PNC TN8100 94－003

第12回 PNC／KfK高レベル廃棄物管理会議
（2／2）別冊資料集

（1993年12月7日～9日，動燃東海事業所にて開催）

—高放射性廃液固化研究報告—

1994年2月

動力炉・核燃料開発事業団
東　海　事　業　所

PNC TN8100 94－003
1　9　9　4　年　2　月

第12回　PNC／KfK高レベル廃棄物管理会議　(2/2) －別冊資料集
(1993年12月7日～9日，動燃東海事業所にて開催)

報告責任者　大内　　仁
編　集　者　捧　　賢一，二村　浩尓

要　　旨

動燃事業団と独KfKとの間に結ばれている高レベル廃棄物管理における協定の一環として，ガラス固化技術を中心とする廃棄物管理に関する会議が1993年12月7日から9日までの3日間，東海事業所において開催された。

本資料は，第12回PNC/KfK高レベル廃棄物管理会議報告書 (1/2) －会議 PNC　PN8100 94-002の別冊資料集として，発表に用いたOHP資料をとりまとめたものである。

報告者所属：環境技術開発部　環境技術第一開発室

別 冊 資 料 目 次

1. 会議日程

1993.12.7

Agenda of
The 12th Annual meeting between KfK and PNC
in the field of High－Level Waste Management
held at PNC Tokai on 7－9 December

The 1st day,Dec.7,Tuesday

8:00 Pick-up at the Hotel

8:25 Arrive at the Tokai-works and clearance procedure at the gate

8:40 Welcome and meeting Mr.Miyahara,the Director and Mr.Sasao,the Deputy director of Tokai works
Move to ETF

9:00 Opening remarks and Confirmation of agenda

TECHNICAL PRESENTATION(1)

OVERVIEW

9:10 Current status of radioactive waste management in JAPAN (PNC: Zaitu,T.)

9:30 Current status of radioactive waste management in GERMANY (KfK: Roth,G.)

VITRIFICATION PLANT AND PROCESS PERFORMANCE

9:50 Conceptual study for the conditioning of the HAWC-WAK waste and on-site vitrification (KfK: Roth,G.)

10:10 Plant description and nonradioactive start-up test of TVF (PNC: Yoshioka,H.)

11:00 Evaluation of the noble metals behavior, ESM feed preparation system (KfK:Grünewald,W.)

MELTER AND PROCESS TECHNOLOGY

11:30 GRAVIS process control and data acquisition system (KfK: Roth,G.)

12:00 Lunch

13:00 Tour of TVF

TECHNICAL PRESENTATION(Continued)

15:00 3-dimensional mathematical modeling and physical modeling of melter (PNC: Ayame,Y.)

15:30 Measurements of DF data for Sr, Cs and Ru for the melter and the off-gas line (KfK: Weisenburger,S.)

16:00 Inspection technique based on LASER for melter and dismantling of spent melter (PNC: Kobayashi,H.)

16:30 Melt level detection system recently tested in the K-6' and K-W3 melter
New overflow heating technique applied in the ESM melter (KfK: Tobie,W.)

17:00 Move to Hotel

The 2nd day, Dec.8 Wednesday

TECHNICAL PRESENTATION(2)

9:00 **FUNDAMENTAL RESEARCH ON THE FUTURE HLLW TREATMENT**

New glass melter (PNC: Igarashi,H.)

Partitioning of heat generating elements (PNC: Yonezawa,S.)

Higher volume reduction glass melting (PNC: Sasage,K.)

WASTE CHARACTERIZATION AND PRODUCT QUALITY ASSURANCE

10:00 Characterization and quality assurance for the HAWC-WAK waste glass if produced in the PAMELA and disposed in Germany (KfK: Weisenburger,S.)

10:30 Characterization of glass and HLLW for the quality assurance(PNC)

Characterization of the glass produced in cold test operation of TVF, (PNC: Kawamura,T.)

Characterization of the HLLW from the Tokai Reprocessing Plant) (PNC: Yamashita,T.)

11:00 Break

TECHNICAL DISCUSSION

11:10 Indentify subjects to discuss and discussion

12:00 Lunch

13:00 Discussion

17:00 Move to hotel

The 3rd day, Dec.9 Thursday

8:40 Summarize the technical discussion

12:00 Lunch

13:00 Summarize the technical discussion

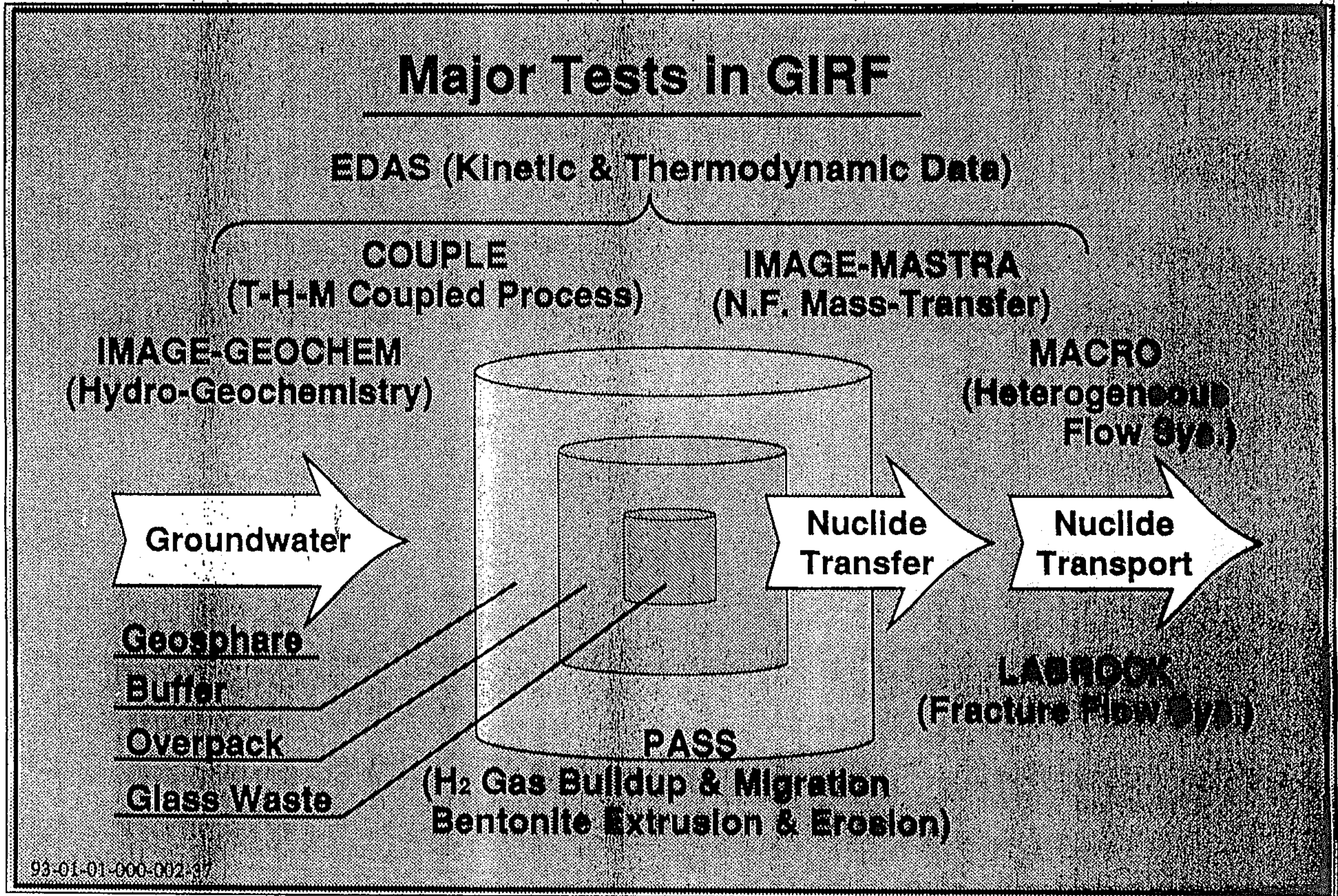
15:00 Future collaboration

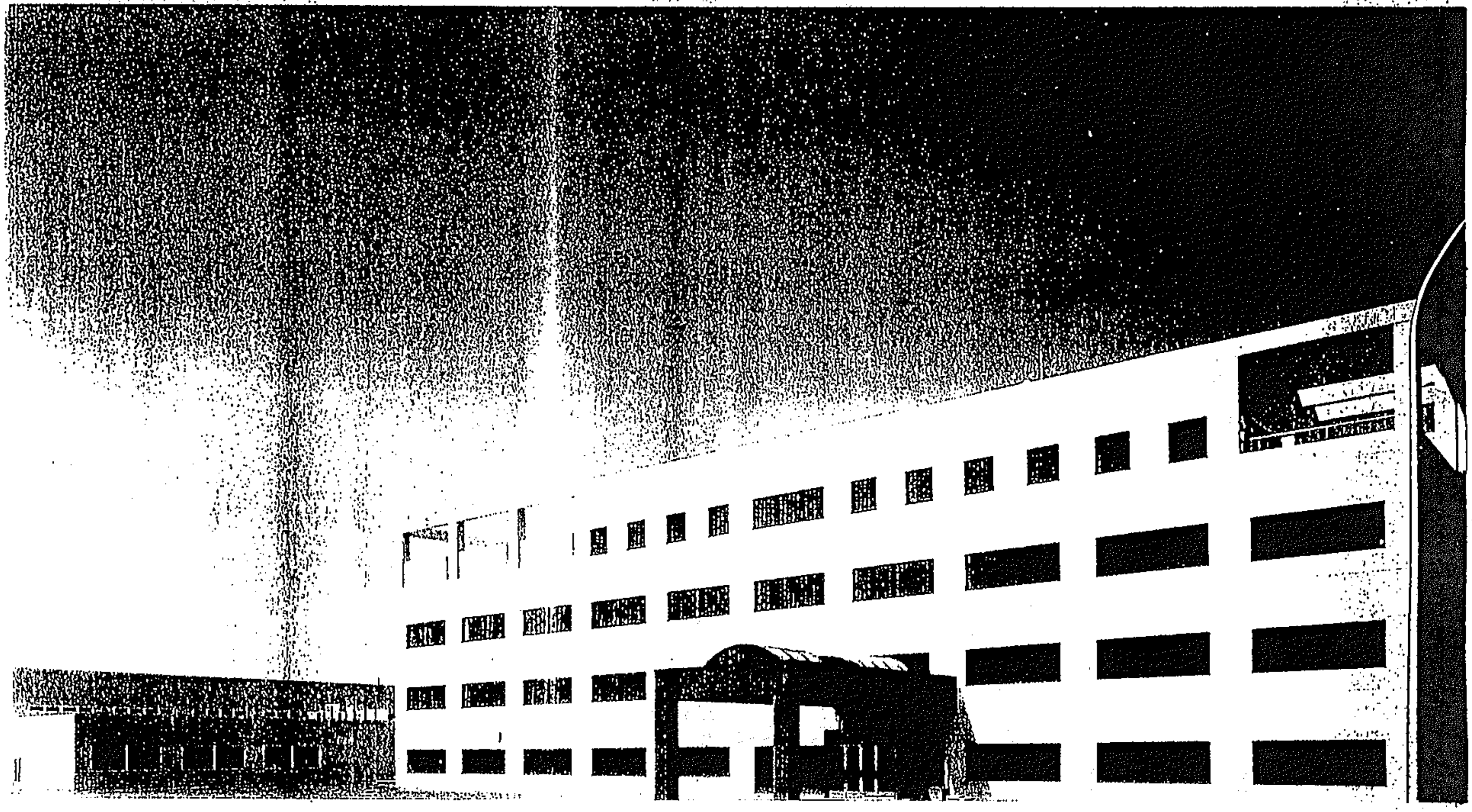
Preparation of the meeting minutes

17:00 Move to Hotel

2. PNC 側の発表資料

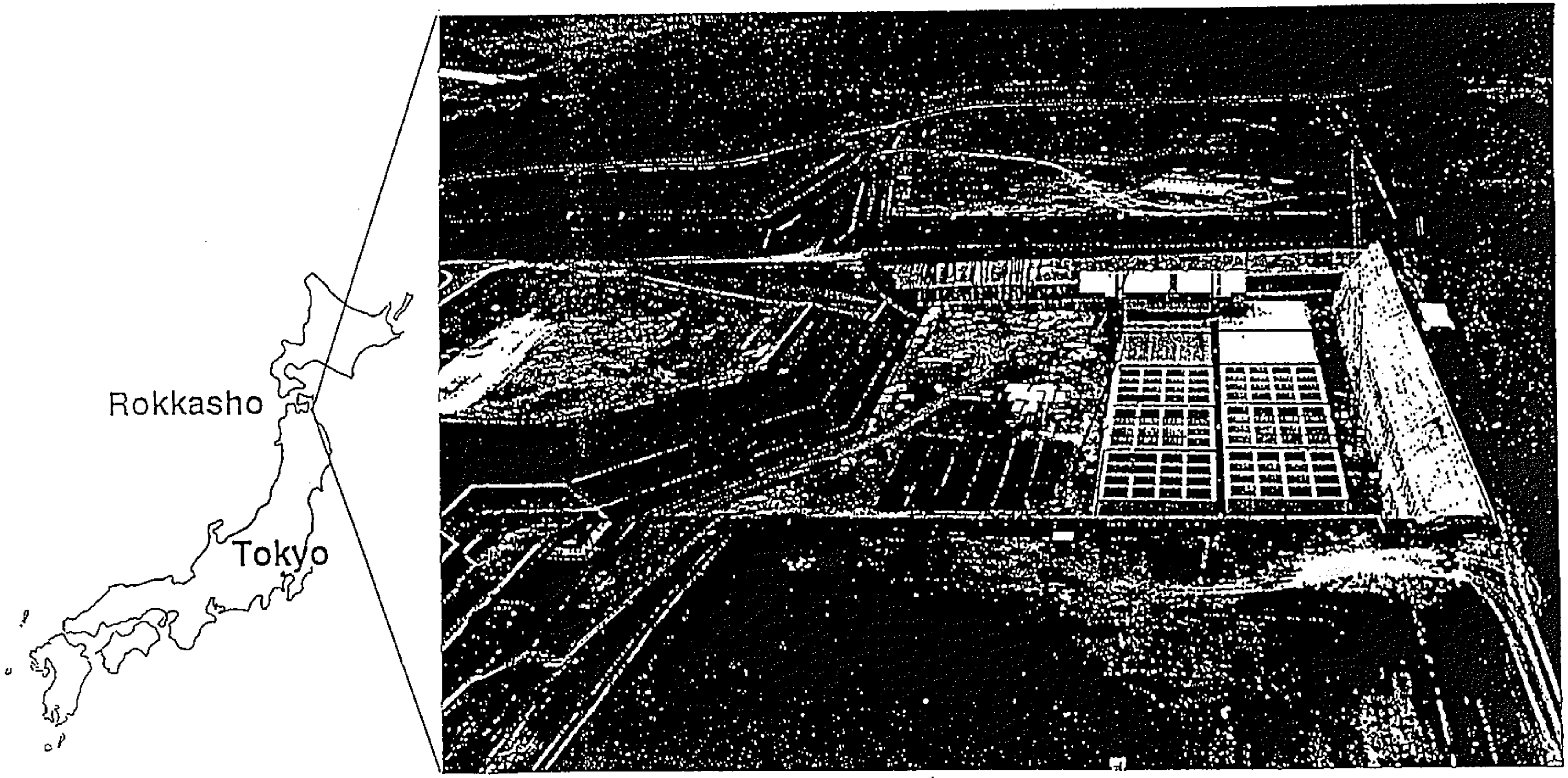
2.1 Current status of radioactive waste management in JAPAN


Major Tests in GIRF
EDAS (Kinetic & Thermodynamic Data)
COUPLE
(T-H-M Coupled Process)
IMAGE-MASTRA
(N.F. Mass-Transfer)
IMAGE-GEOCHEM
(Hydro-Geochemistry)
MACRO
(Heterogeneous
Flow Sys.)
Groundwater
Nuclide
Transfer
Nuclide
Transport
Geosphere
Buffer
Overpack
Glass Waste
LABROCK
(Fracture Flow Sys.)
PASS
(H2 Gas Buildup & Migration
Bentonite Extrusion & Erosion)
93-01-01-000-002-37



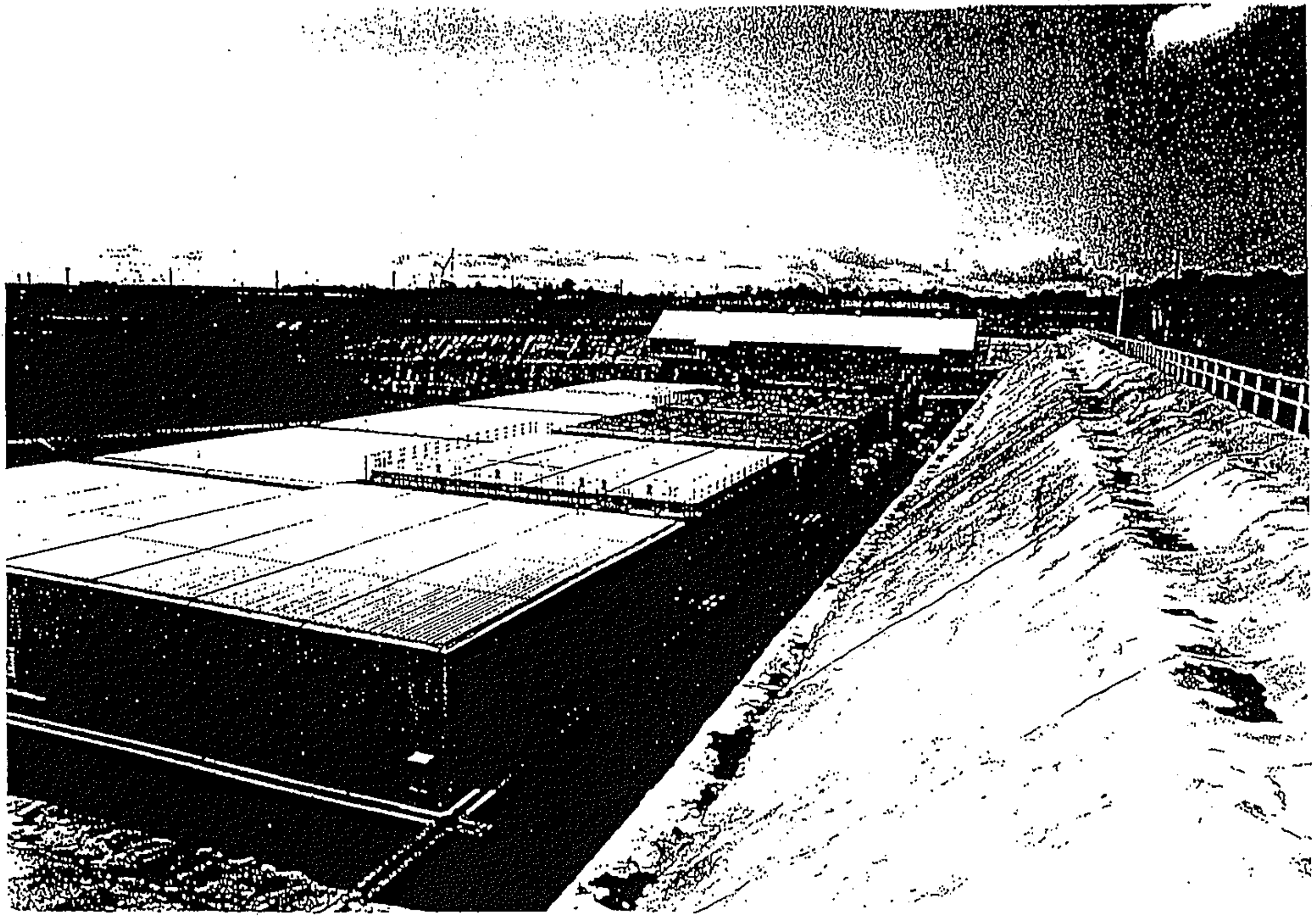
Geological Isolation Research Facility (GIRF)

