design principles for the sampling system are;

(1) All parts of the smapling devices should be made of 18Cr/8Ni austenitic stainless steel.

(2) The sampling lines should be as short as possible.

(3) To prevent settling of suspended crud in sampling line, the lines have a minimum number of fittings, valves and other devices tend to act as particulate traps.

(4) Sample flow rate should be constant as long as possible for sampling interval.

(5) To collect crud from a continuous sample flow, Millipore filter should be utilized.

(6) Whenever the temperature of samples exceed 40 C, sampling cooler should be installed to protect Millipore filter from degradation by temperature.

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The system essentially consists of sampling tube, a sampling cooler and crud probes as shown in Fig. 1.

6.2 Sampling methodology

To collect corrosion product species, one or two millipore filters (0.45 m mesh) are installed in each crud probes.

It is well known that the crud concentrations in primary coolant vary considerably with reactor operational conditions in general. To evaluate the performance of the crud separator accurately in all operational conditions of the loop, it might be the best way to sample, determine the concentrations and calculate the efficiency at each corresponding the operational conditions.

In practice, a builup of crud on filter membranes for a long sampling period will certainly increase the pressure drop to the extend that it becomes impossible to maintain the desired flow rate, particularly for the sampling line of the crud separator inlet.

A long-term sample collection method allows long term averaging of crud concentration, thereby, providing a firm basis for performing mass balance, if individual flow rates of both crud probes could be maintained close to the same values.

In principle, the smaple collection rates and total activities are chosen to ensure collection of sufficient amount for analysis without any erroneous.

Samples are analyzed for metallic ions such as Fe, Ni, Cr, Mn and as far as possible, Co by atomic absorption spectrometer or plasma emission spectrometry and by gamma spectrometry for the following radionuclides: Fe-59, Mn-54, Cr-51, Co-58 and Co-60 respectively.

6.3 Analysis methodology

The analytical procedure of crud is well documented elsewhere, the following shows one of the procedure.

The membranes are placed in 10 ml of concentrated HCl and heated for 1 hour at approximately 90°C. Then 5 ml of concentrated HNO_3 is added, and the resultant mixture is digested for an additional hour. Five more milliliters of concentrated HNO_3 is then added, and the temperature is increased to slightly over 100°C to evaporate most of the HCl. Heating is continued until the liquid volume is decreased to about 10 ml. The beaker containing the sample is removed from the heat, allowed to cool, and then

the liquid quantitatively transfered to a 100 ml volumetic flask for dilution to volume with DI water. The total dissolution procedure requires 6 to 8 hours. In this procedure, the Millipore is totally dissolved. Millipore blank is run on each sample batch. Isotopic activity of samples is determined by gamma spectroscopy. The Millipore is analyzed prior to dissolution although in cases where multichannel analyzer deadtime is high, an aliquot of the digested sample is analyzed. The results are reported for CO-60, Co-58, Mn-54, Fe-59 and Cr-51 although other isotopes are observed routinly.

7. Conclusion

Proposal for JMTR/Halden Project joint development on crud separator system was introduced briefly.

The reports concerning mechanical design calculation and performance estimation of the crud separator system allow a decision to install of the system on an in-pile water loop of Halden Project.

Acknowledgement

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References

1) H. Kanbe, T. Inoue, T. Tomizawa, H. Koyama, H. Itami: Deposition of Radioactive Corrosion Product in a High-pressure and High-temperature Water Loop and its Decontamination, Nucl. Tech. 60, 367 1983

2) H. Itami, H. Ito, I. Tanaka, K. Sezaki and H. Tanaka: The Present Status of Irradiation Activities in JMTR, IAEA-SR-119, IAEA Seminor on Applied Research and Service Activity for Research Reactor, Copenhagen, Denmark. 9-13 Sep. 1985

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Table 1 Schedule of the joint development on crud separator system