Management of LLW



Shallow Land Burial at Rokkasho

PNC



Shallow Land Burial at Rokkasho

PNC

Management of Radioactive Waste Containing TRU Nuclides

- Minimize the Generation and Develop the More Advanced Technology to Reduce the Volume

- Dispose of :

1. 11GBq/ton

Below → Possibly by shallow Land Burial

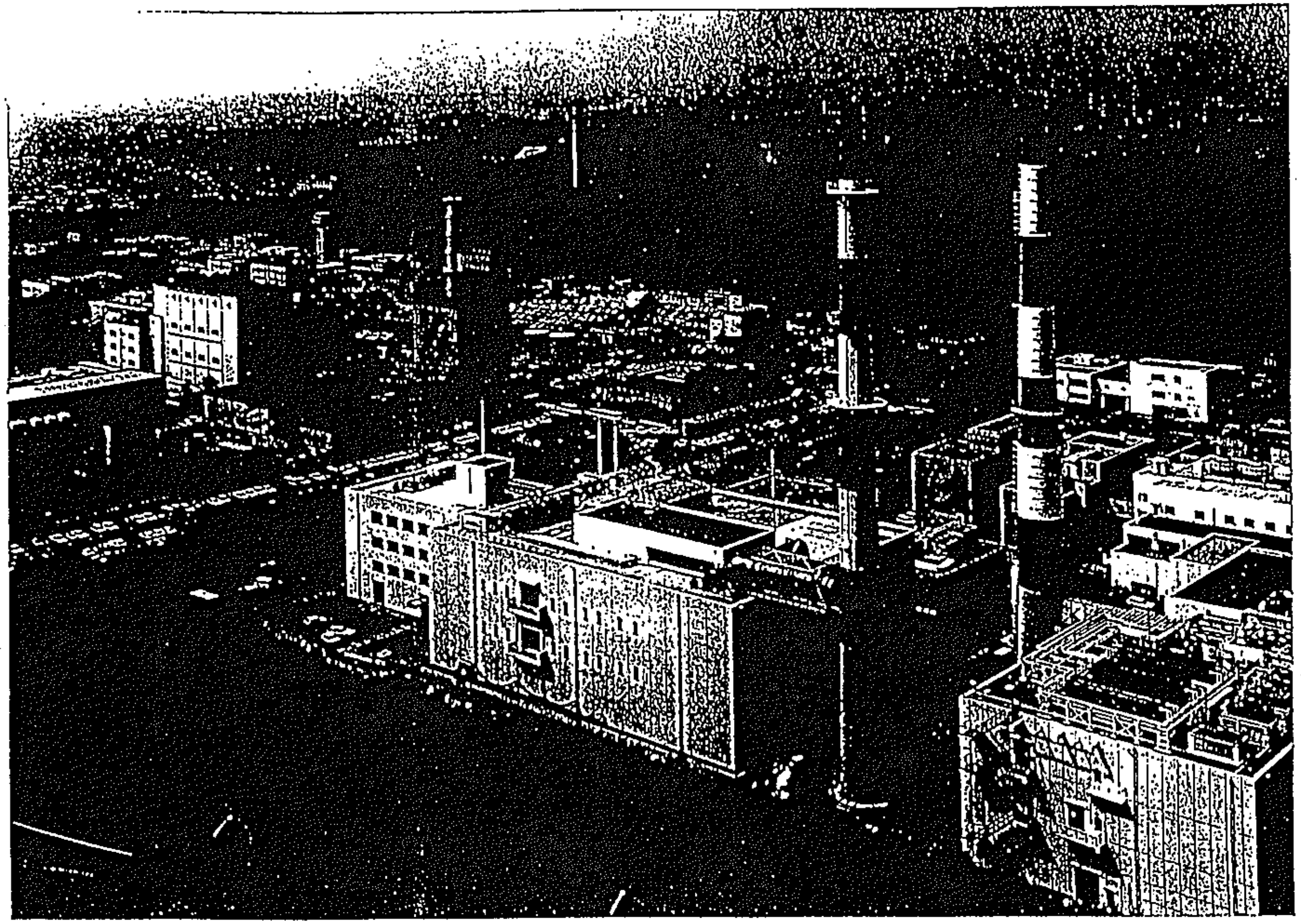
Above ↓

TRU Waste

More Adequately in Underground Repository

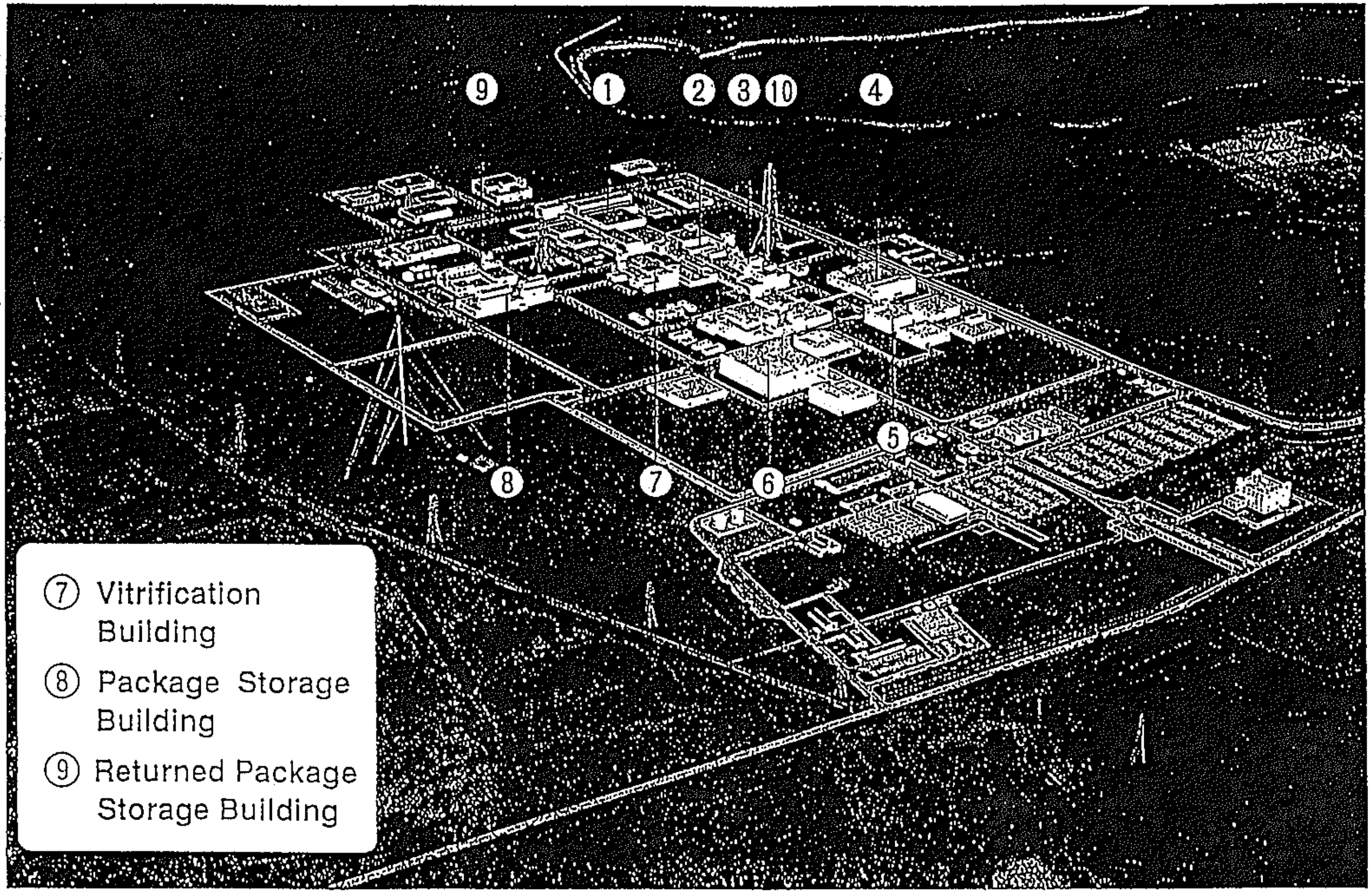
- Clarify the Feasibility of Disposal Technology by the Late of 1990's

Management of HLW



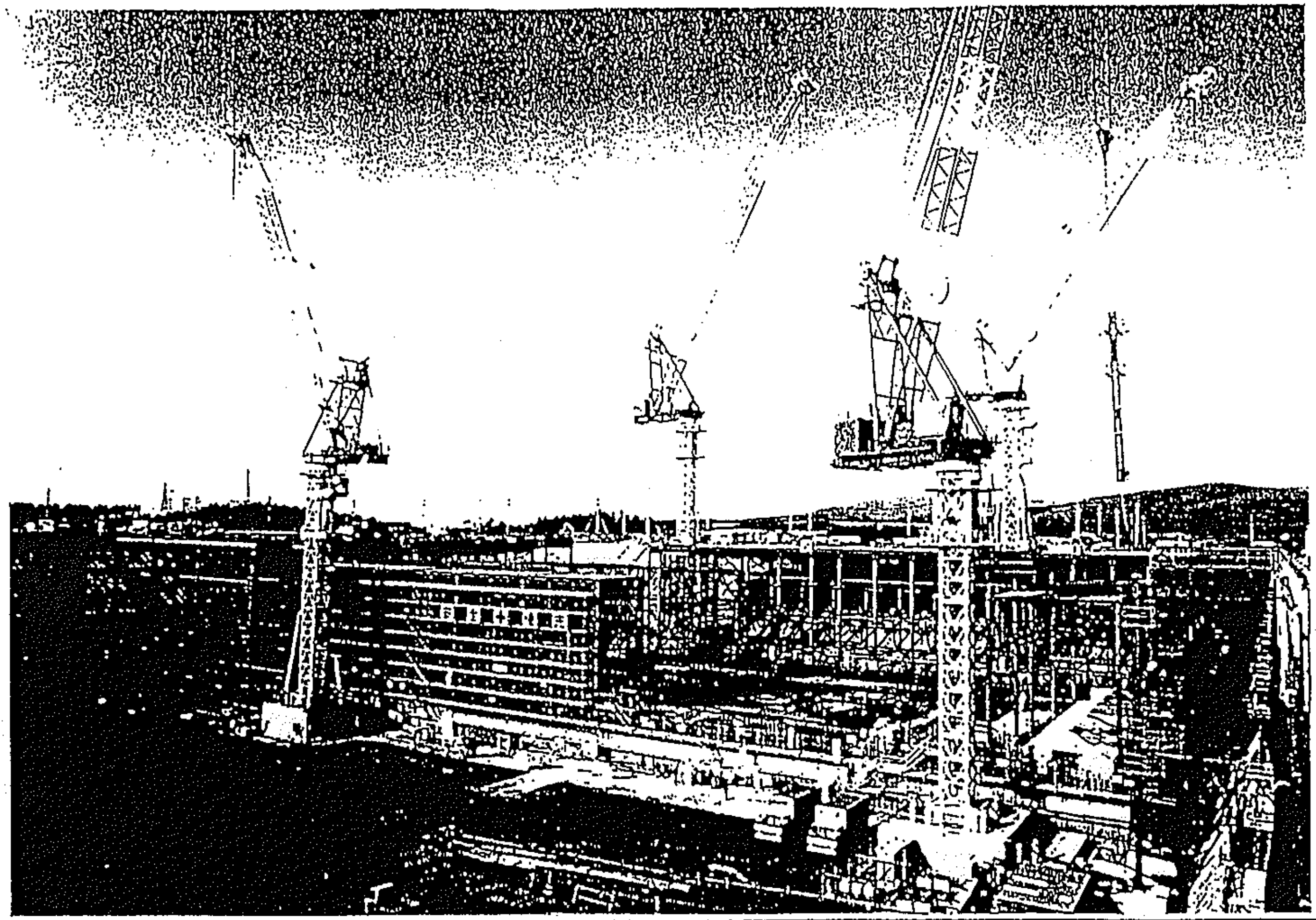
Tokai Vitrification Facility

PNC



General Layout of the Reprocessing Plant at Rokkasho

PNC



Construction of Returned Vitrified Package Storage Building

HLW Disposal Program should be Based on Careful Consideration

It is Considered Highly Important :

- To Provide a Clear Distinction between Implementation of Disposal and R&D as Independent Processes

- To Increase the Transparency of the Overall Disposal Program by Defining Concrete Schedules and the Roles & Responsibilities of the Organization Involved

PNC

Overall Procedures & Schedule for Implementing Geological Disposal

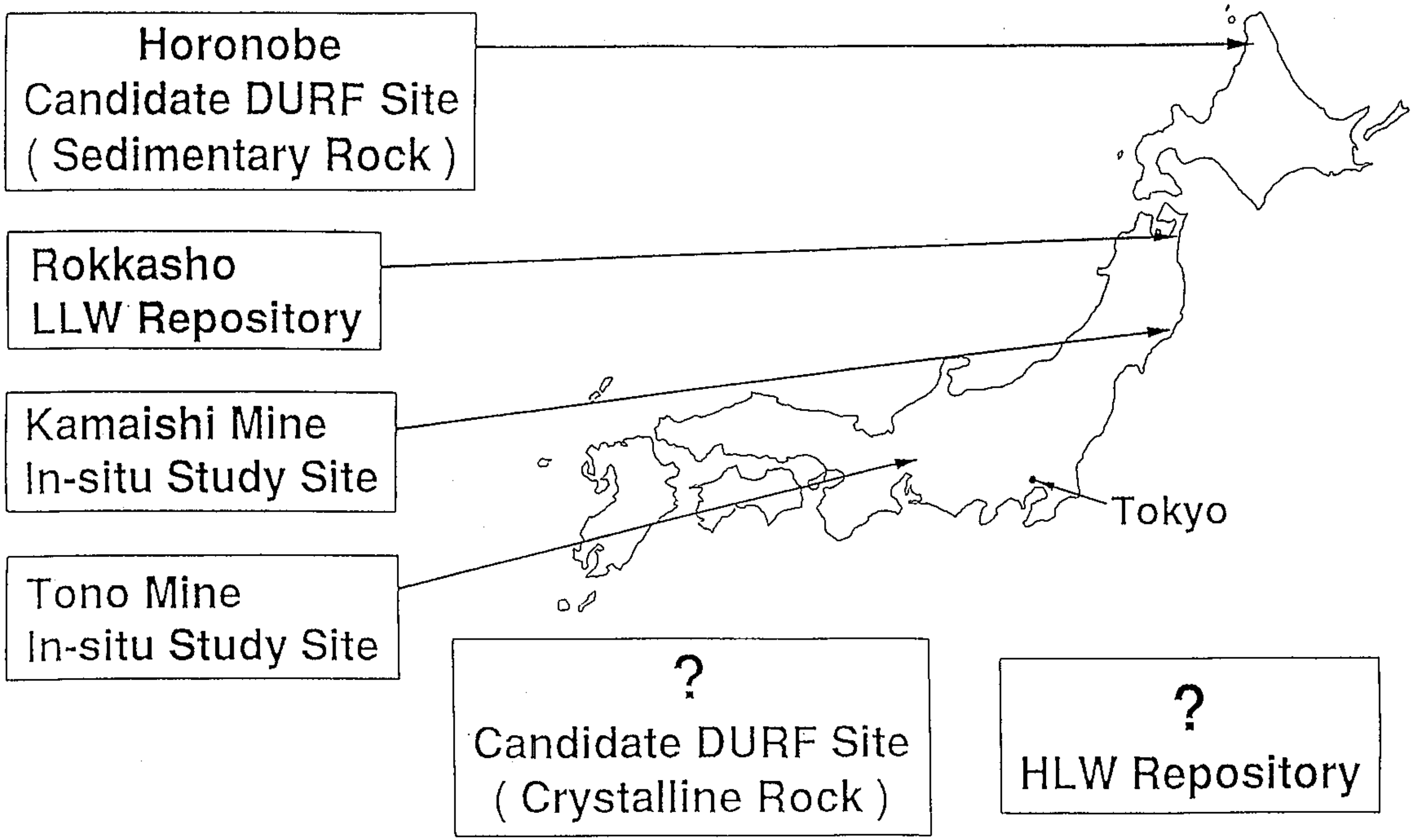
1993 Steering Committee on High-level Radioactive Waste Project (SHP) was Established on 28th of May

~2000 Implementing Organization will be Established
- Site Selection with Local Acceptance
- Site Characterization Studies & Demonstration of Disposal Technology
- Design of Repository and Application for Licensing

Safety Investigations for Granting License Conducted by the Government

2030 ~ Mid of 2040's Start of Repository Operation

PNC



In-situ Study Sites where PNC is Conducting Research and Development.

(DURF means deep underground research facility.)

PNC

HLW Disposal Program should be Based on Careful Consideration

- Reviews of the Results of R &D Work should be Carried out by Governmental Authorities at Appropriate Intervals

- It is Important to Ensure that Local Communities' Views and Wishes are Reflected in the Decision-making Process during Each Stage of the Program

PNC

Roles and Responsibilities

Government
- Overall Responsibility
- Policy and Rule Making

PNC
- Research and Development
- Geological Environment Study

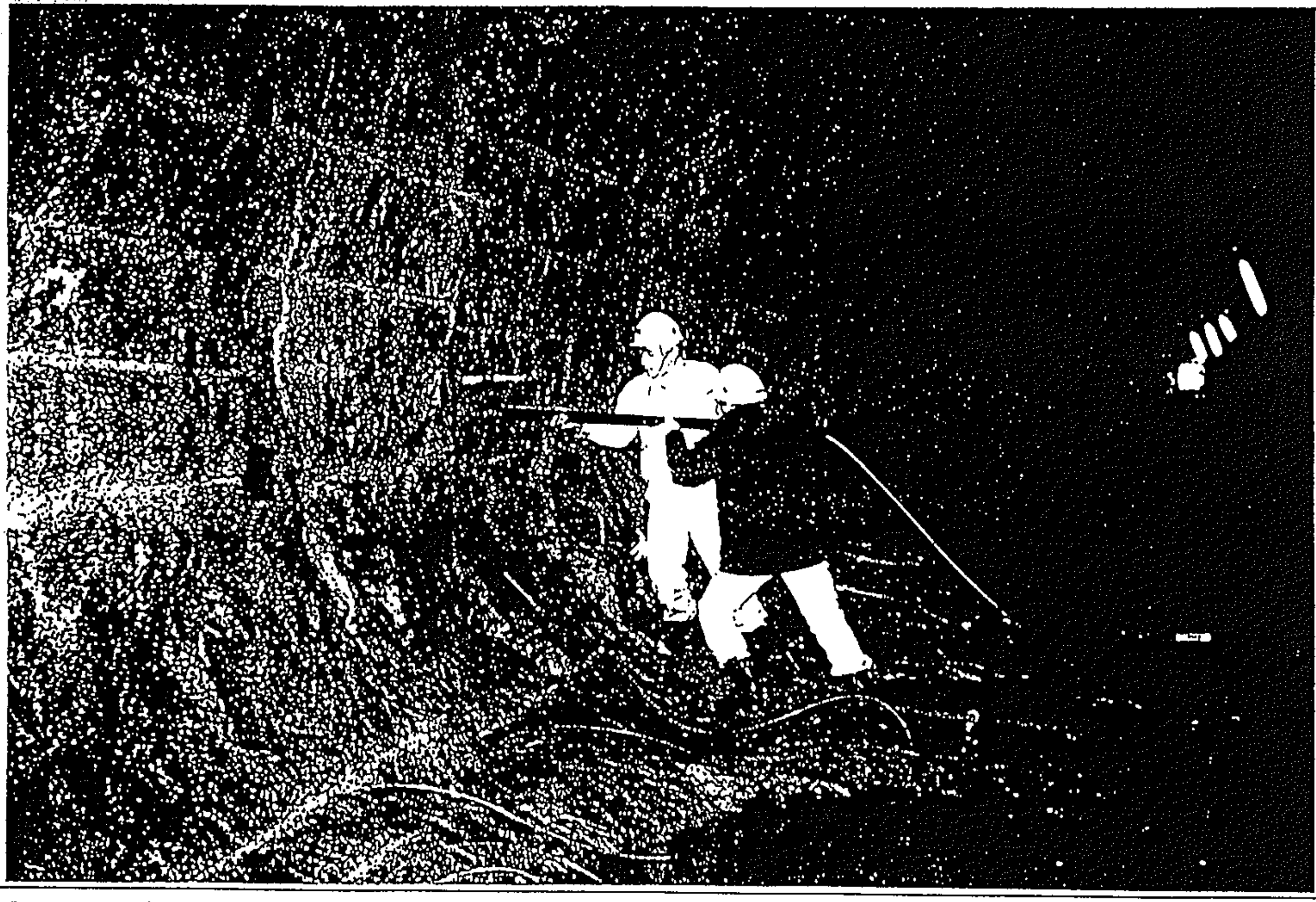
Utilities
- Collection of Disposal Cost
- Cooperation in R&D as Waste Producers

PNC

PNC's First Progress Report on Geological Disposal of HLW

- Submitted to the Authority in September 1992
- Provided Information for the Public to Find out the Current Status of R&D
- Reviewed and Evaluated by Authority in July 1993
- The Second Progress Report is Scheduled to be Submitted before the Year 2000

PNC



In-situ Experiments at Kamaishi Mine

PNC

2.2 Cold testing status of Tokai Vitrification Facility

PNC TN8100 94-003

COLD TESTING STATUS OF TOKAI VITRIFICATION FACILITY

M. YOSHIOKA

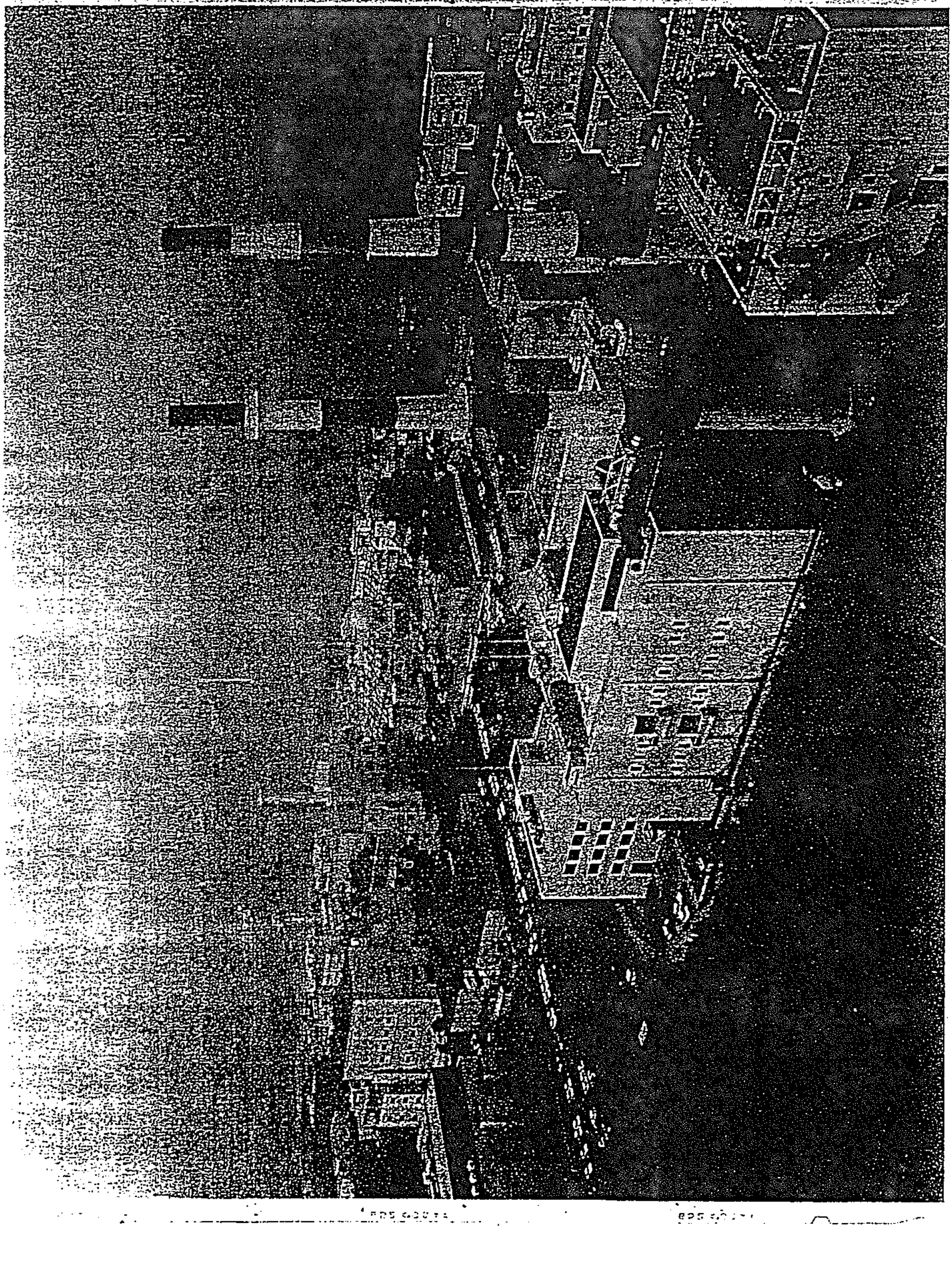
The 12th Annual KfK/PNC Meeting
on
High-level Waste Management

December 7-9, 1993

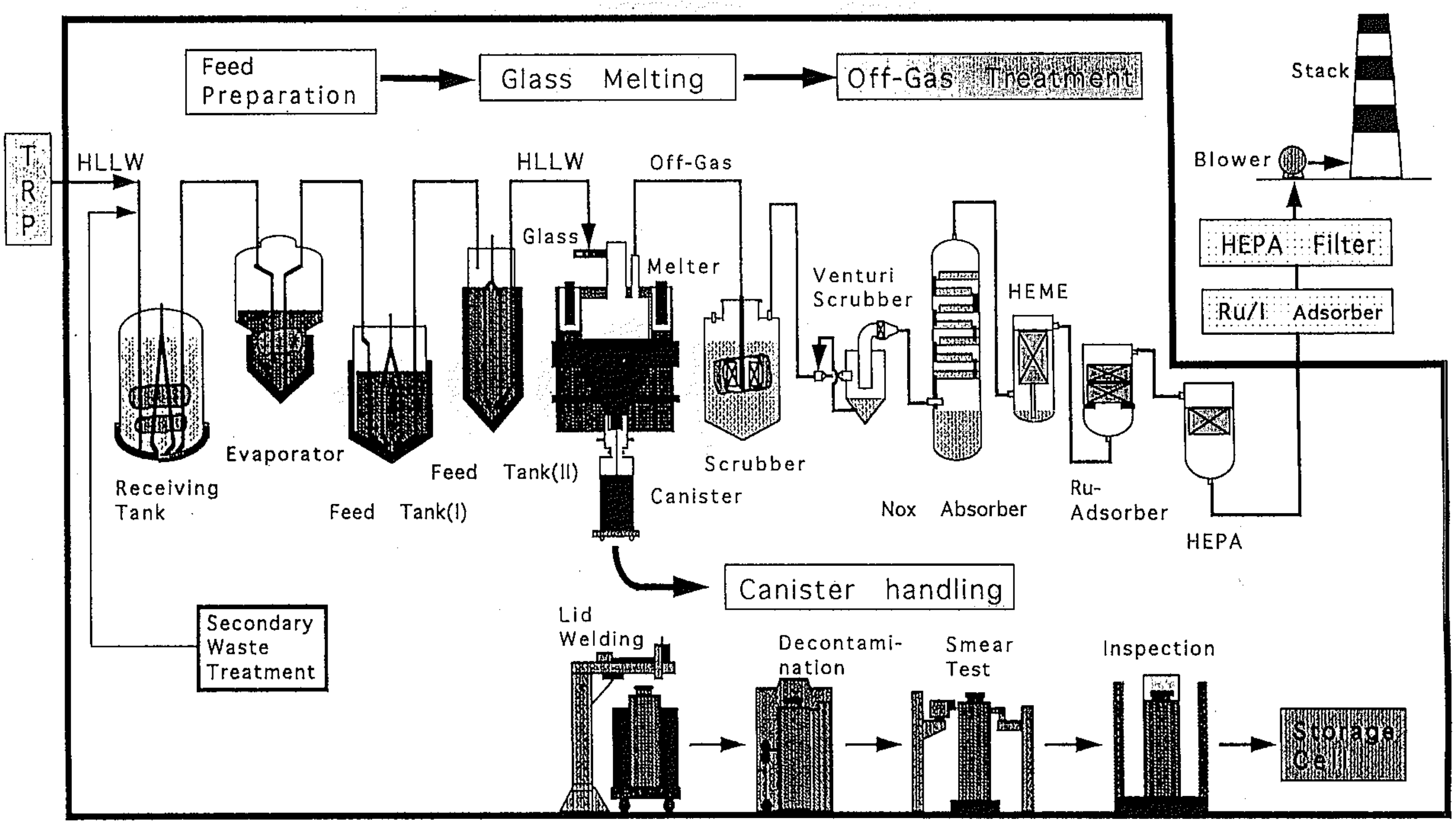
Power Reactor and Nuclear Fuel
Development Corporation

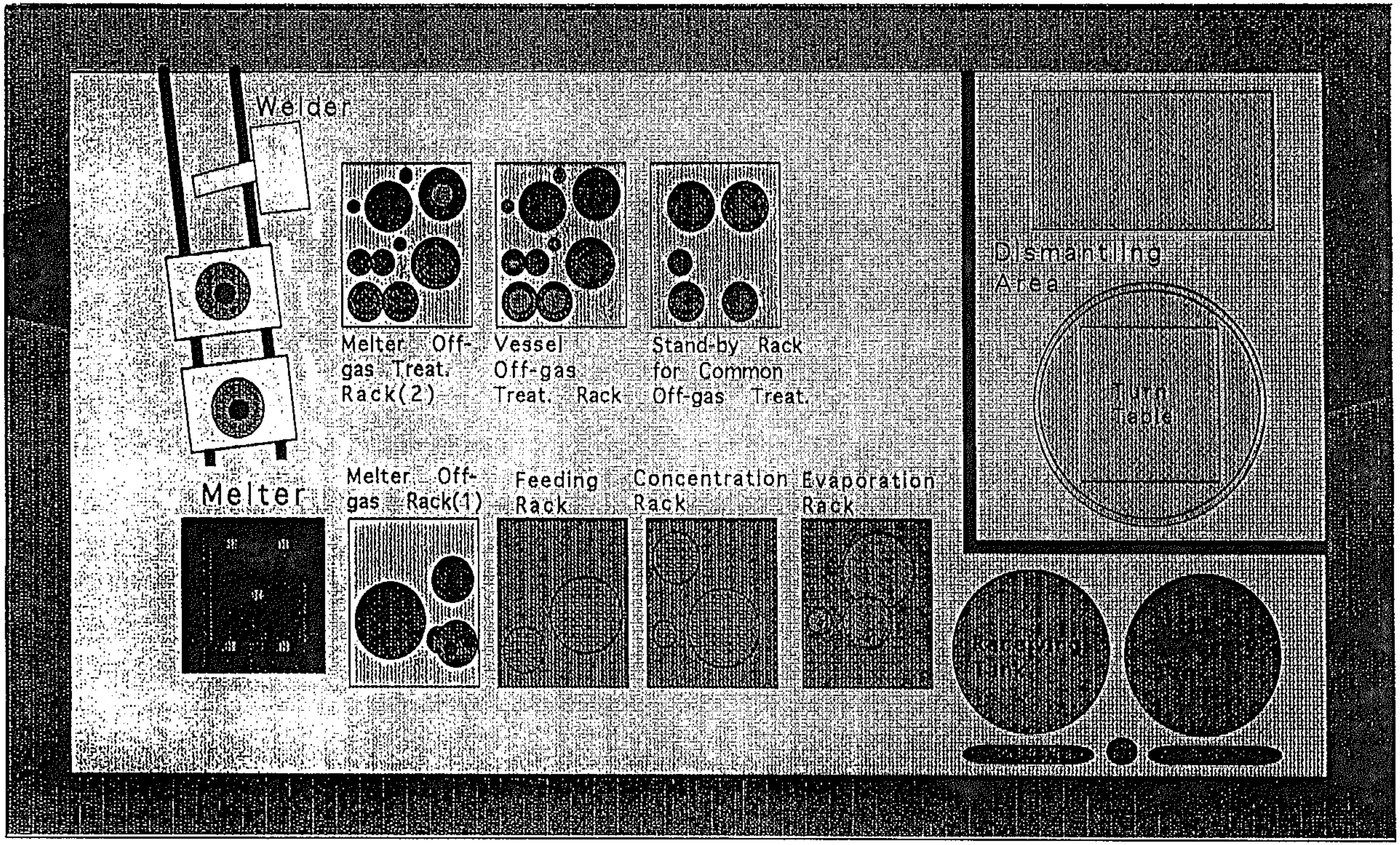
PNC

- OUTLINE OF TVF
  - Vitrification Process in TVF
  - Status of Cold Test Operation
- PROCESS CONTROL FOR GLASS PRODUCT
- MELTER OPERATION RESULT
- PERFORMANCE OF OFF-GAS TREATMENT PROCESS