completed
schedule

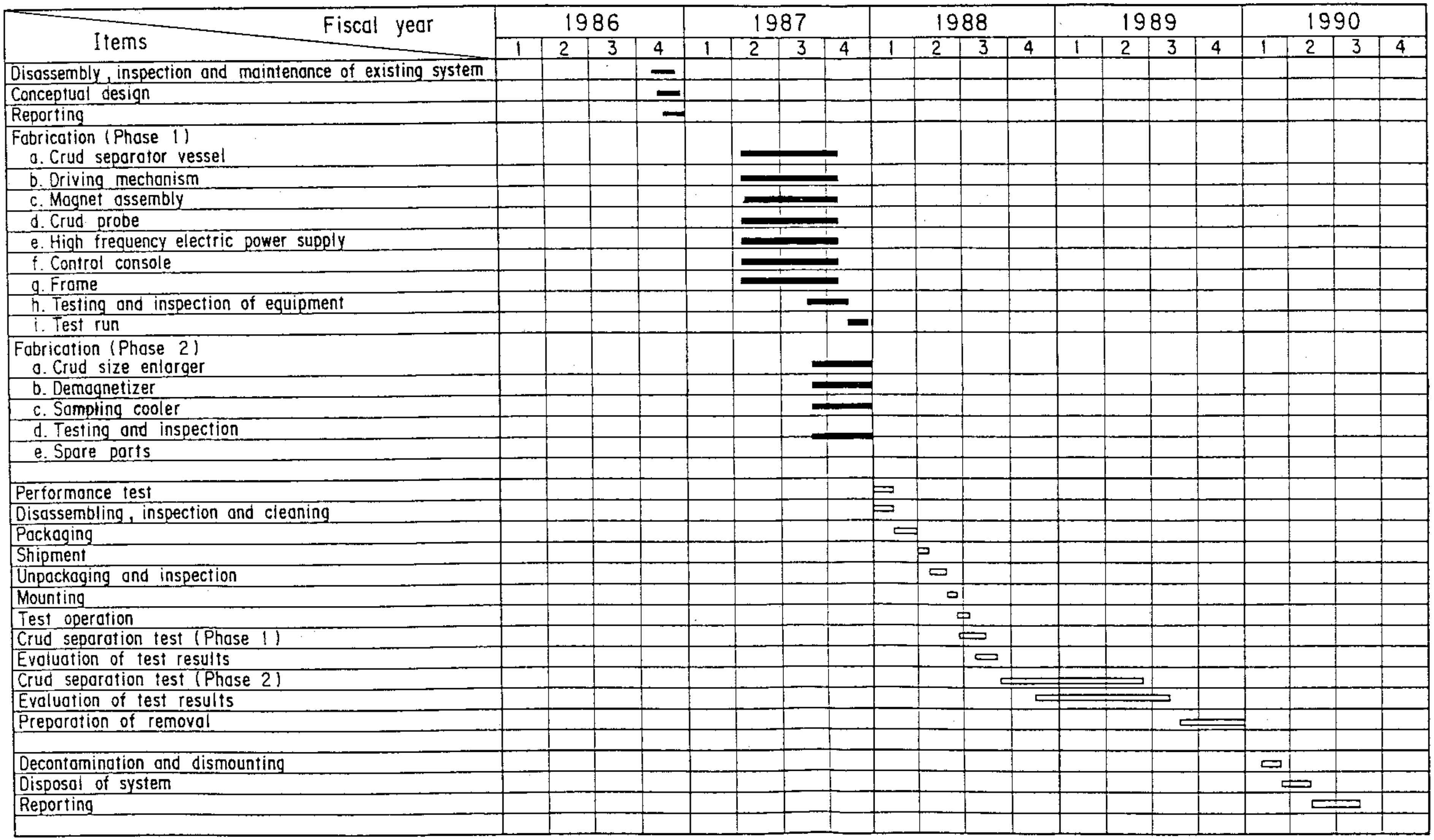


Table 2 High temperature and high pressure crud separator experimental results obtained in JMTR

Test Run	Crud Composition	Crud Size (μm)	Concentration (ppm)	Rotation Rate (rpm)	Flow rate (ℓ/min)	Separation Factor (%)
1	$\gamma \cdot Fe_2O_3$	1.65	13.0	100	1	87.5
2			13.0		2	84.6
3			12.1		1	80.9
4			12.1		2	79.0

Test Condition :
Press. : 71 kg/cm^2 G
Temp. : 260 °C
Diss. O_2 : Max. 401 ppb

Table 3 Crud separator system data and calculated stresses

	CRUD SEPARATOR		DEMAGNETIZER	CRUD ENLARGER
	OUTER SHELL	INNER SHELL		
MATERIALS	SUS 316 - TP	SUS 316 - TP	TITANIUM	SUS 316 - TP
VOLUME	1.3 Liter		17.3 cm^3	58 cm^3
DESIGN PRESSURE	85 kg / cm^2		85 kg / cm^2	85 kg / cm^2
DESIGN TEMPERATURE	350 ℃		350 ℃	350 ℃
OUTSIDE DIAMETER	165 mm	131 mm	13.8 mm	34 mm
INSIDE DIAMETER	151 mm	101 mm	9.4 mm	25 mm
WALL THICKNESS	7 mm	15 mm	2.2 mm	4.5 mm
HOOP STRESS	9.7 kg / mm^2	- 4.2 kg / mm^2	2.3 kg / mm^2	2.9 kg / mm^2
ALLOWABLE STRESS	11.2 kg / mm^2	11.2 kg / mm^2	4.4 kg / mm^2	11.2 kg / mm^2