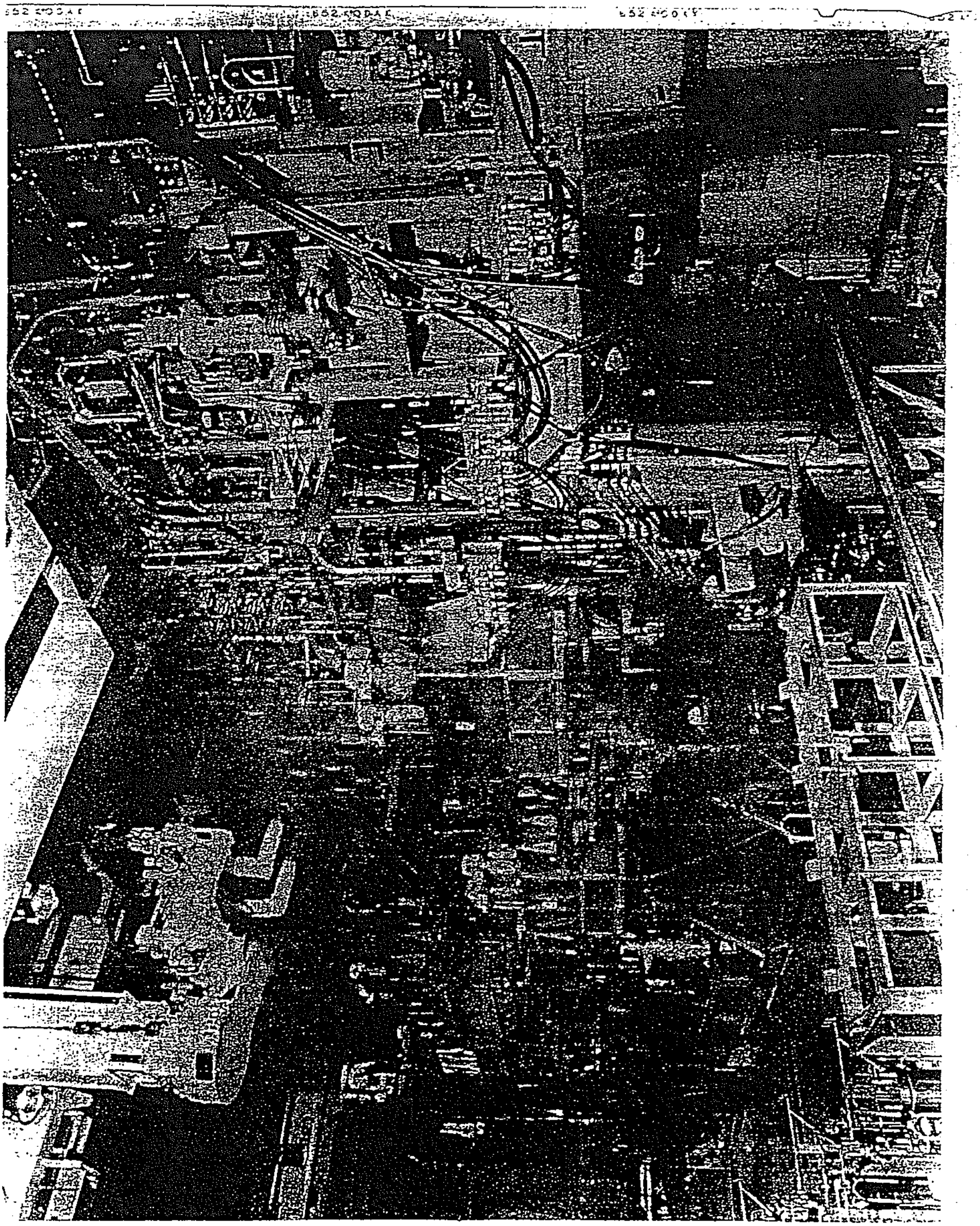


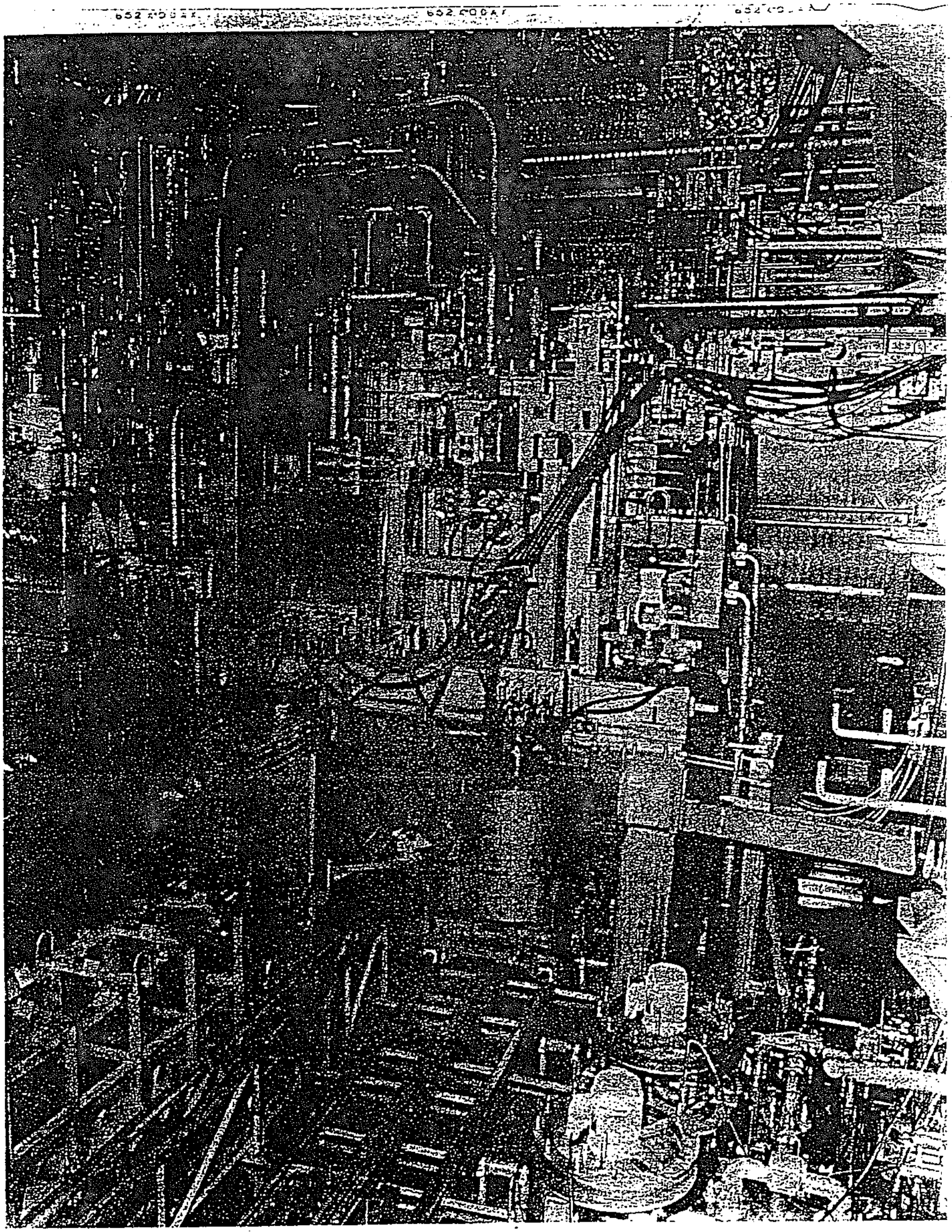
MAIN PROCESS FLOW IN TVF



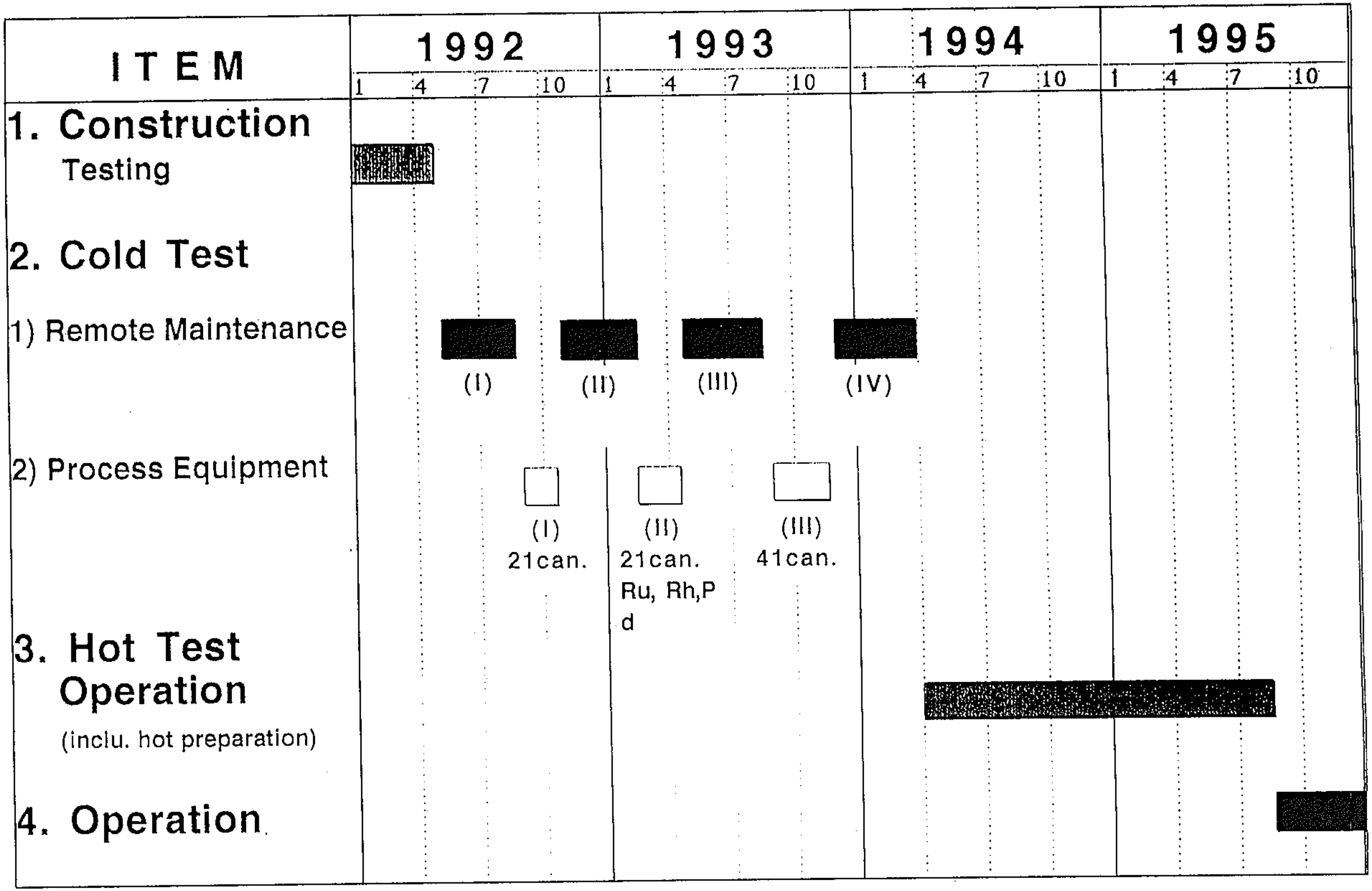


RACK LAYOUT IN VITRIFICATION CELL

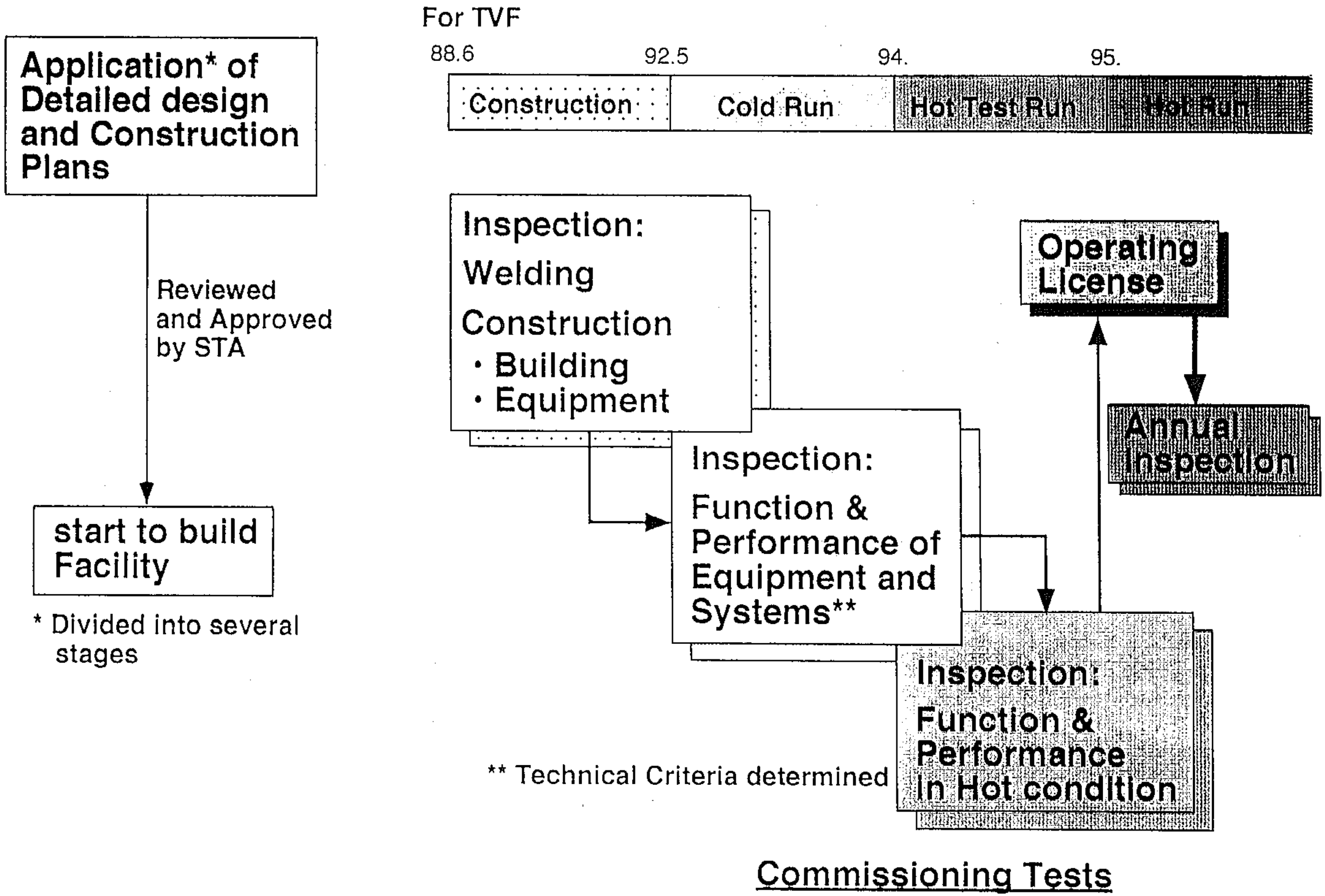




SCHEDULE OF TVF



CONSTRUCTION AND INSPECTION CONDUCTED FOR OPERATION



QUALITY CONTROL OF GLASS PRODUCT

CONTROL VALUE

Waste Oxide Content:

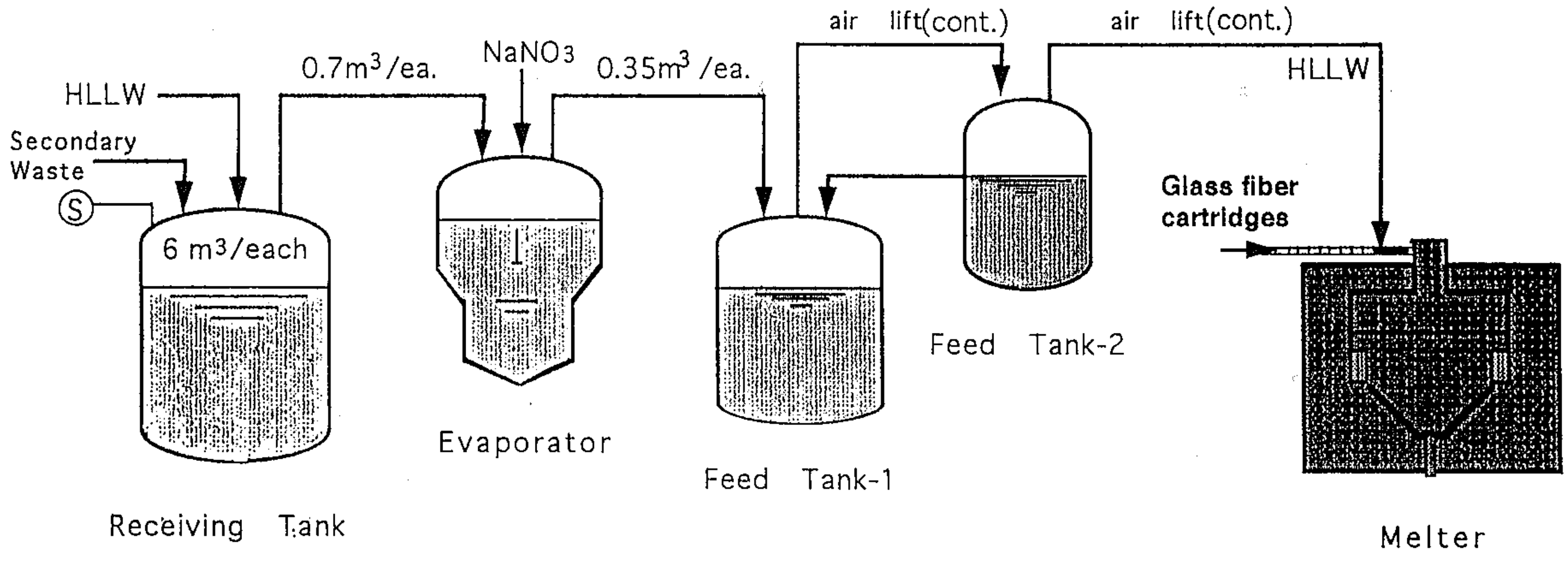
≦ 30 wt%
(Target 25 wt%)

Sodiumu Oxide Content:

8～12 wt%
(Target 10wt%)

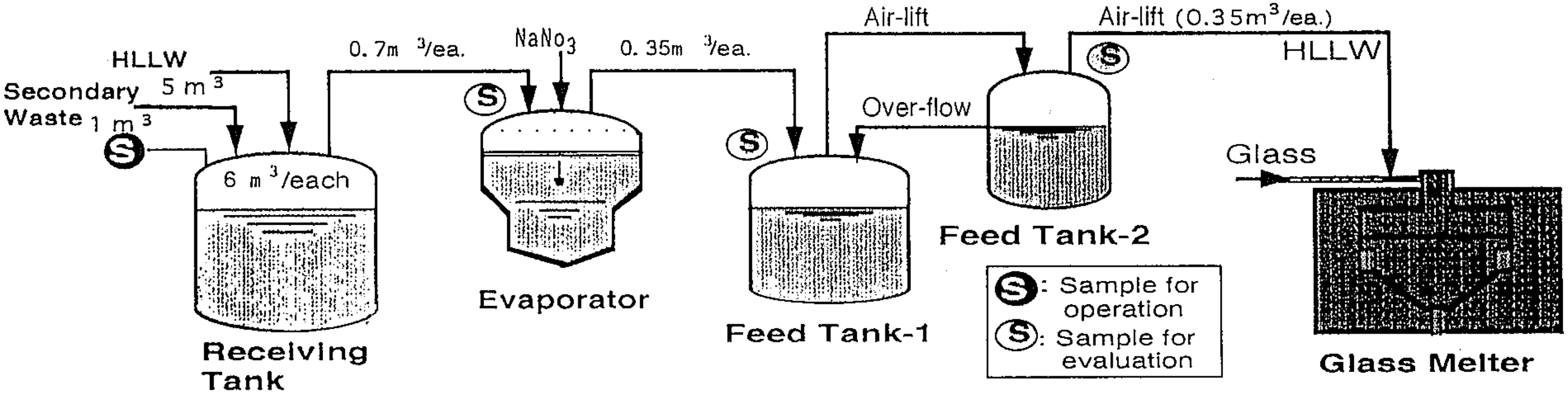
TVF STANDARD GLASS COMPOSITION

Glass elements	Content(%)	
SiO_2	46.7	75wt%
B_2O_3	14.3	
Al_2O_3	5.0	
Li_2O	3.0	
CaO	3.0	
ZnO	3.0	
Na_2O	10.0	25wt%
P_2O_5	0.2	
Fe_2O_3	1.9	
NiO	0.5	
Cr_2O_3	0.5	
FP Oxide	9.6	
Actinide	2.3	
Total	100.0	



PROCESS	RECEIVING →	CONCENTRATION →	FEEDING →	MELTING
	batch ope.	batch ope.	continuous ope.	continuous ope.
PROCESS CONTROL	•Analyze Waste Oxide [WO], Na_2O content (g/l) •Start process control based on these data	•Adjust Na_2O content by adding $NaNO_3$ •Control the concentration ratio (about 2 times)	•Determine HLLW feed rate(L/h), glass feed rate (sec/cartridge) by estimated WO, Na_2O content •Control the feed rates to get 25% of WO, 10% of Na_2O in glass product	•Control Glass Melting •Control Glass Pouring (Batch Pouring)

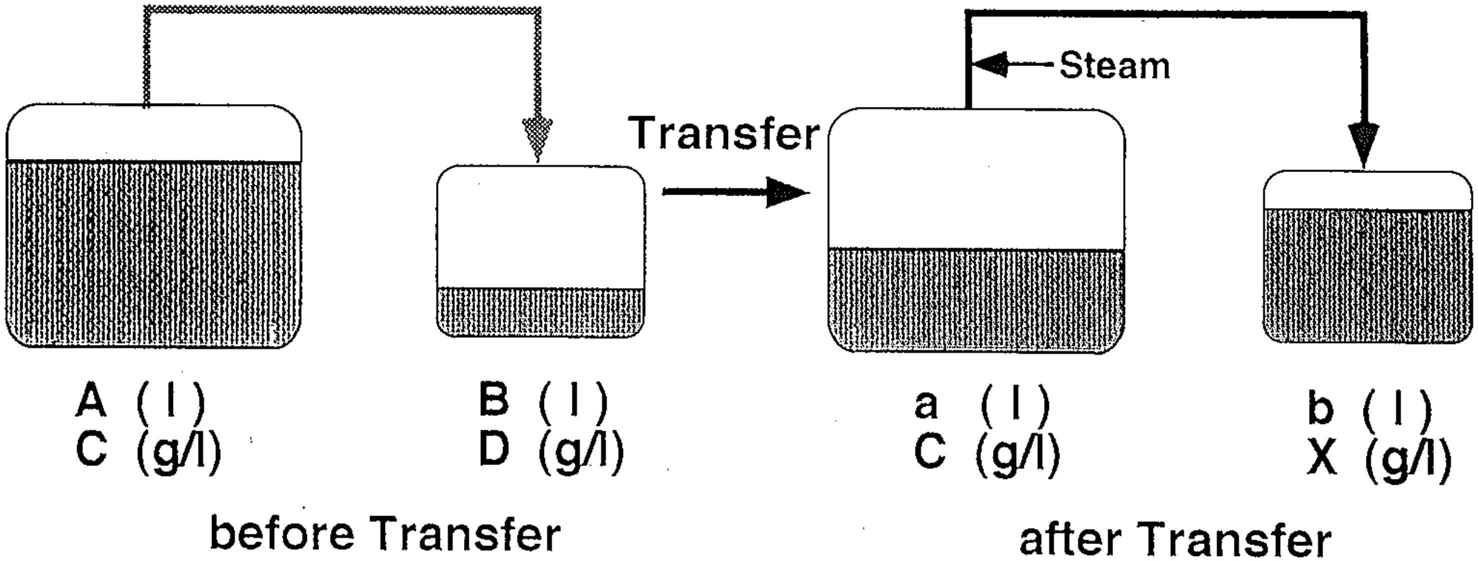
PROCESS CONTROL FOR GLASS PRODUCT QUALITY



		Receiving Tank	Evaporator	Feed Tank-1 - Tank-2
Process control		Analysis (Total waste oxide [WO] and sodium oxide [Na_2O])	• Estimation of HLLW concent. after transfer • Adjustment of Na_2O, Concentration at 2 times • Estimation of concent.	• Estimation of HLLW concent. after transfer • Setting of HLLW(l/h) and Glass(sec/each) feed rate HLLW(l/h) <---- production rate, WO content, HLLW concent. Glass(sec/fiber) <---- production rate, WO content, ave. weight of cartridge • Operation value(WO, Na_2O) = Estimated concent. X HLLW feed / (Estimated concent. X HLLW feed + Glass feed
TEST ITEM	Estimation method of concen.		Comparison of estimated concent. with analyzed one	Comparison of estimated concentration with analyzed one
	Quantitative feed			Evaluation of feed result (feed accuracy) with target in HLLW and Glass
	Control accuracy of product			• Comparison of analyzed value (WO, Na_2O) with Operation value • Comparison with solidified glass