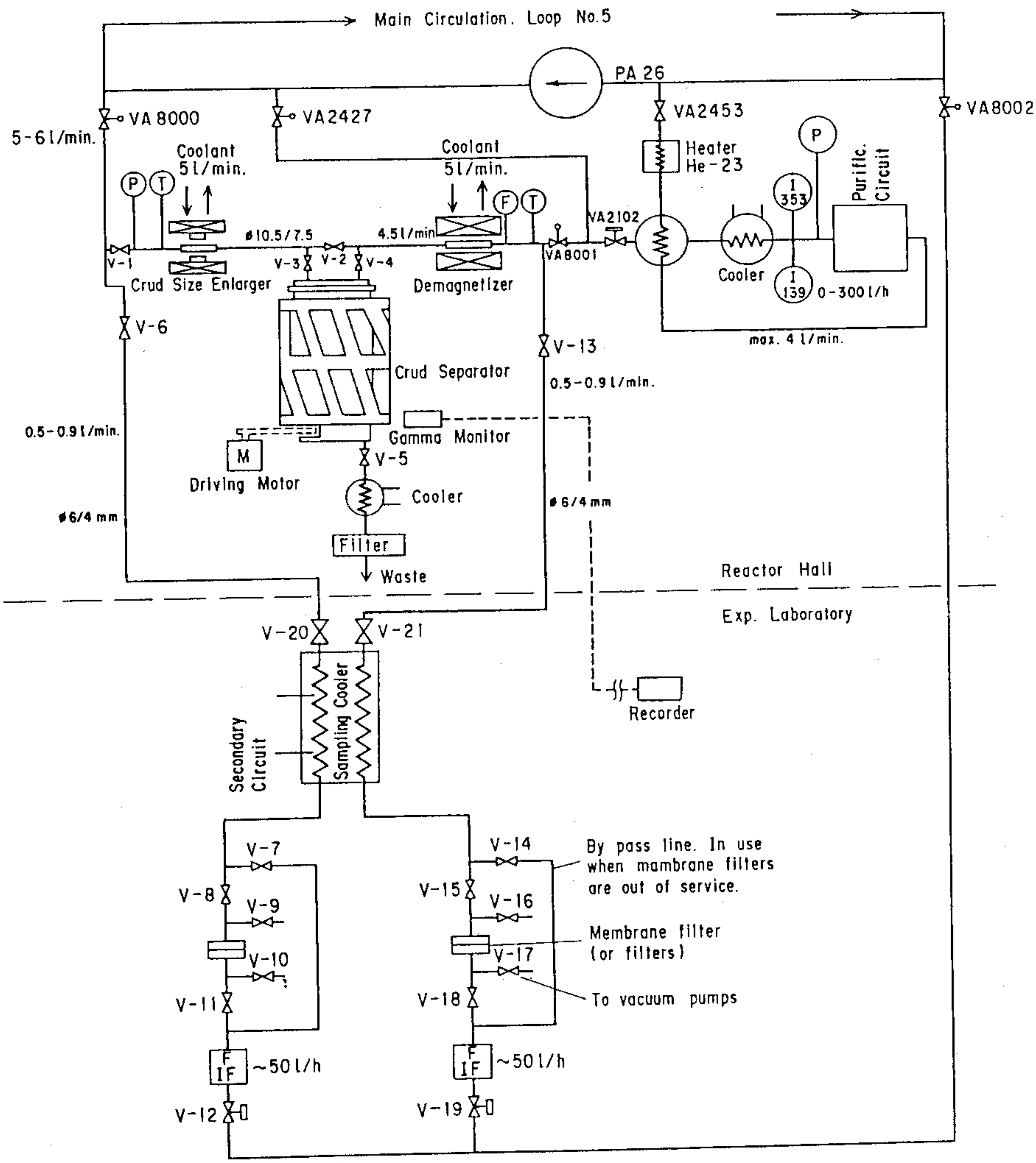


Fig. 1 Schematic flow diagram of crud separator system for the HBWR

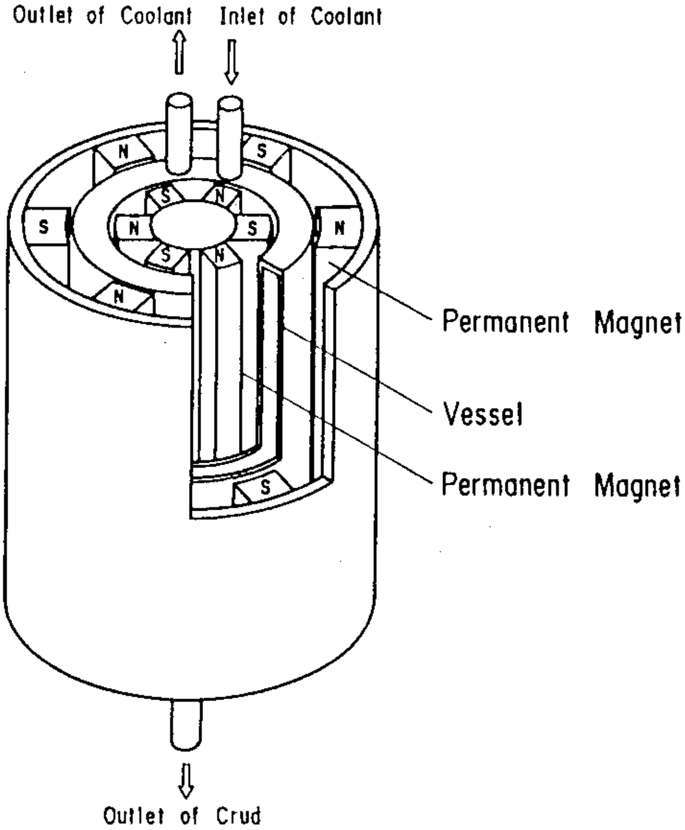


Fig. 2 Permanent magnetic separator schematic

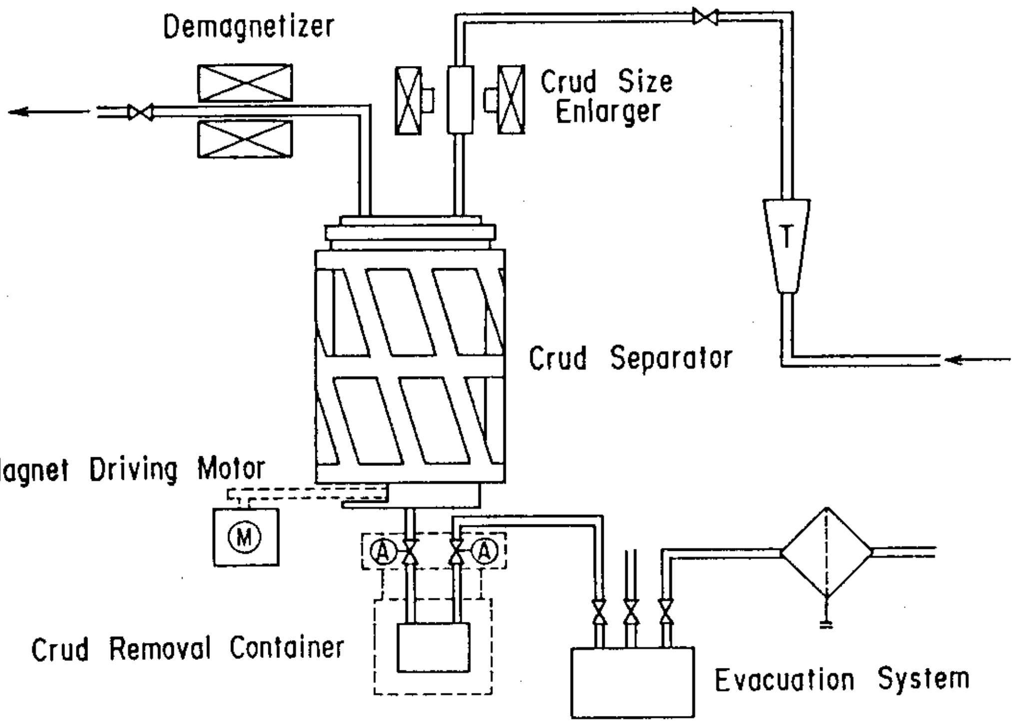


Fig. 3 Conceptual circuit diagram of crud separator system

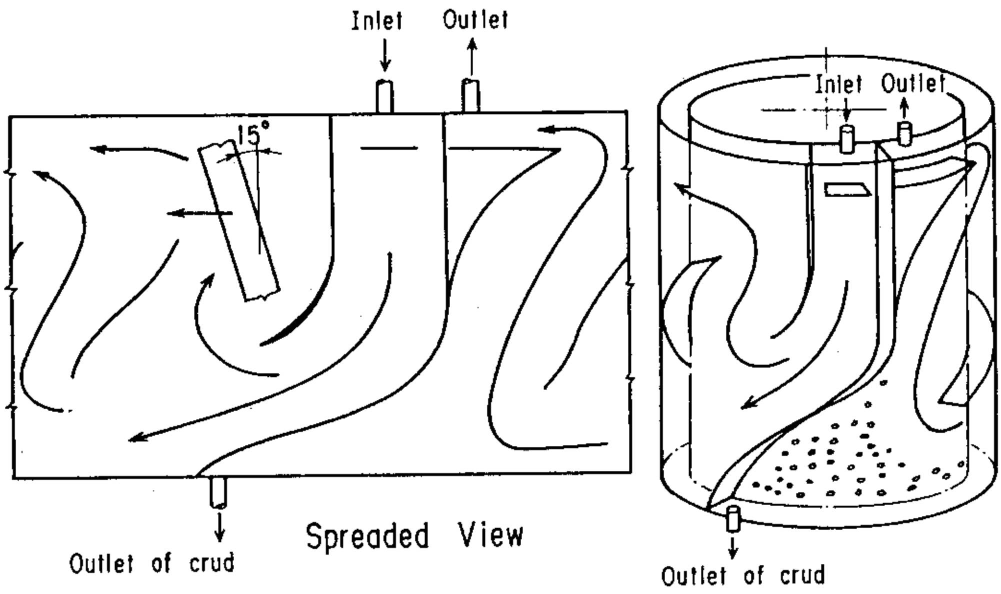


Fig. 4 Schematic view of crud separator vessel
(Originally designed)