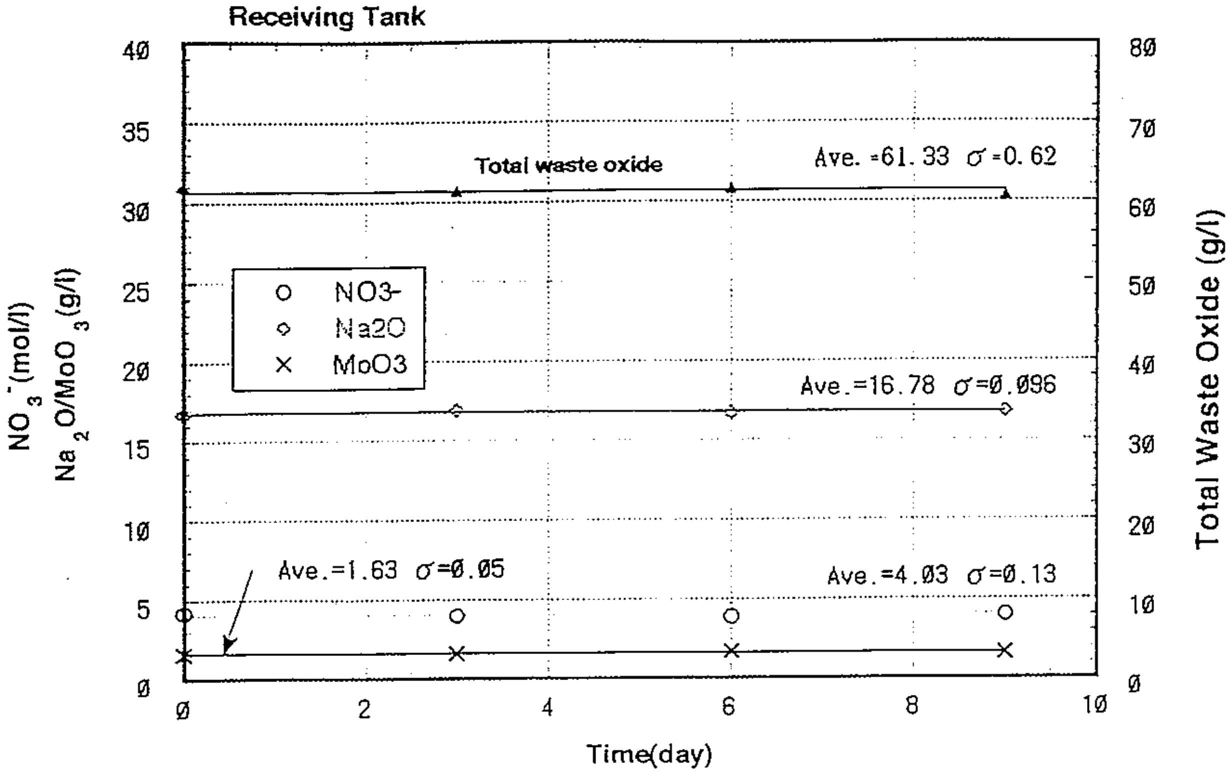
TEST FOR GLASS PRODUCT QUALITY CONTROL

Estimation method of HLLW Concentration(W.O, Na_2O)

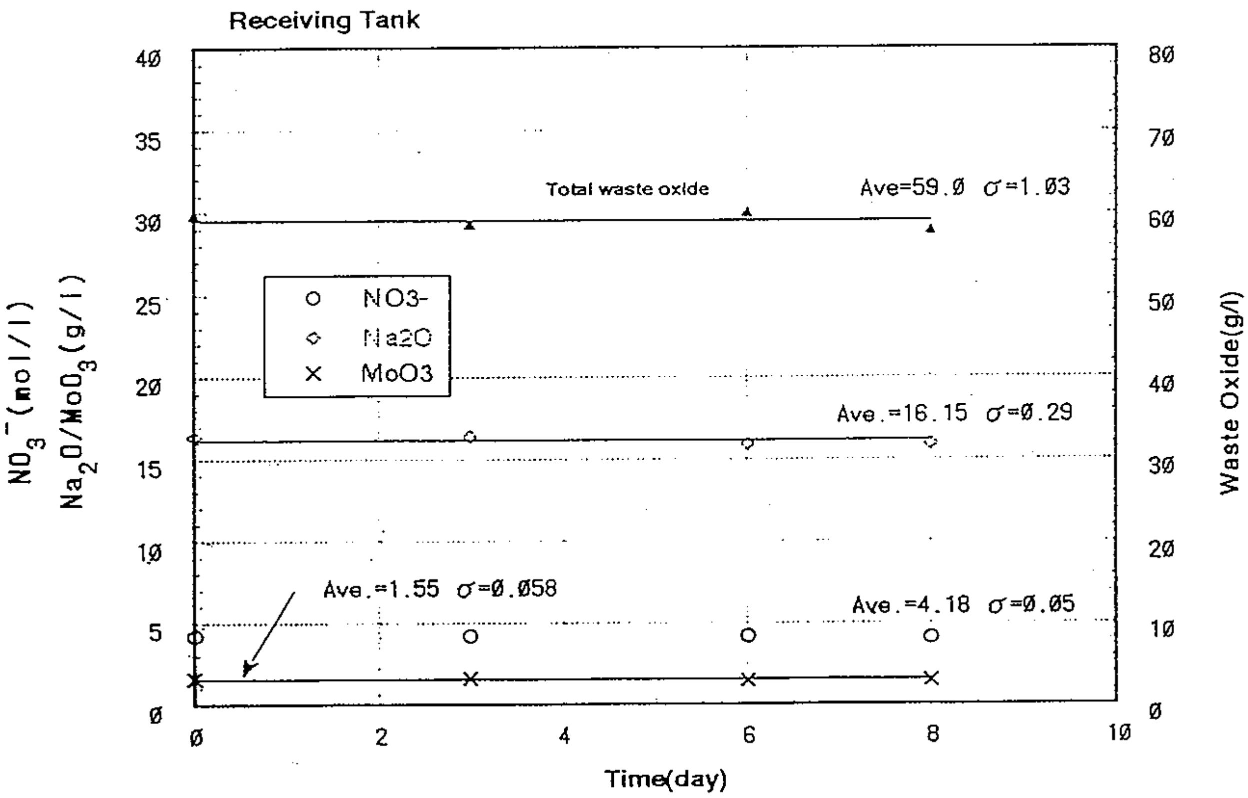


Equation

$$X = \frac{(A - a) \times C + B \cdot D}{b}$$



CHANGE OF CONCENTRATION IN HLLW



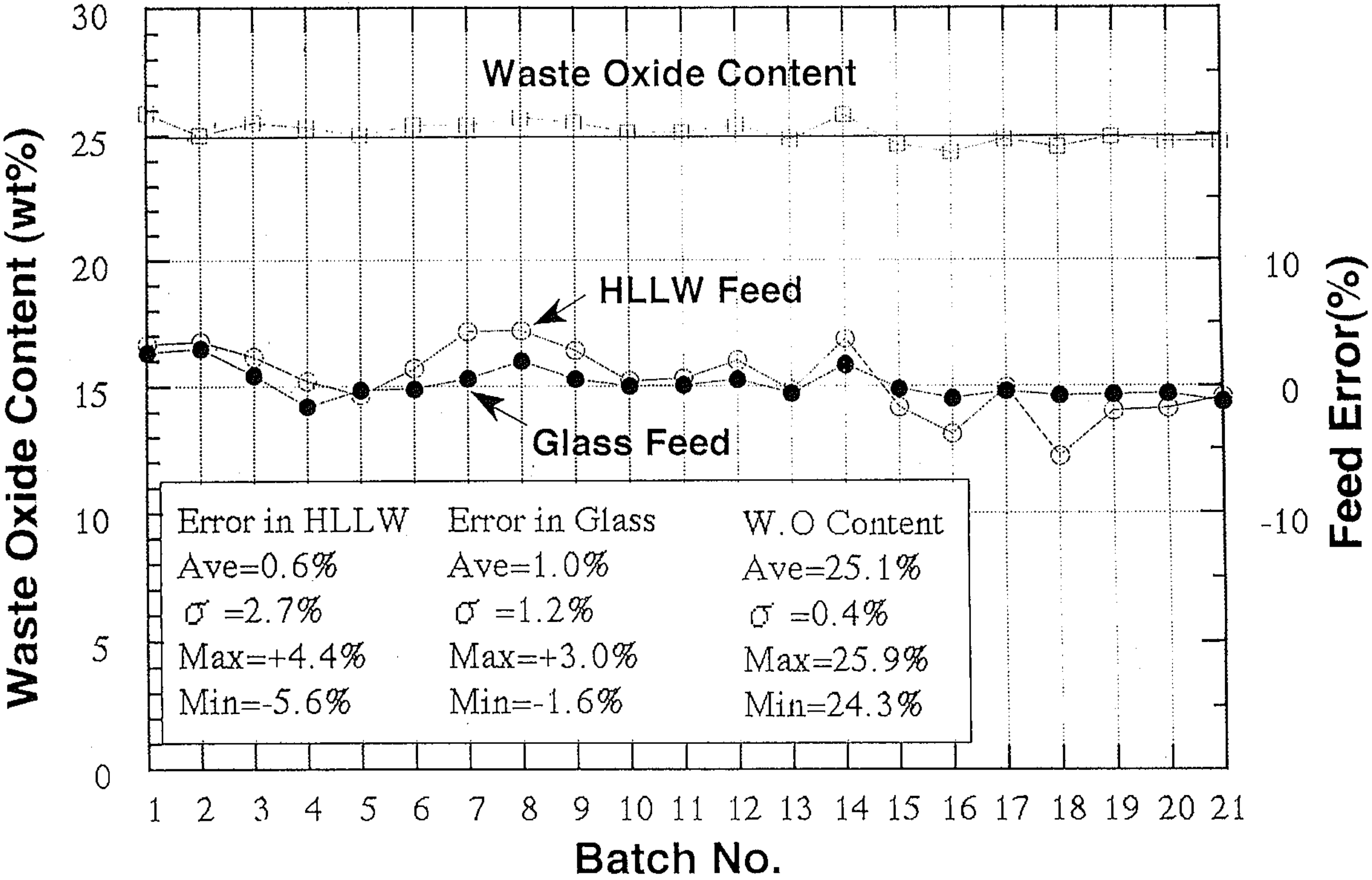
CHANGE OF CONCENTRATION IN HLLW AND RECOVERY

Evaluation of Estimation Accuracy for HLLW Concentration

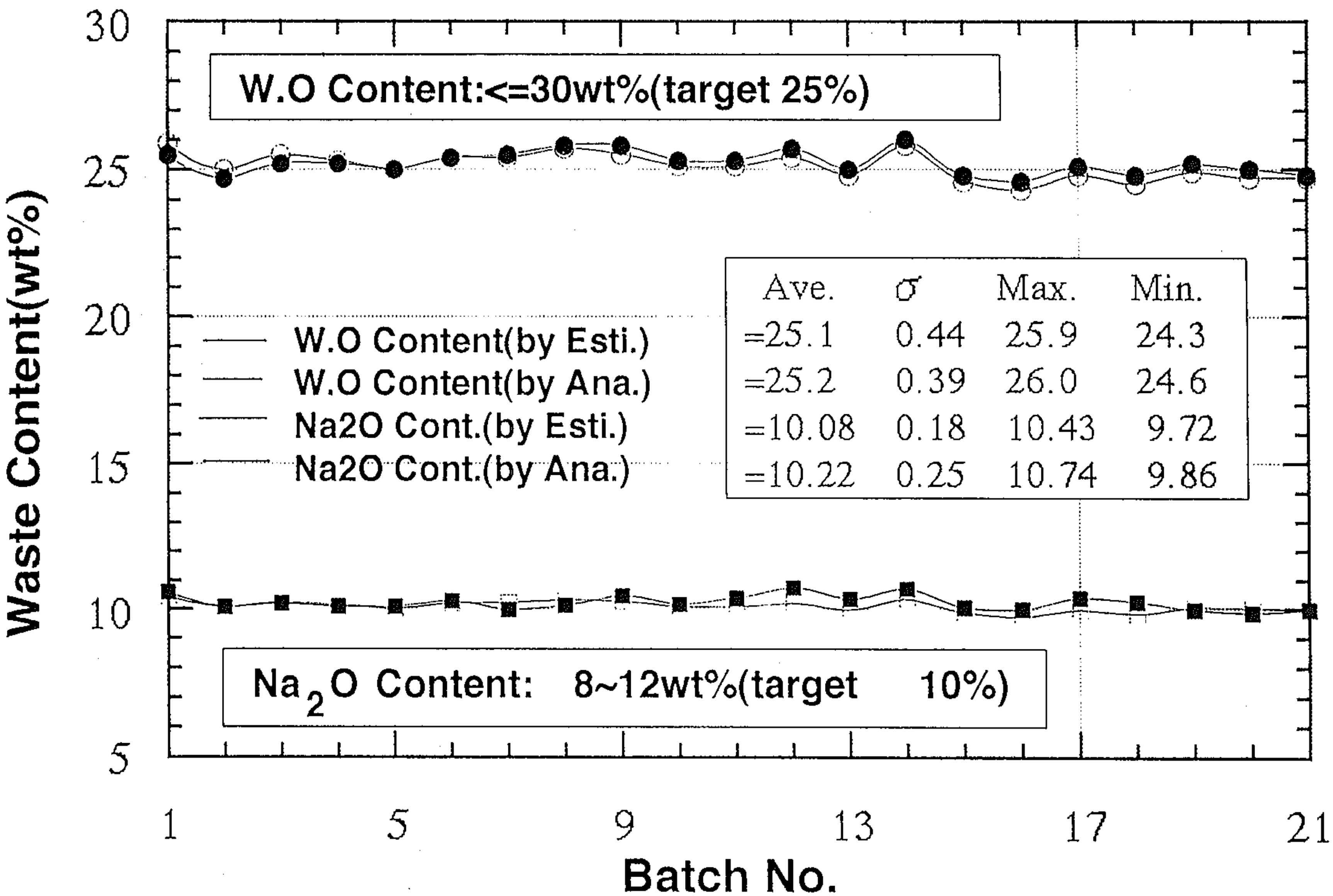
Control Item \ Transfer		Receiving Tank --> Evaporator		Evaporator --> Feed Tnk-1	
		Content (wt%)	Error (%)	Content (wt%)	Error (%)
Total Waste Oxide	Ave.	24.9	-0.41	25.0	0.04
	σ	0.65	2.61	0.36	1.45
Sodium Oxide	Ave.	9.98	-0.15	10.18	1.81
	σ	0.44	4.44	0.32	3.25

Assump.: Feed amount to get the target content by estimated concentration
Evalua. : Content by analyzed concentration and feed amount

$$\text{Error}(\%) = \frac{(\text{Content by Analysis}) - (\text{Content by Estimation})}{(\text{Content by Analysis})}$$



Operation Result in Quantitative Feed



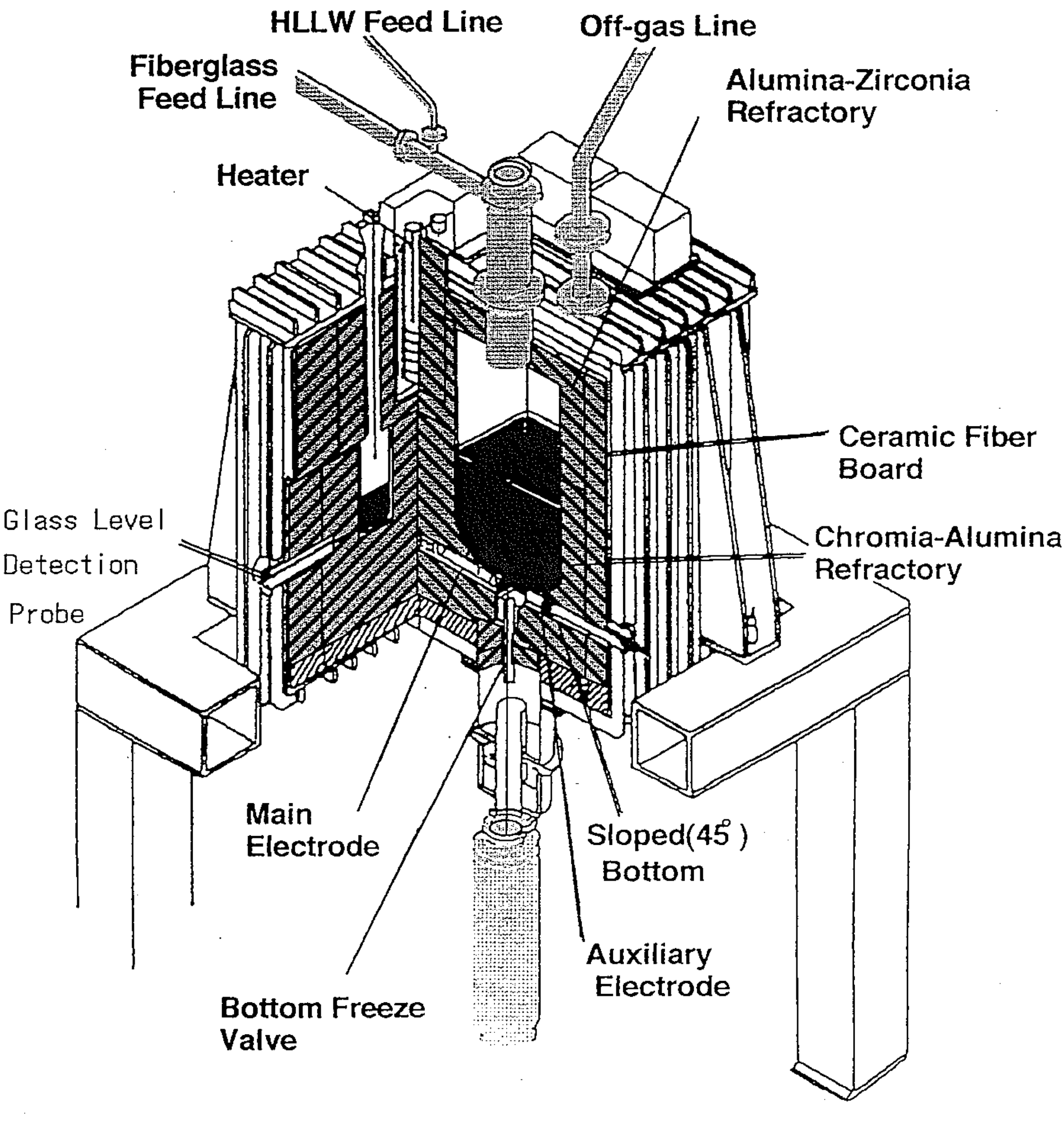
RESULT OF GLASS PRODUCT CONTROL

TEST RESULT FOR GLASS PRODUCT QUALITY CONTROL

Evaluation Method \ Control Item	Total waste oxide (wt%) (target:25wt%)			Sodium oxide (wt%) (target:10wt%)		
	Max.	Min.	Ave.	Max.	Min.	Ave.
Eval. by Analysis data	26.0	24.6	25.2	10.7	9.9	10.2
Eval. by Estimated data	25.9	24.3	25.1	10.4	9.7	10.1
Eval. by Analysis of Glass	26.3	24.2	25.2	11.0	10.0	10.7

Statistical Evaluation of Control Limit with 95% Confidence

Total Waste Oxide: Target ± 1.2 wt%
Sodium Oxide : Target ± 0.8 wt%



TVF MELTER STRUCTURE

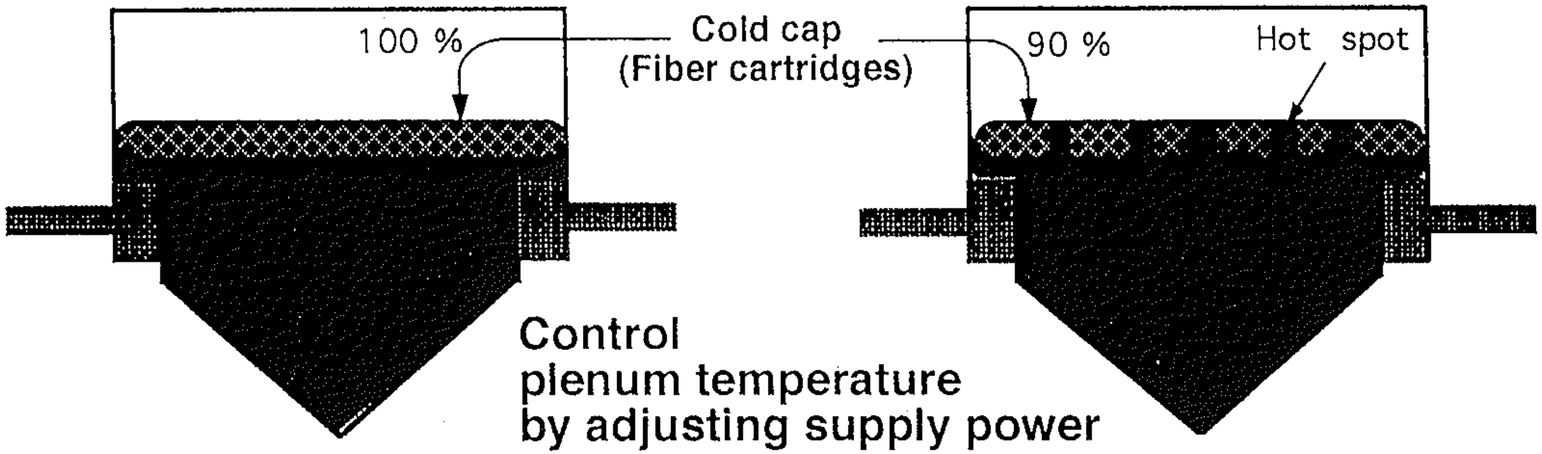
PROCESS CONTROL FOR THE MELTER OPERATION