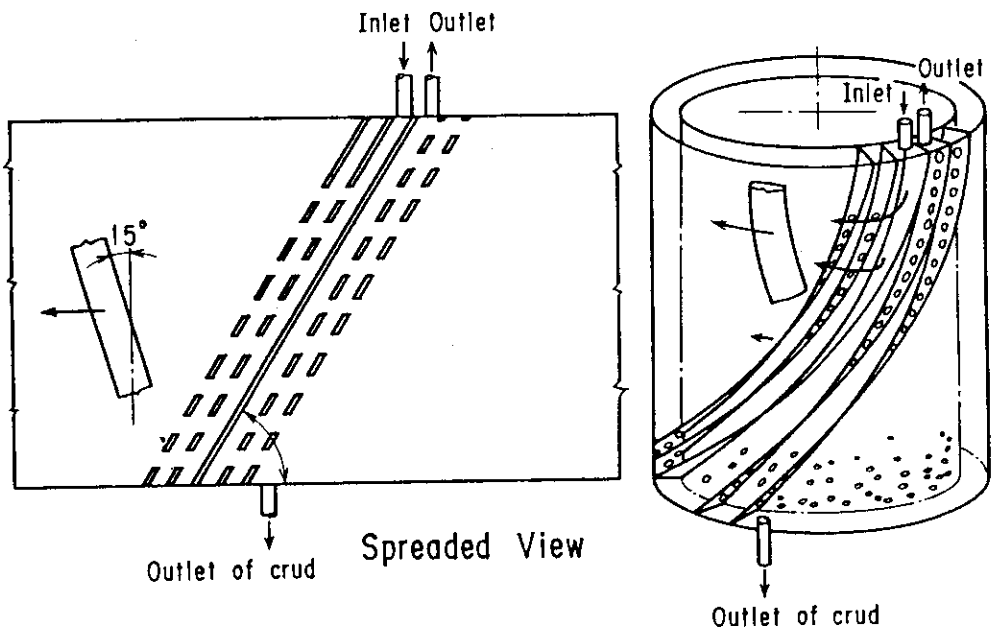


Fig. 5 Schematic view of crud separator vessel
(Advanced type)