(1) Low Plenum Temp. Operation

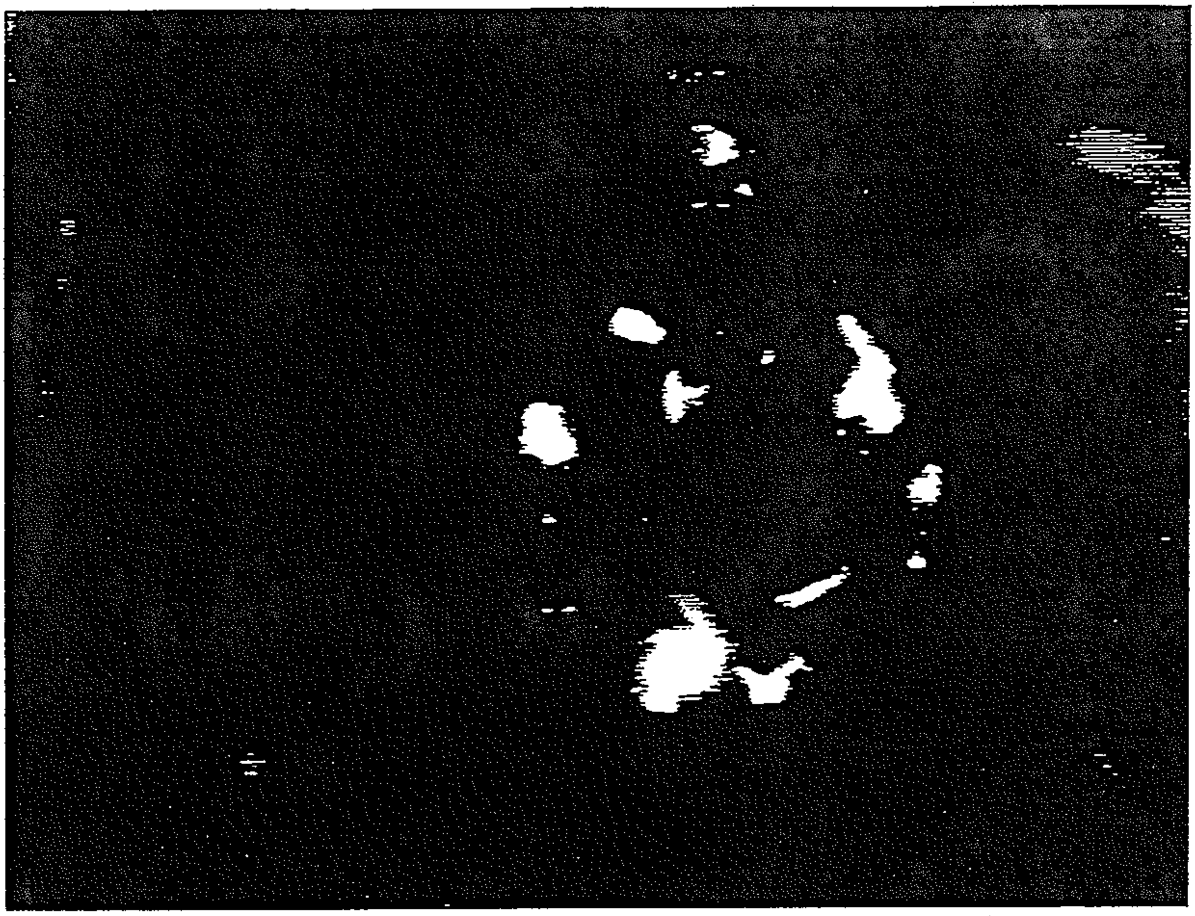
- about 300°C in Plenum space
- No Glass surface (almost 100 % Cold cap coverage)
- No pressure surge (due to Fiber cartridge)

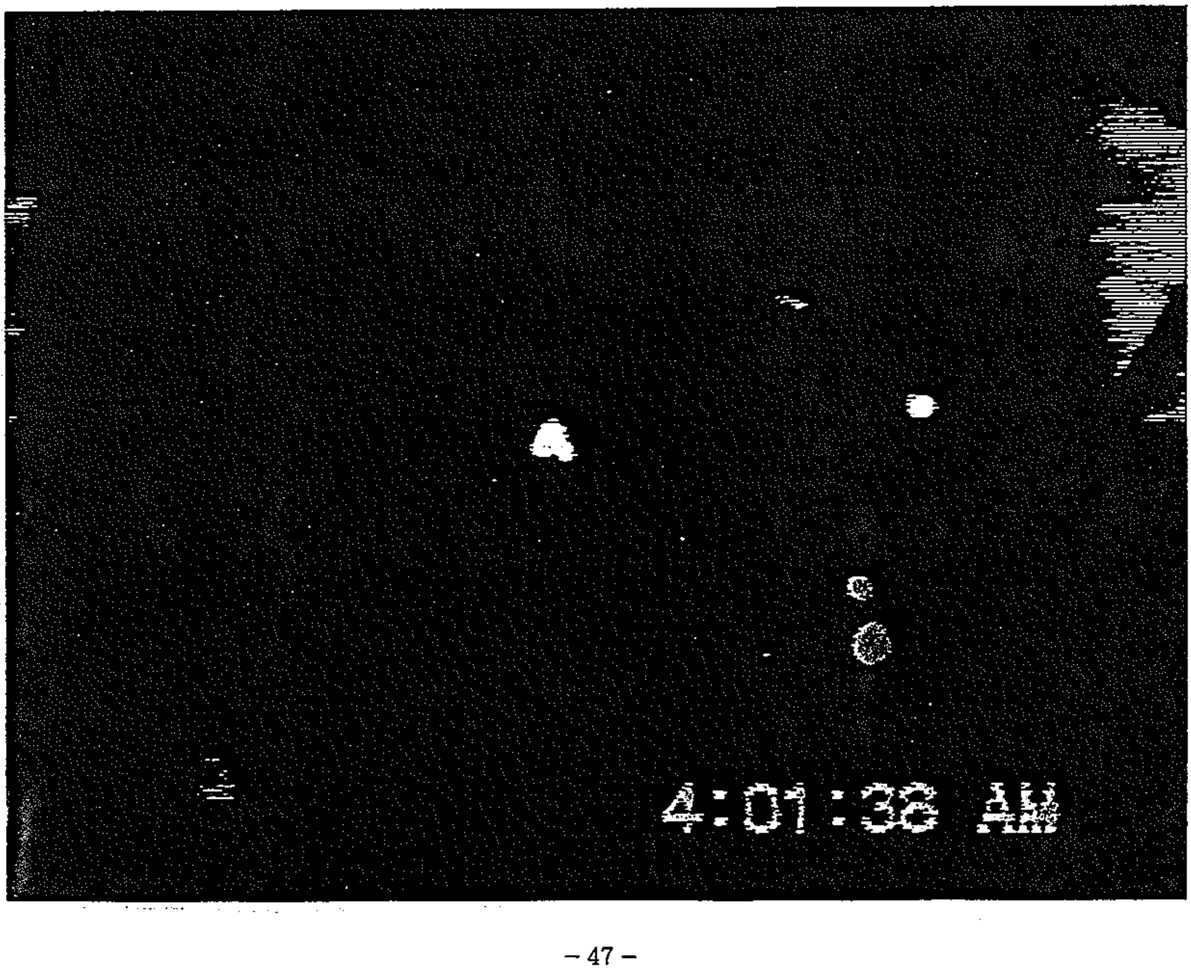
(2) High Plenum Temp. Operation

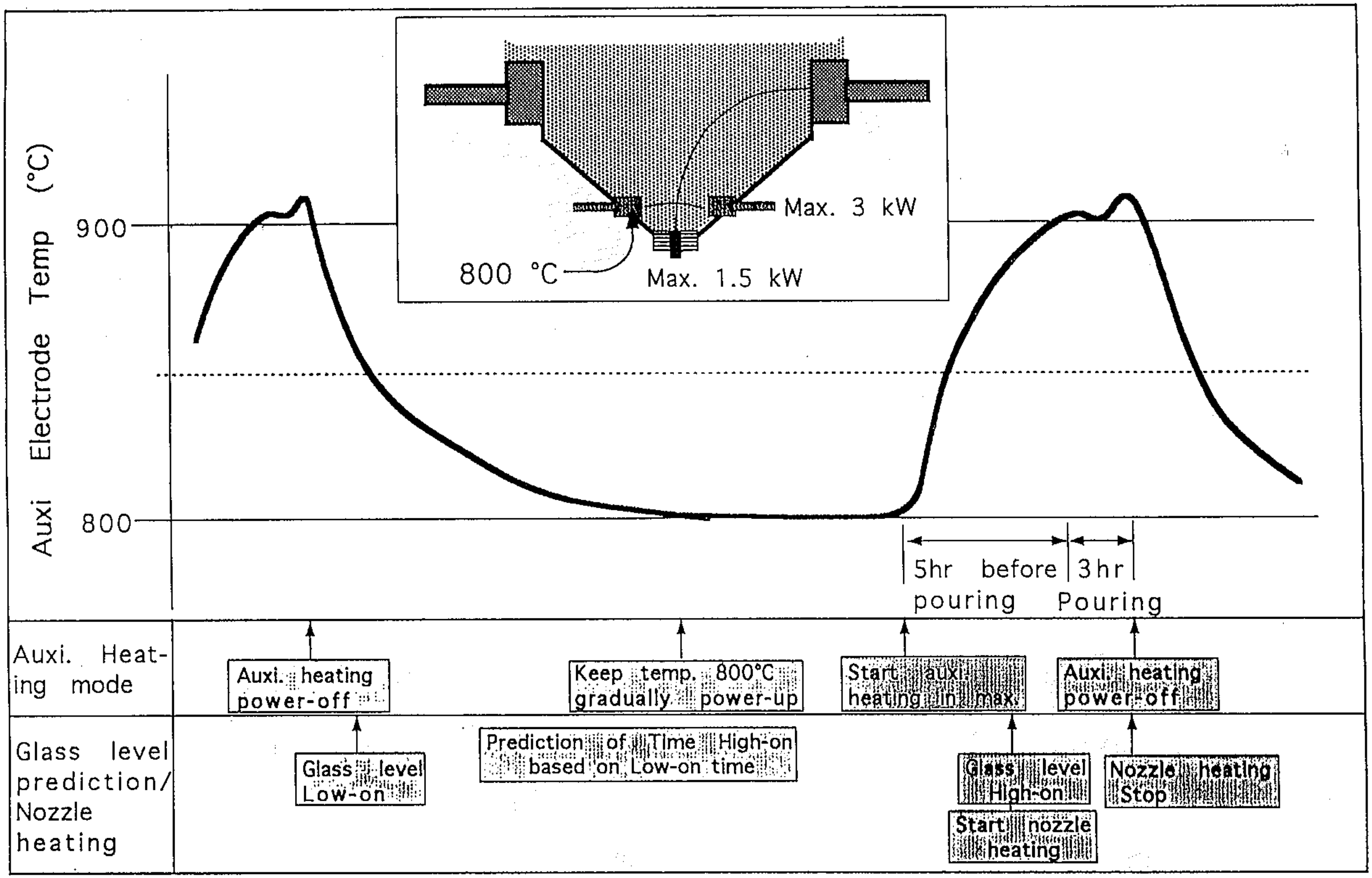
- 400-500°C in Plenum space (Exposure of glass surface)
- Expect high Melt rate
- Increment of Particle release
- Difficult to control bottom temp.