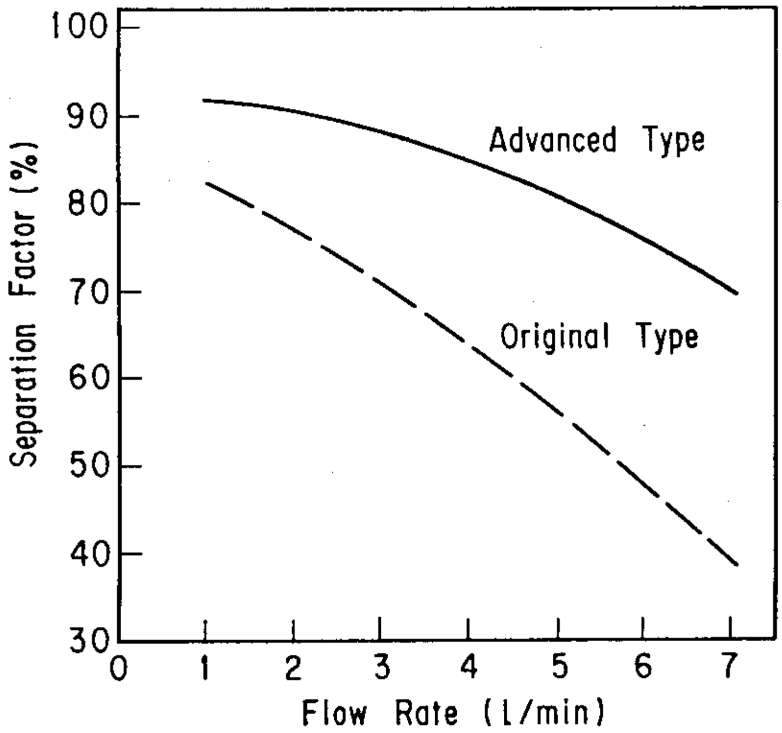


Fig. 6 Improvement of separation factor Yielded by vessel modification

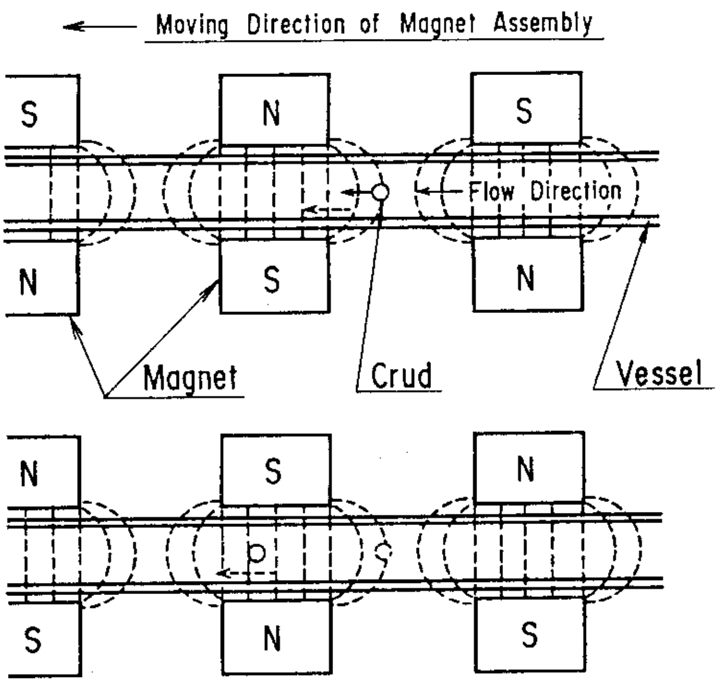


Fig. 7 Magnetic separation process

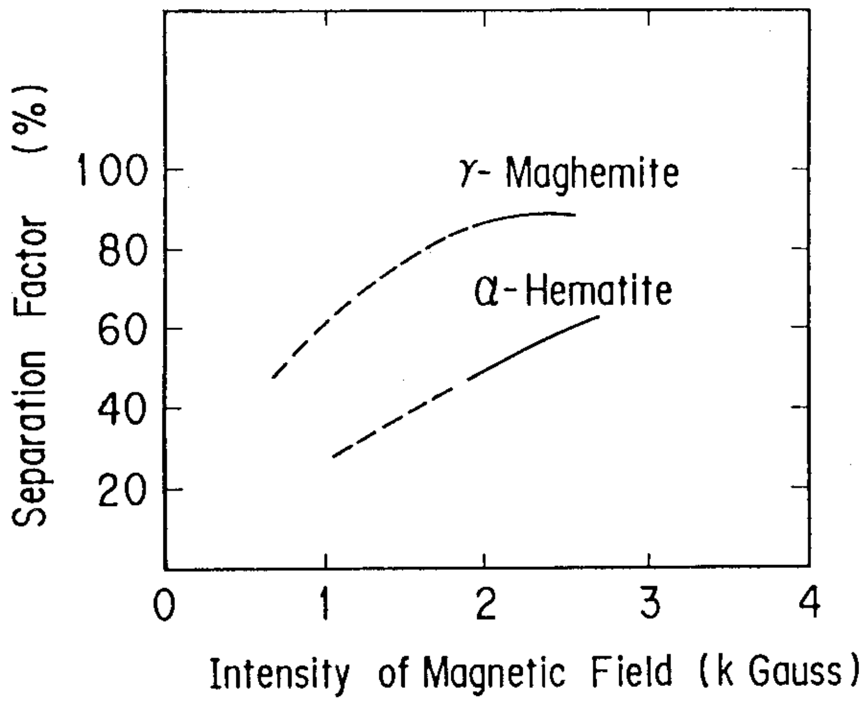


Fig. 8 Intensity of magnetic field v.s. separation factor of hematite and maghemite

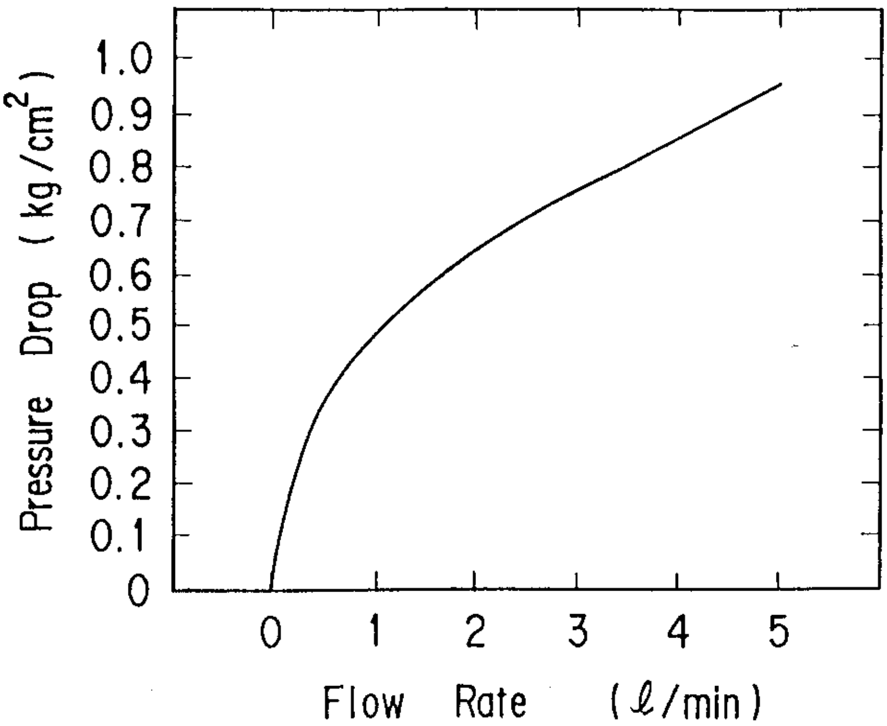


Fig. 9 Pressure drop vs. flow rate for crud separator (advanced type)

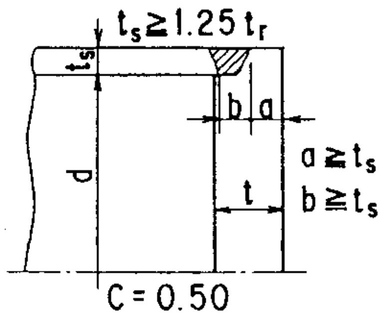


Fig. 10 Weld details for end plate

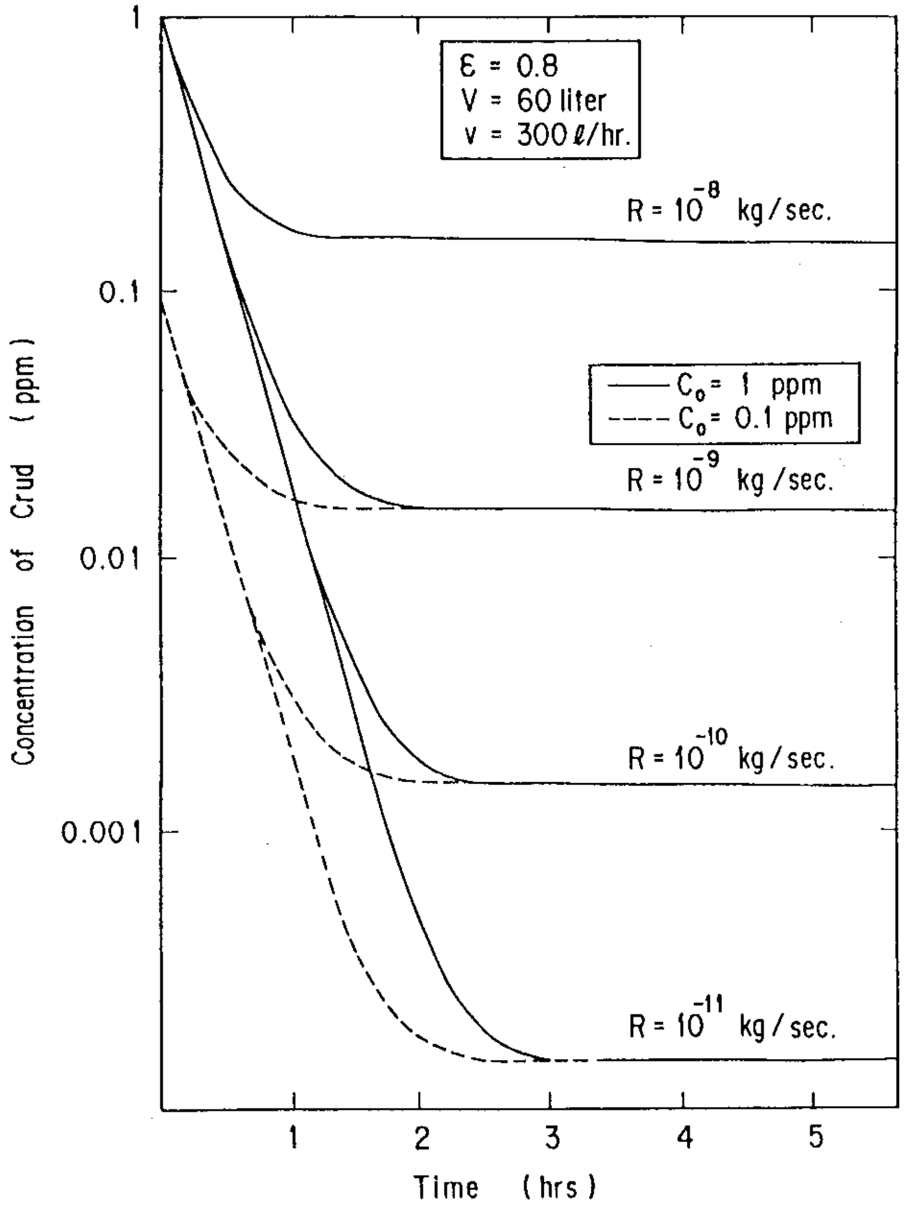


Fig. 11 Concentration variation of crud (ε=0.8)

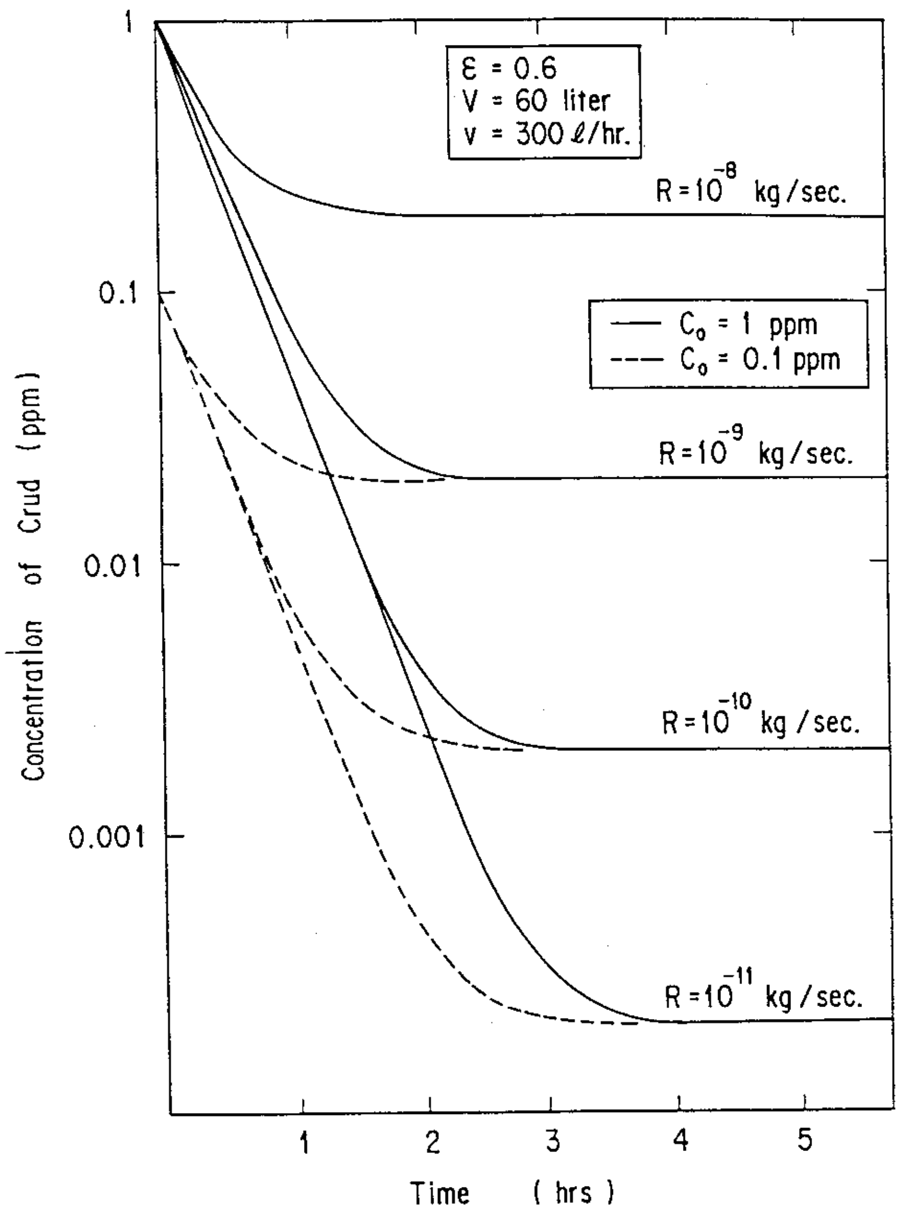


Fig. 12 Concentration variation of crud (ε=0.6)