Control
plenum temperature
by adjusting supply power

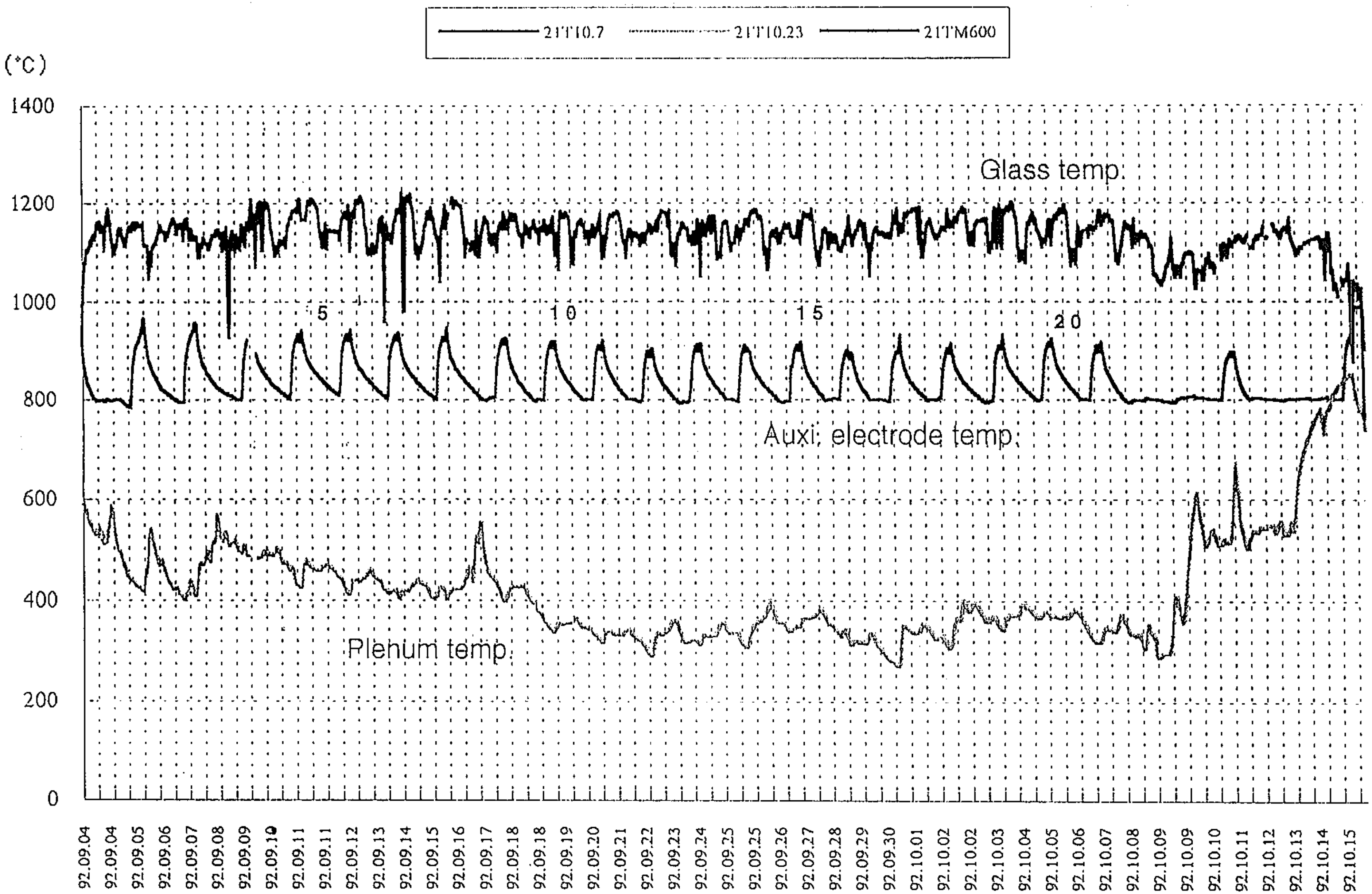



4:01:38 AM

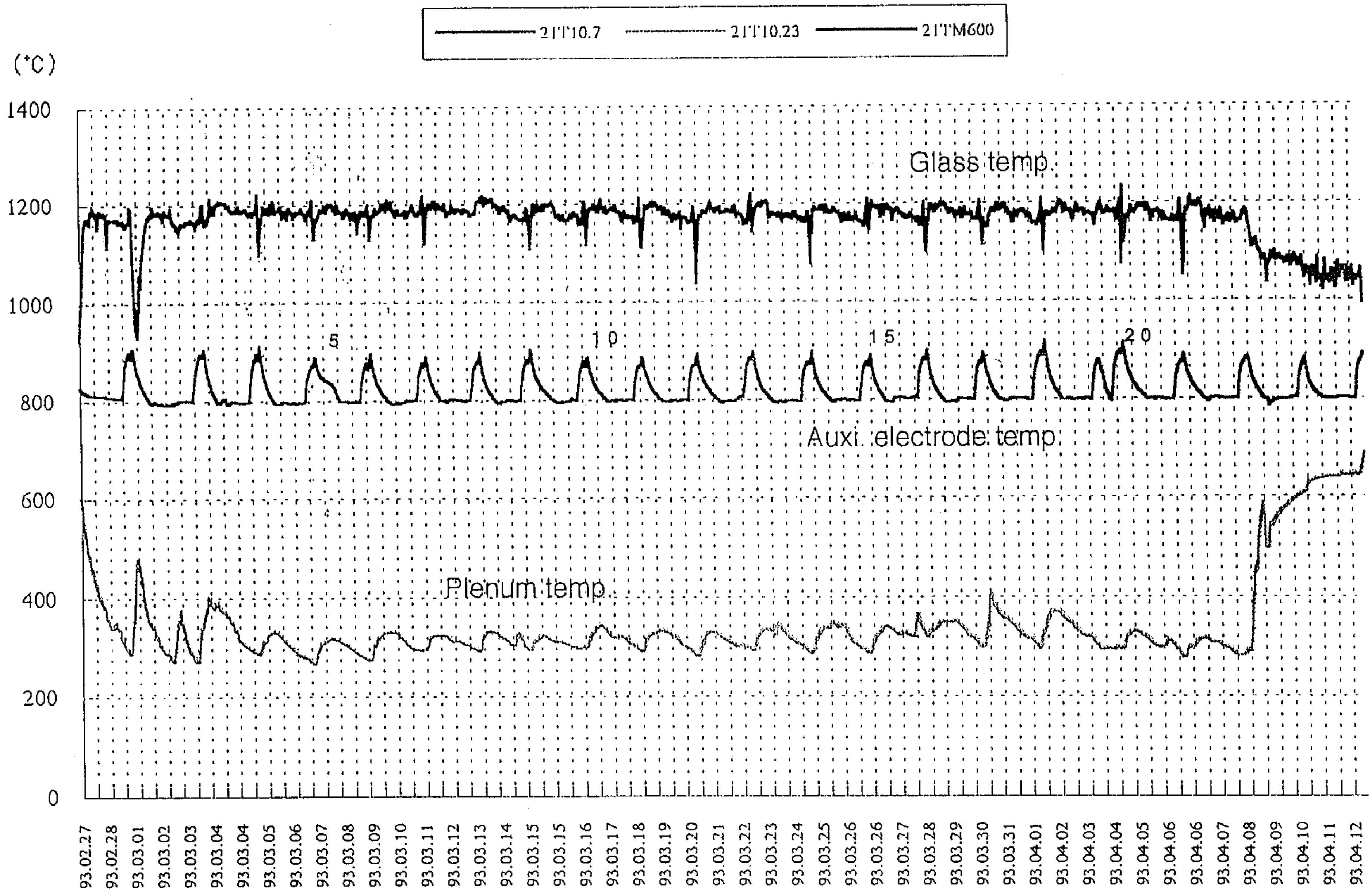


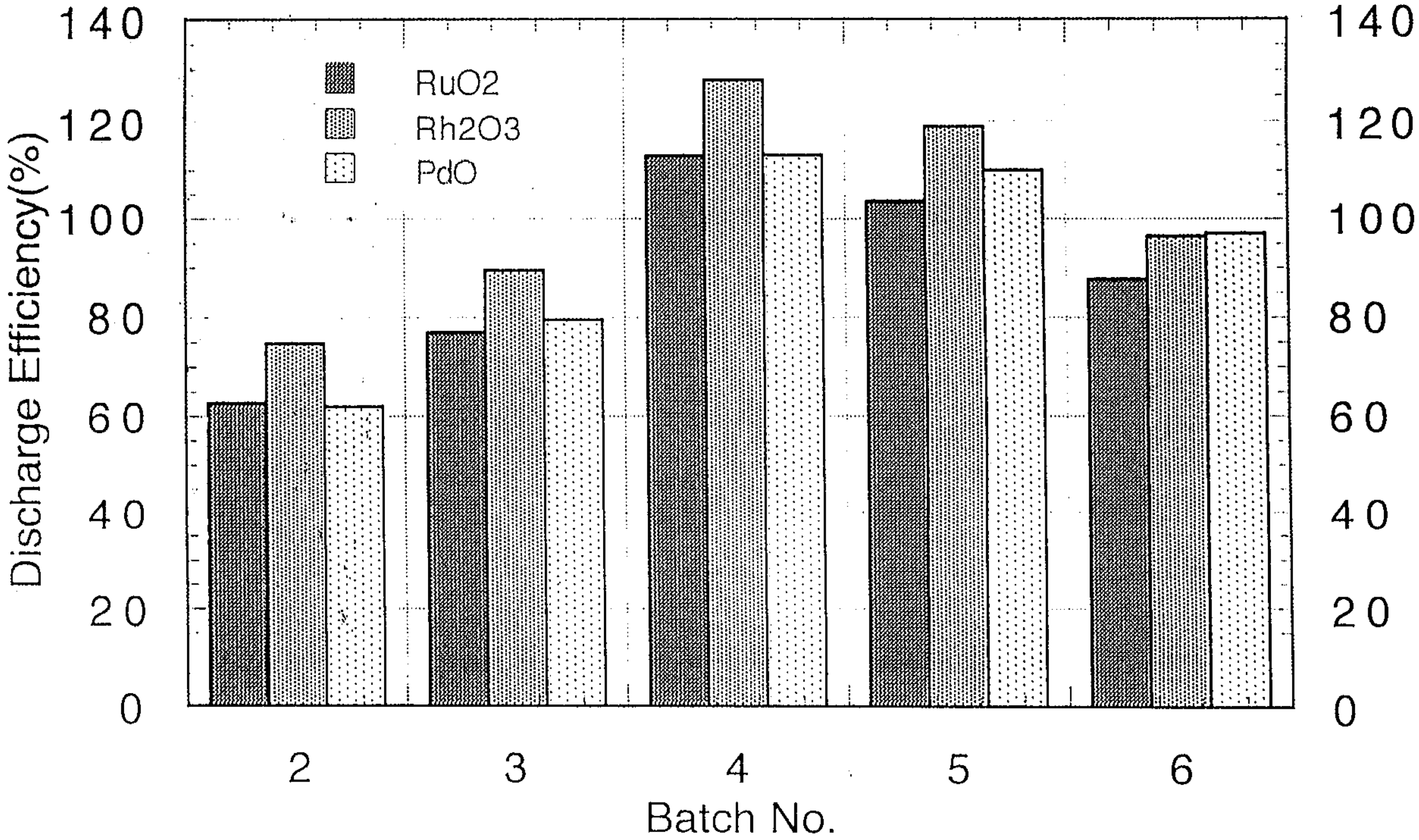
MELTER OPERATION BY BOTTOM TEMP. CONTROL MODE

MELTER OPERATION RESULT(1ST RUN)

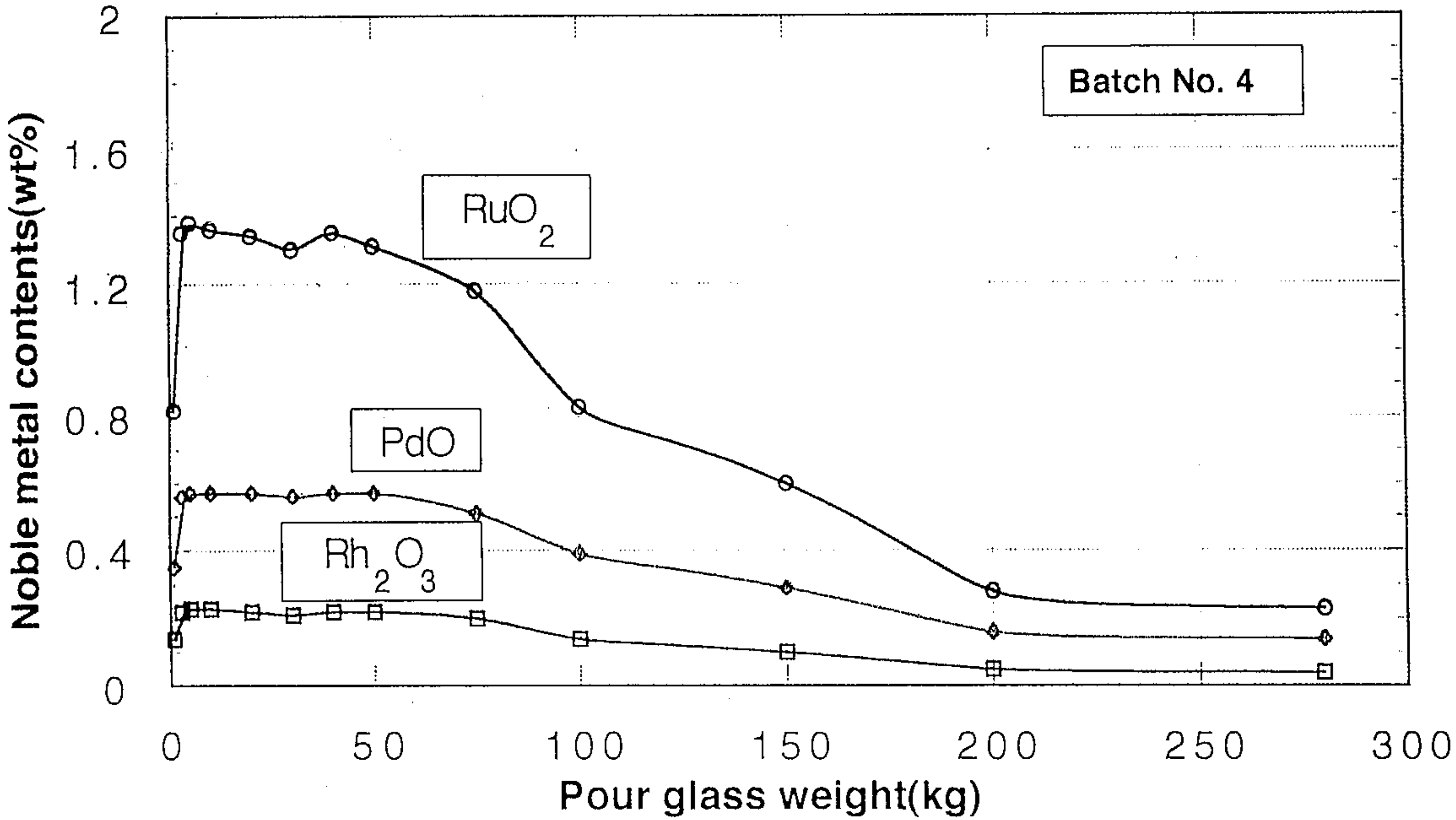


MELTER OPERATION RESULT (2ND RUN)



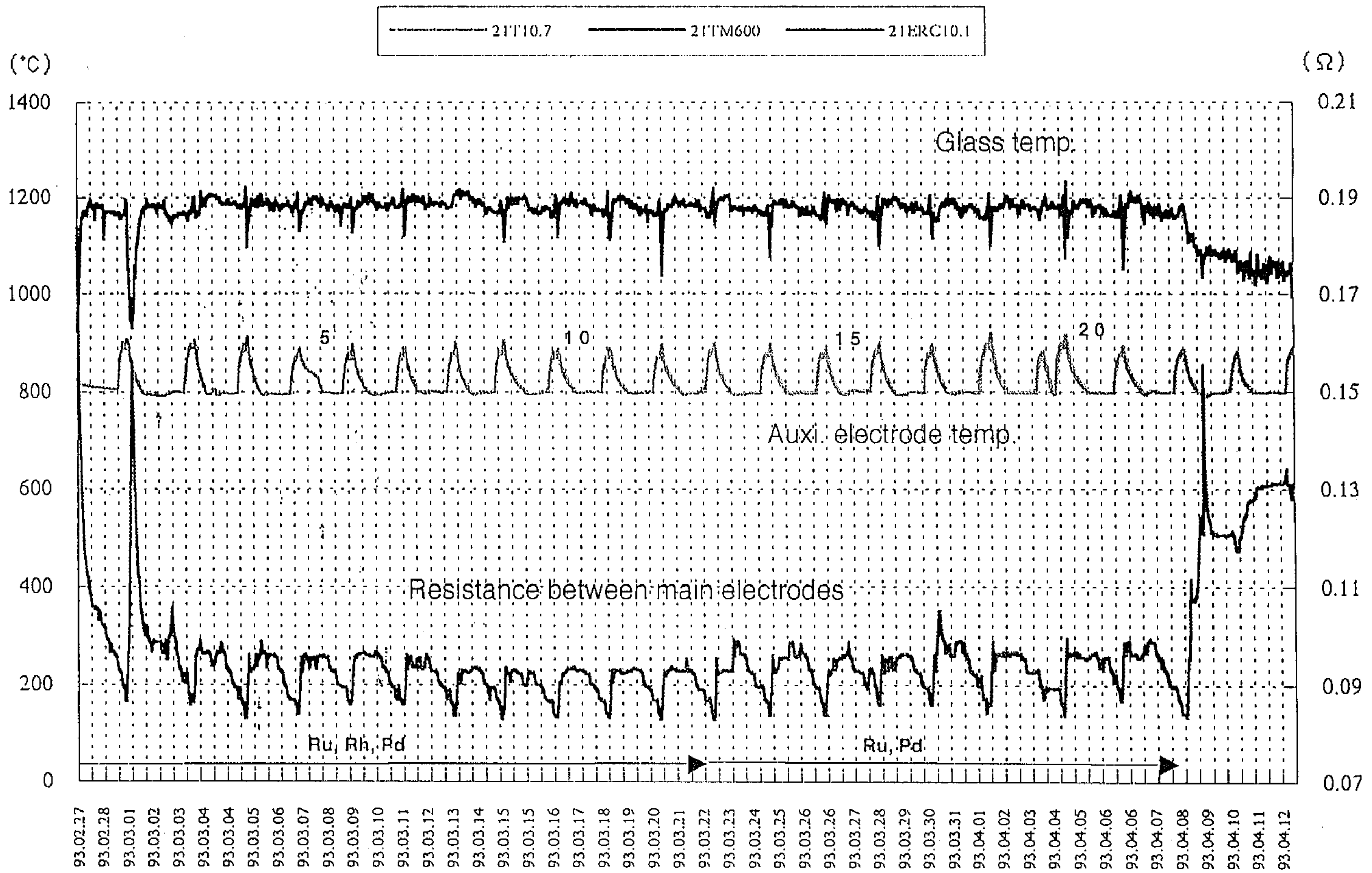


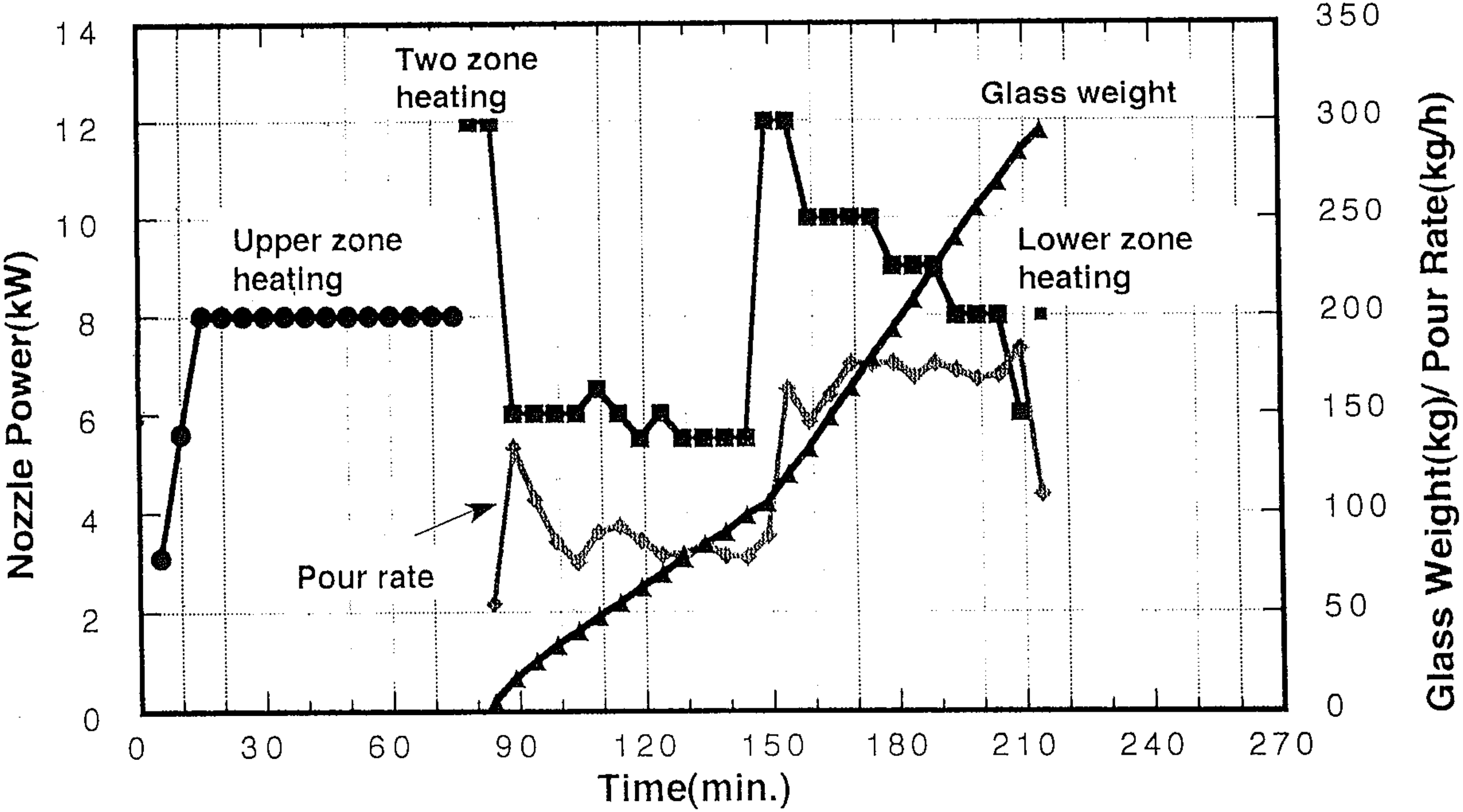
DISCHARGE OF NOBLE METALS IN MELTER OPERATION



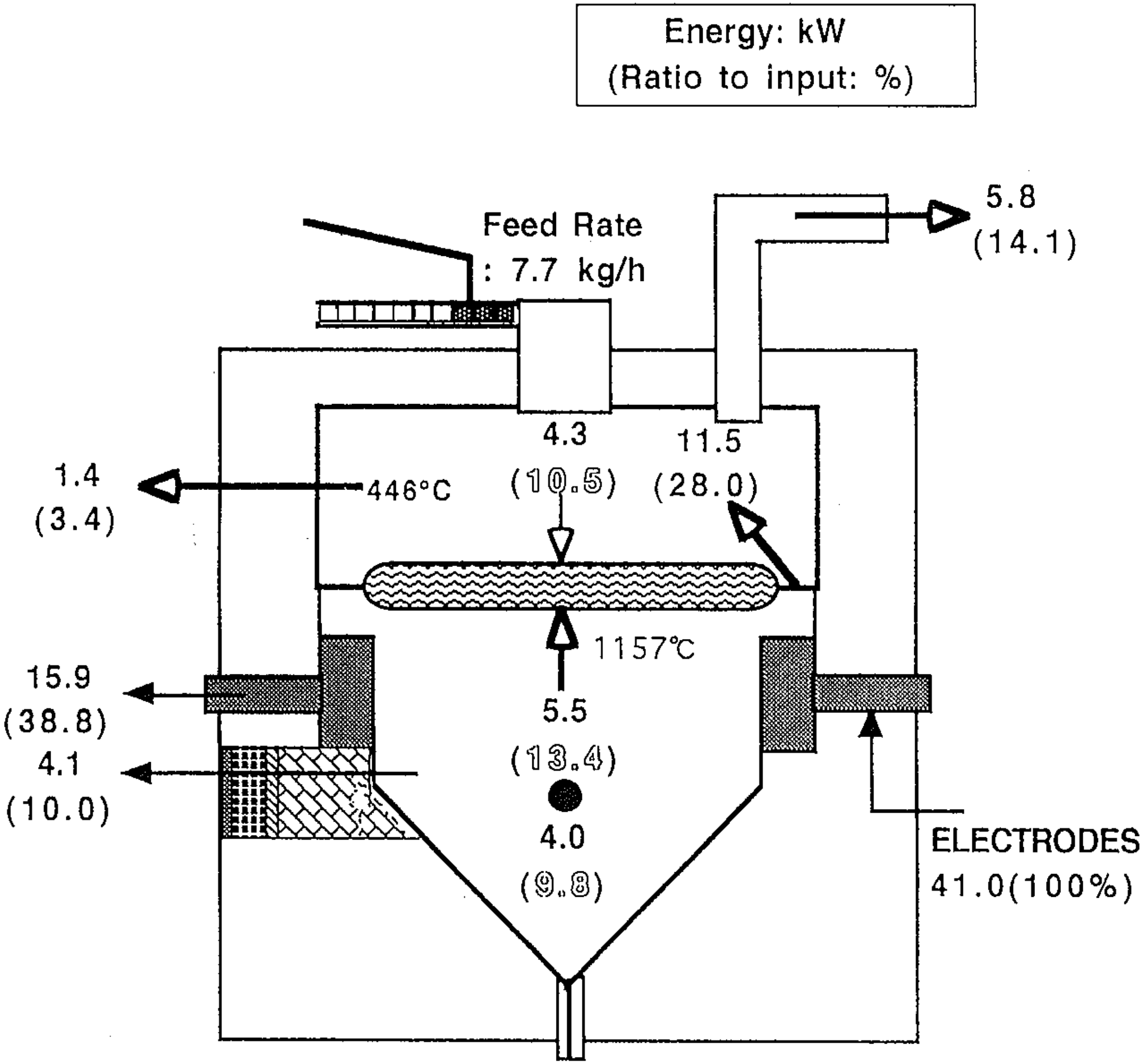
Change of noble metal contents during pouring

CHANGE OF RESISTANCE (2ND MELTER RUN)