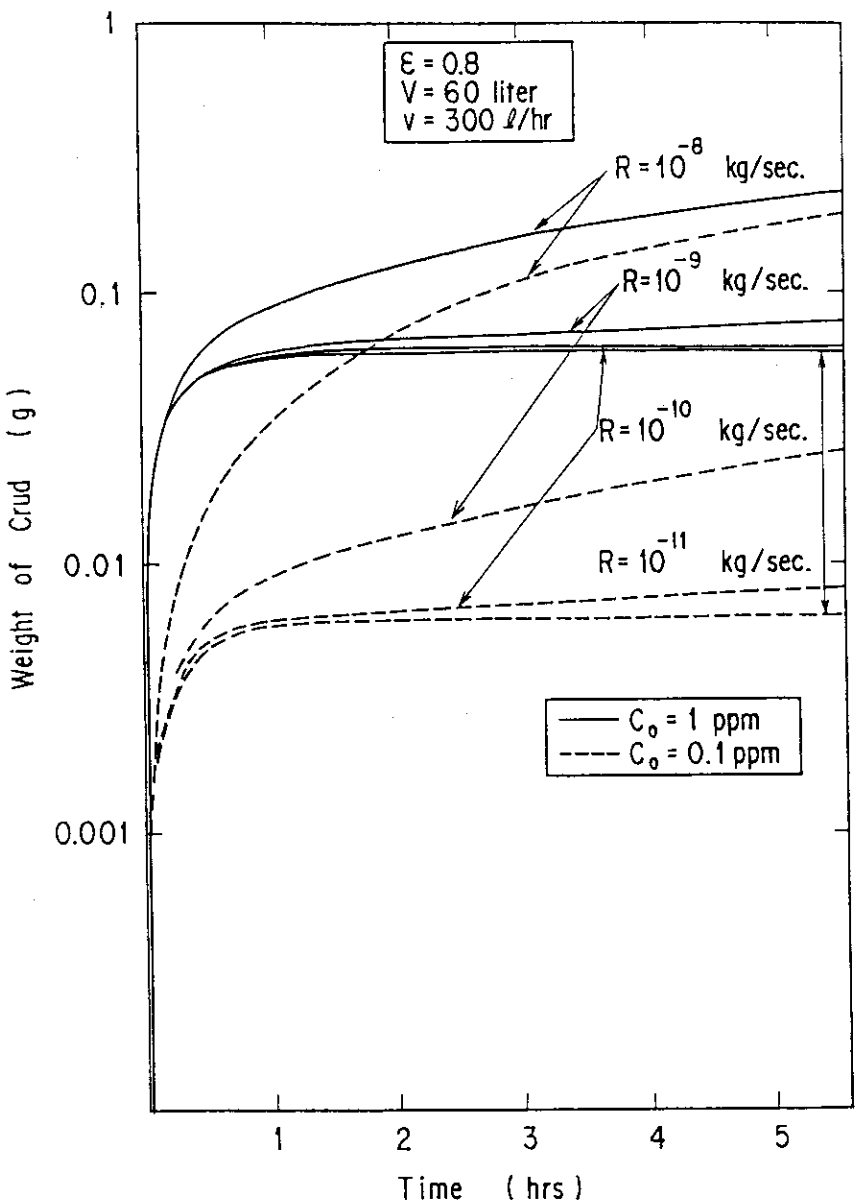


Fig. 13 Accumulation of crud at the separator (ε=0.8)

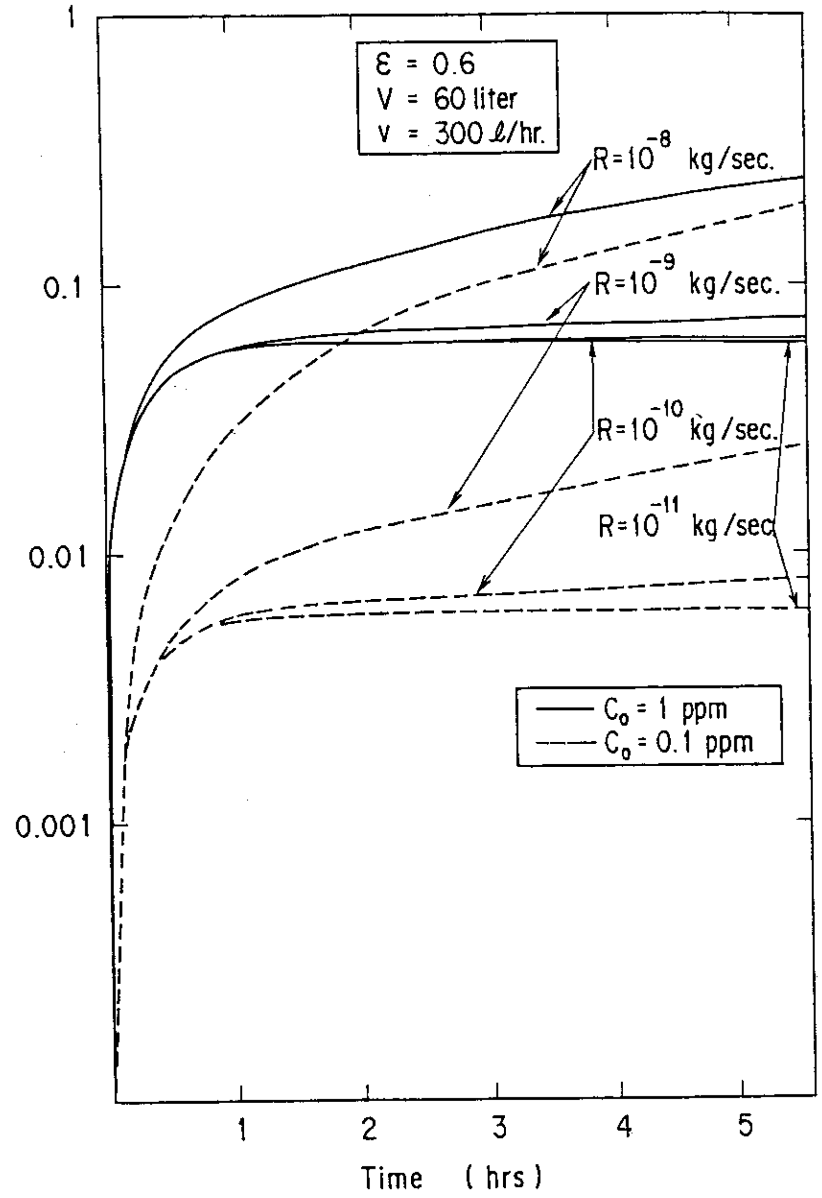


Fig. 14 Accumulation of crud at the separator (ε=0.6)

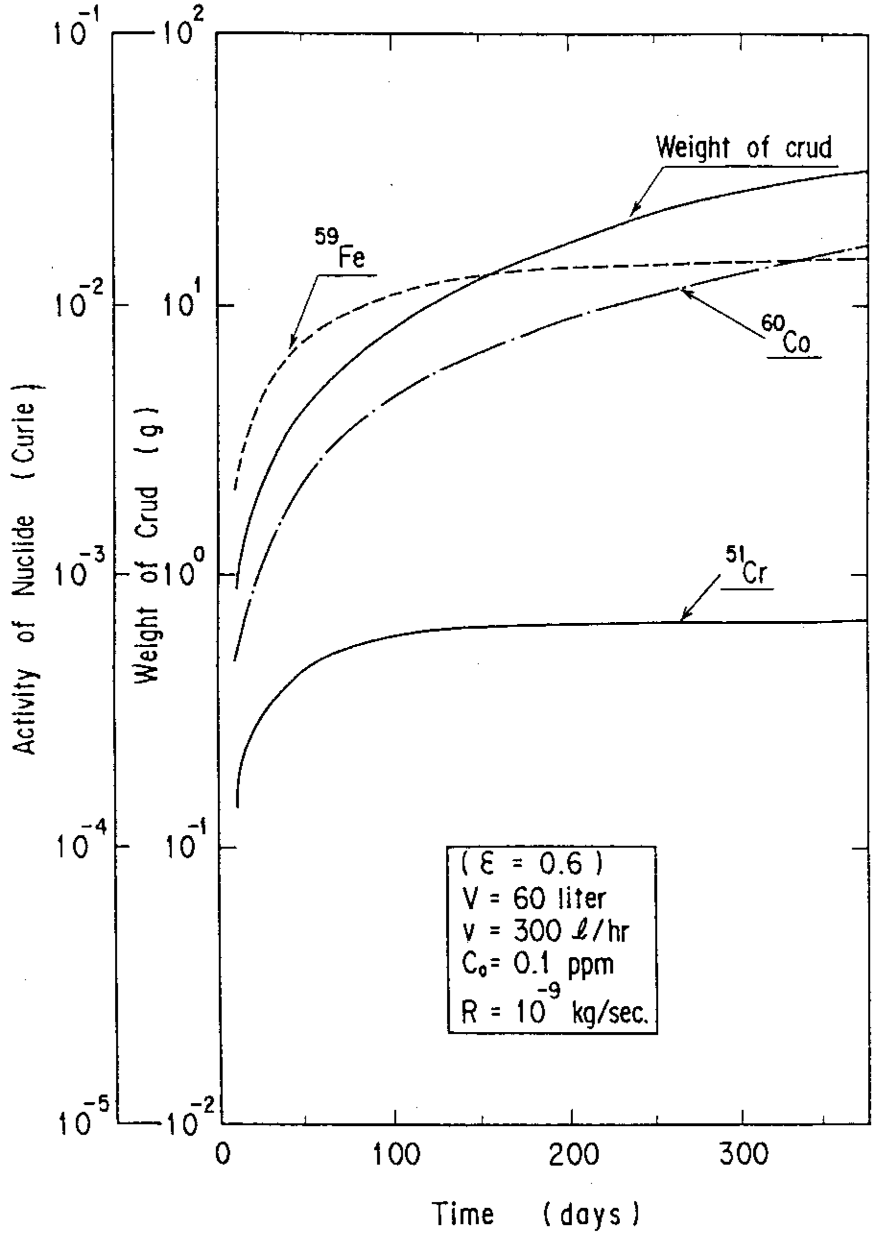


Fig. 15 Accumulation of crud and activity Build-up of major nuclides at the separator (ε=0.6)

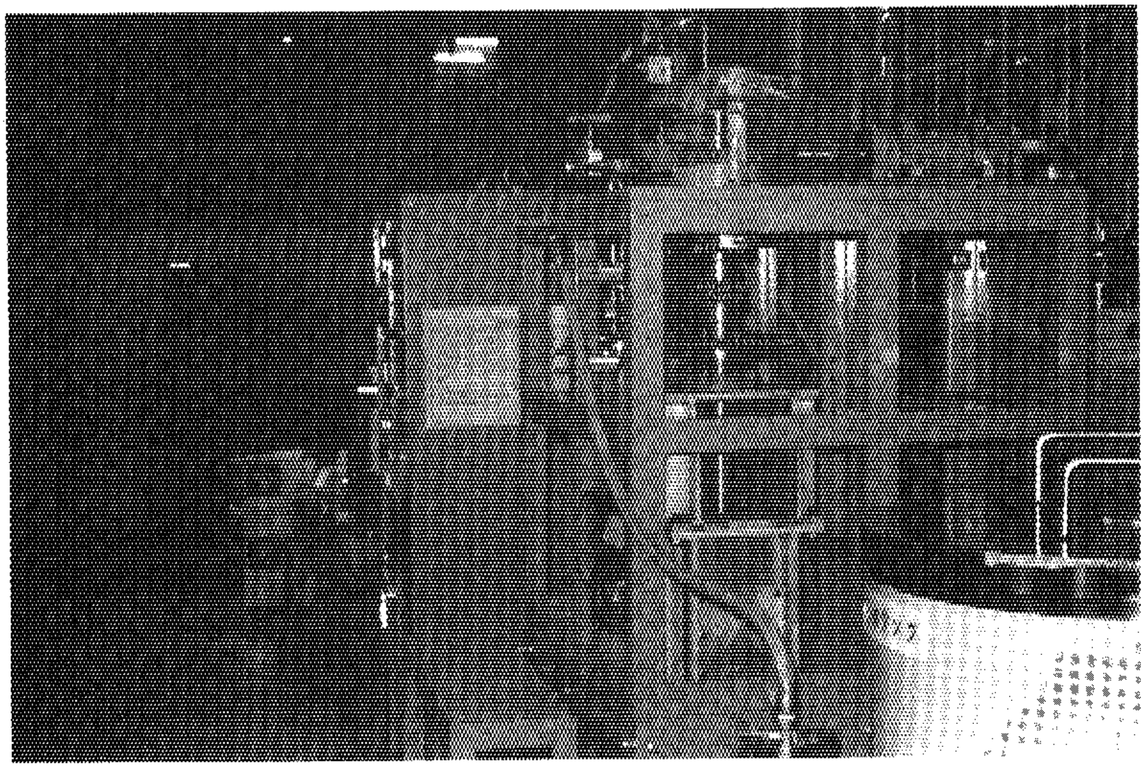
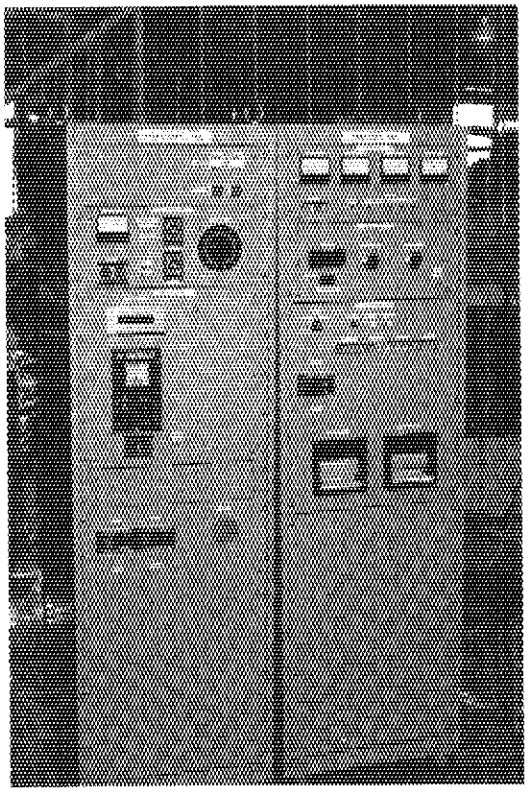


Photo. 1 Crud separator system

Magnet Driving Controller



Enlarger & Demagnetizer Controllers

Photo. 2 Control panel