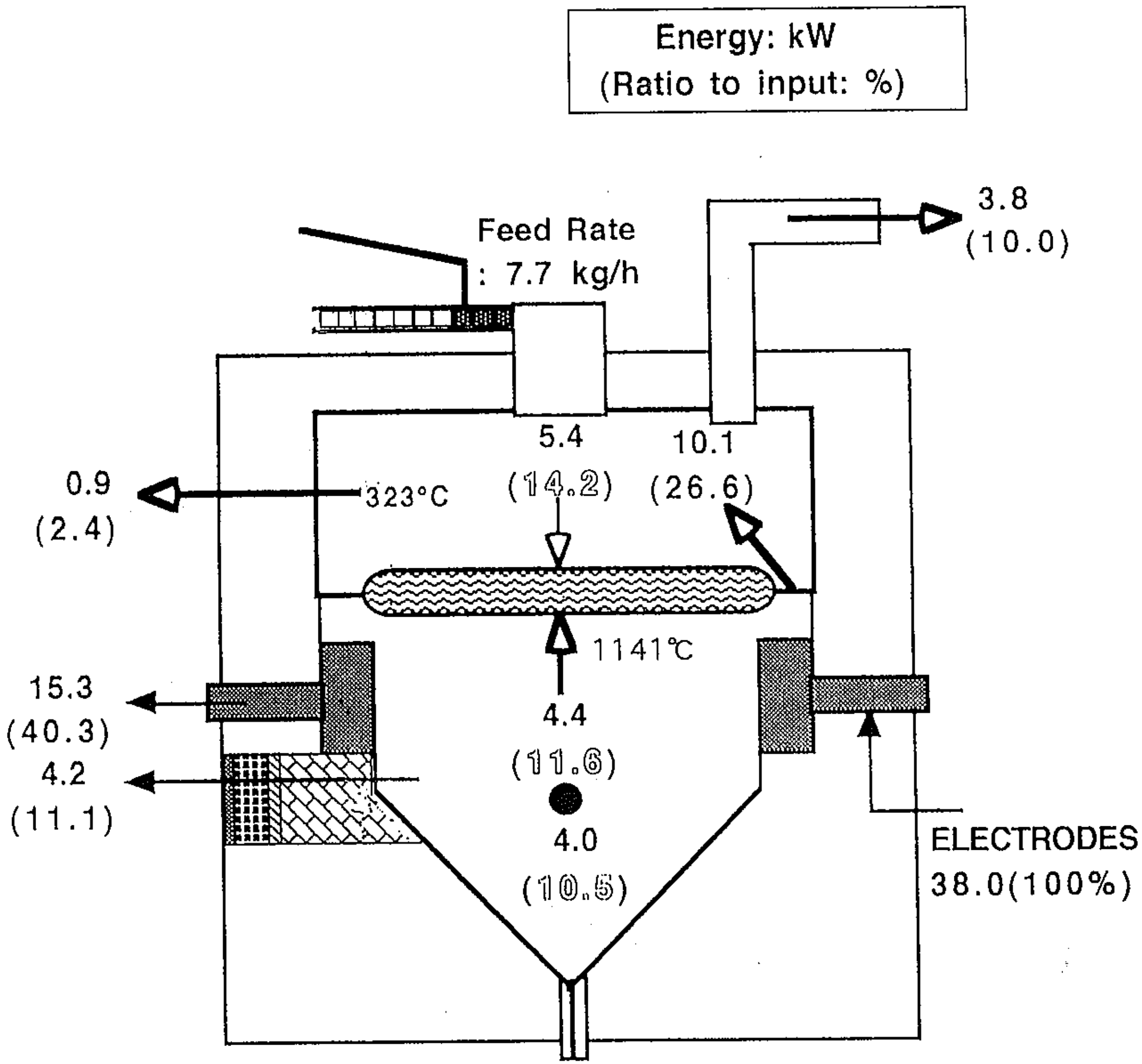


GLASS POURING RESULT IN 2ND MELTER RUN



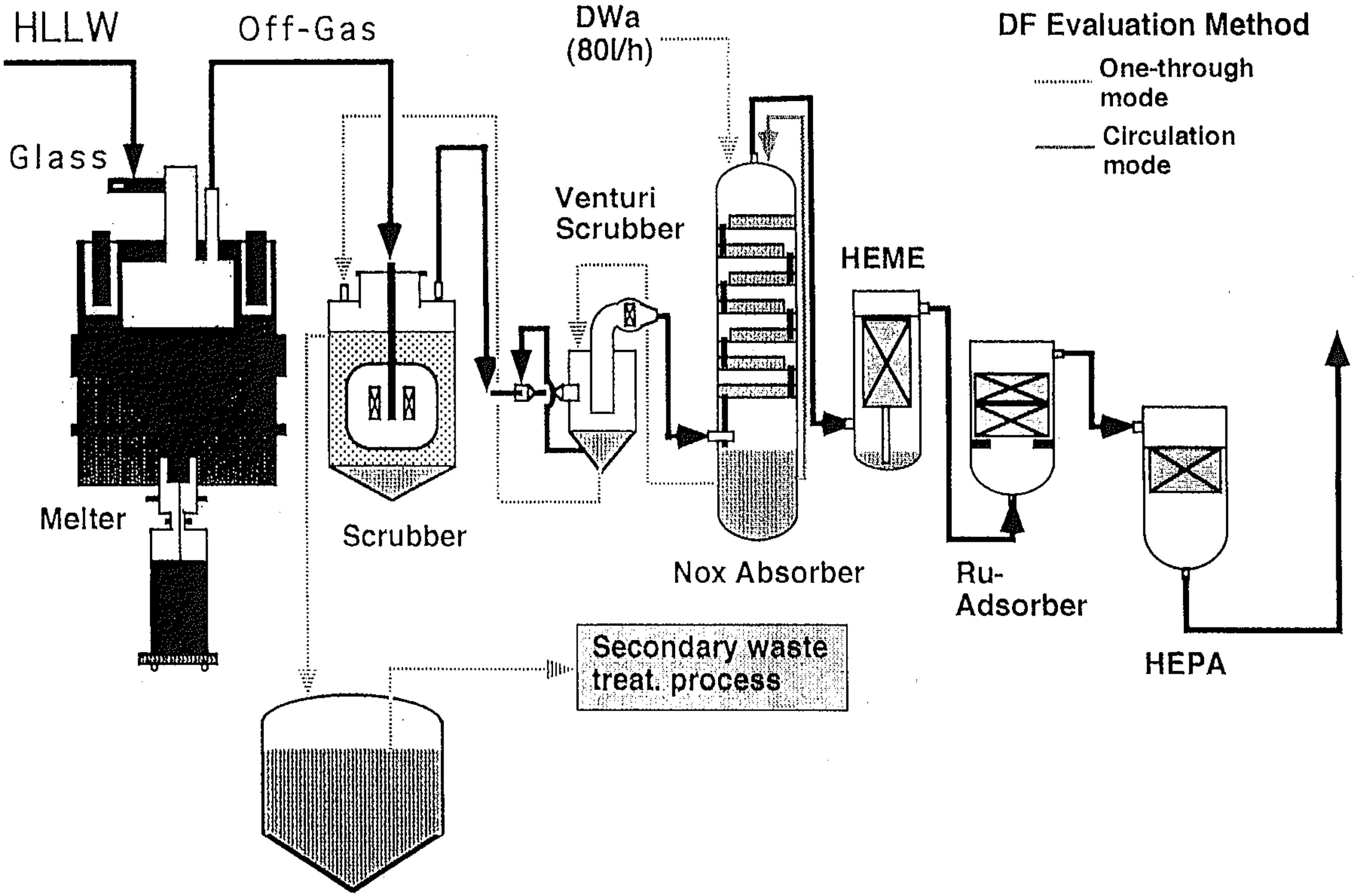
SUPPLY (kW)[Result]	
ELECTRODES	41.0
DEMAND (kW)[Estim.]	
COLD CAP	9.8
by N. Convection	5.5
by Radiation	4.3
GLASS MELTING	4.0
MASS FLOW	5.8
Steam	2.7
Gas	3.1
CONDUCTIVE HEAT LOSS	5.5
Plenum space	1.4
Melt pool	4.1
HEAT LOSS BY ELECTRODES COOLING	15.9
TOTAL	41.0

THE ENERGY BALANCE OF THE TVF MELTER(PC-92-1)
DURING THE FEEDING OF BATCH NO. 6

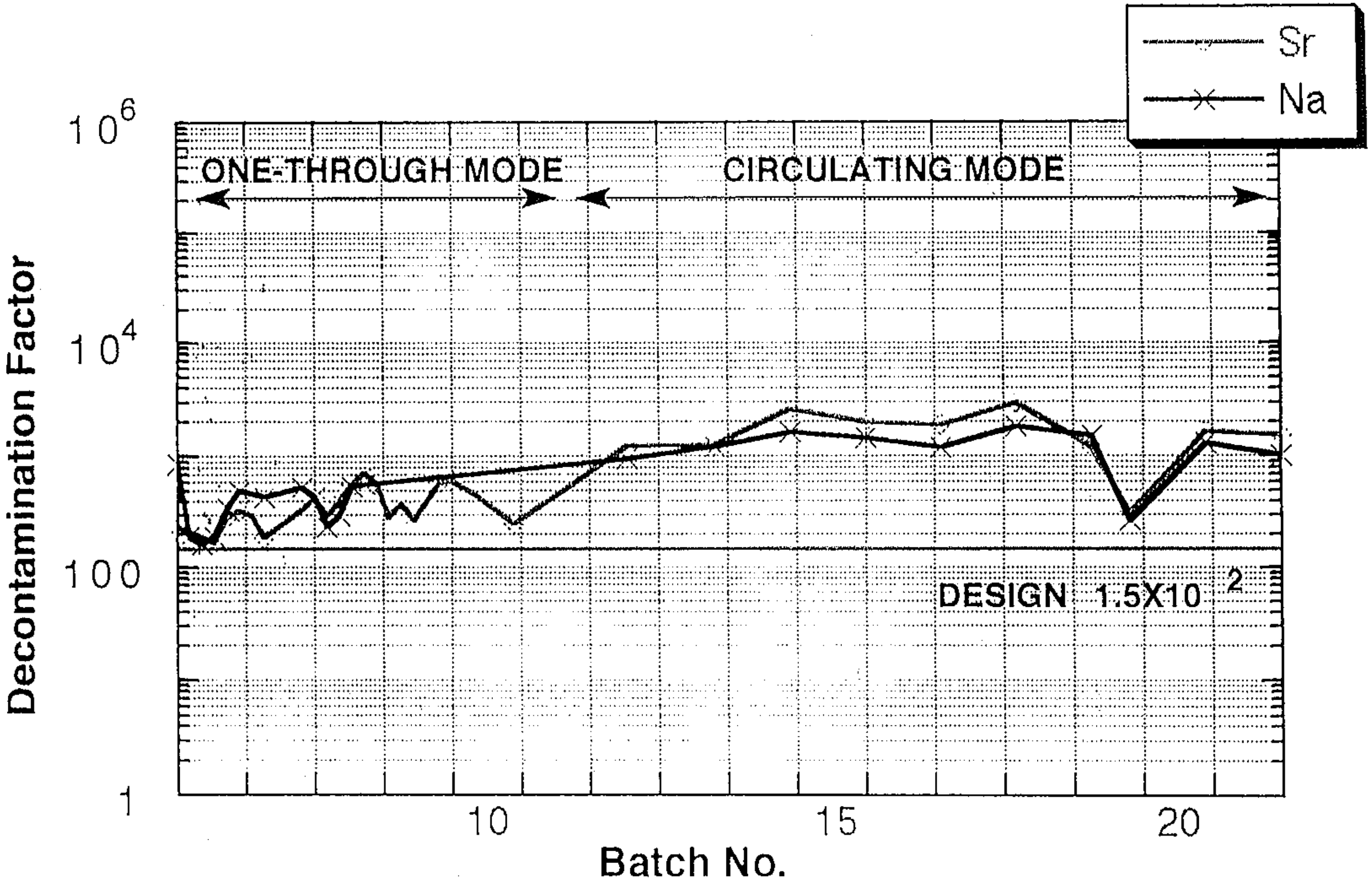


SUPPLY (kW)[Result]		
ELECTRODES		38.0
DEMAND (kW)[Estim.]		
COLD CAP		9.8
by N. Convection	4.4	
by Radiation	5.4	
GLASS MELTING		4.0
MASS FLOW		3.8
Steam	1.7	
Gas	2.1	
CONDUCTIVE HEAT LOSS		5.1
Plenum space	0.9	
Melt pool	4.2	
HEAT LOSS BY ELECTRODES COOLING		15.3
TOTAL		38.0

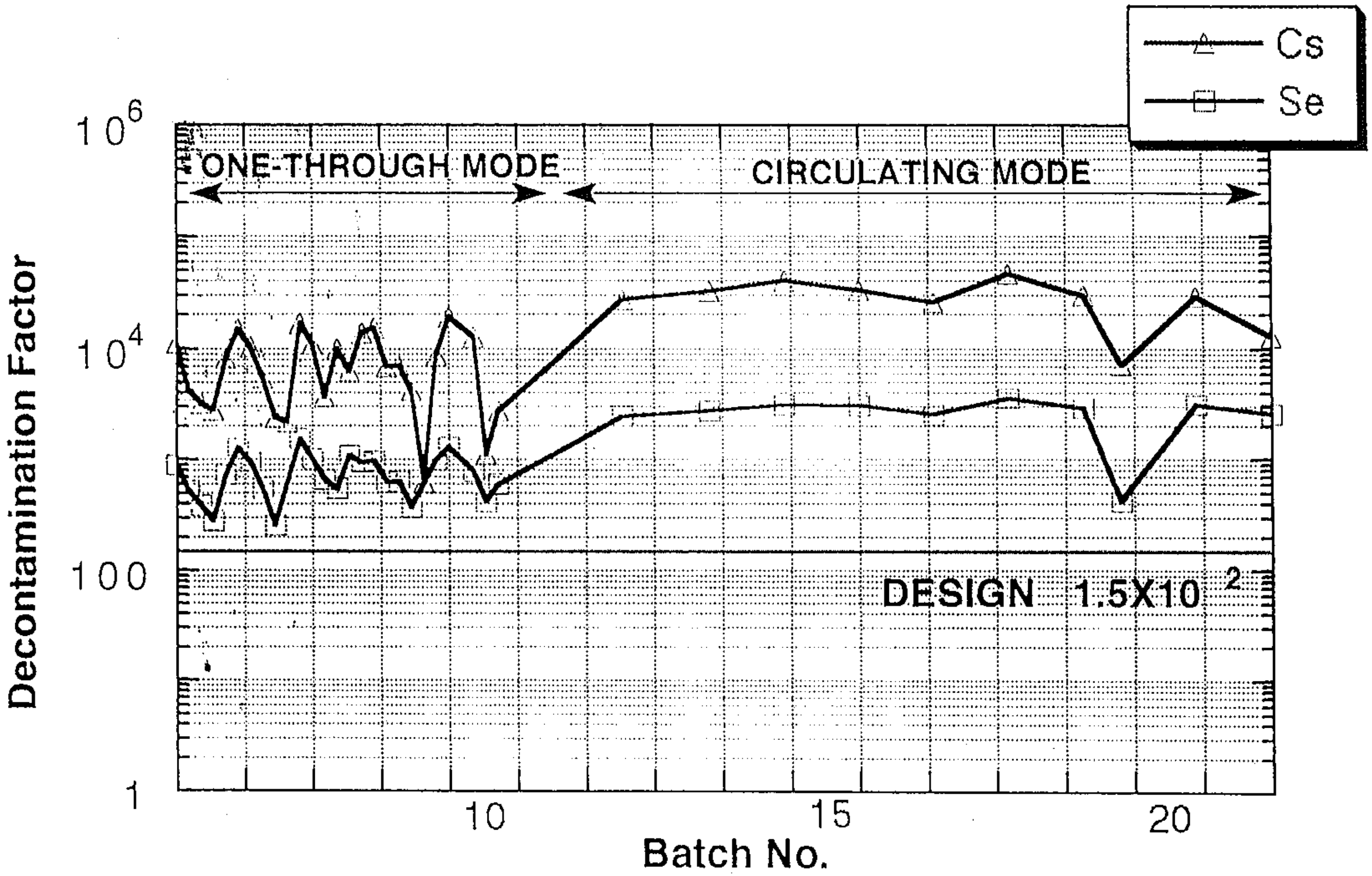
THE ENERGY BALANCE OF THE TVF MELTER(PC-92-1)
DURING THE FEEDING OF BATCH NO. 12



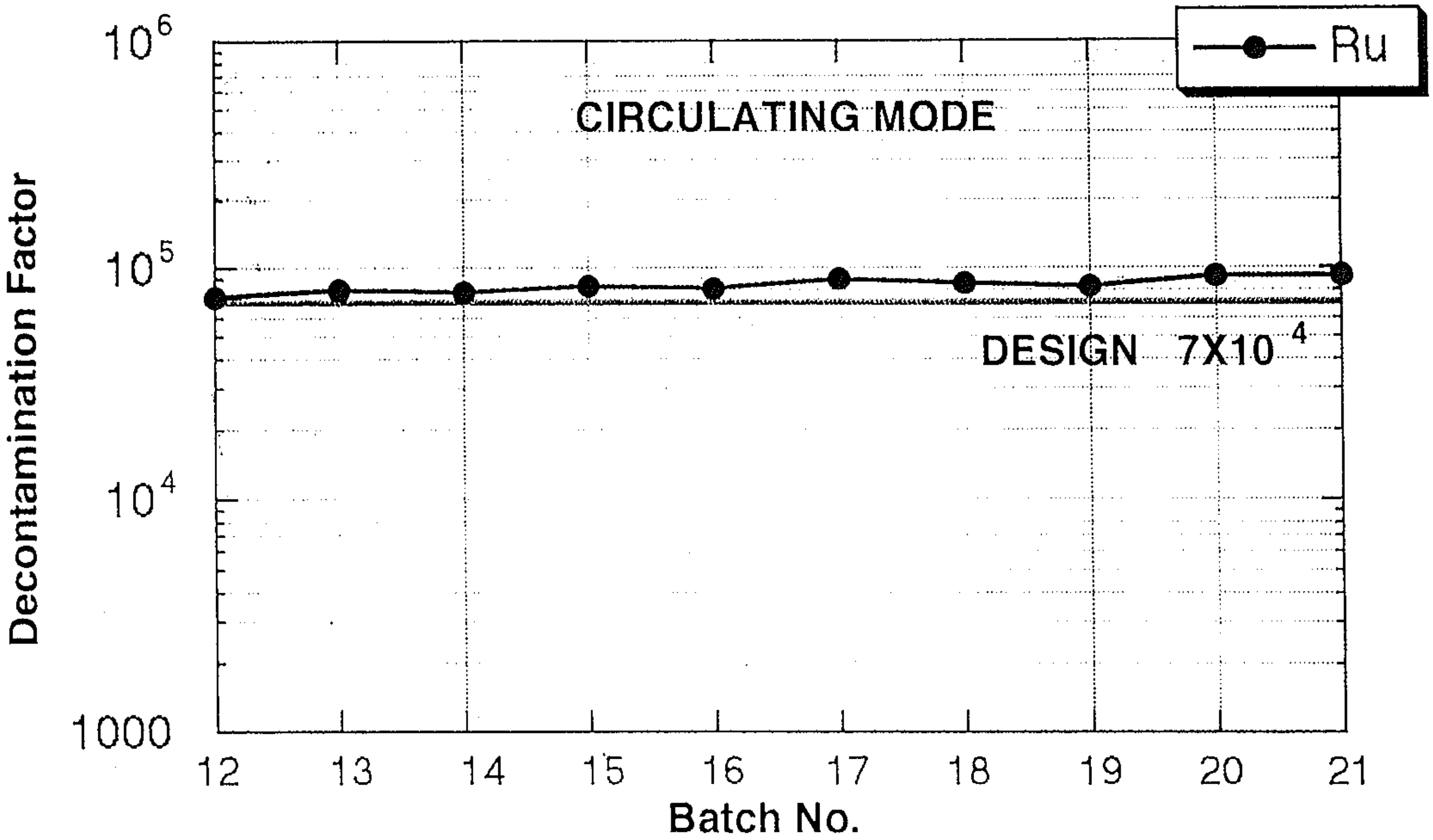
MELTER OFF-GAS TREATMENT PROCESS



DF EVALUATION FOR NON-VOLATILE ELEMENTS



DF EVALUATION FOR SEMI-VOLATILE ELEMENTS



DF EVALUATION FOR VOLATILE ELEMENT

TEST ITEMS AND RESULTS IN COLD TEST RUN

TEST ITEM	Product Quality Control	Safety of Process	Melter Operation Mode	Function of Process Equipment
PROCESS	• Pretreatment of HAW • Glass Feed • Glass Melting • Canister Handling	• All Equipment • Off-Gas Treatment	• Glass Melter • Glass Pouring	• All Equipment especially Glass Melter Evaporator
CONFIRMATION ITEM	• Quantitative feed of HAW and glass • Estimation method of HAW concentration • Accuracy of Quality control (glass composition) • Other operating condition	• Decontamination factor in Melter off-gas treat. process • Safety function and control method of equipment	• Melter operation (control) method correspond to noble metal • Glass pouring mode (bottom heating mode) • Glass pouring control	• Function of equipment in change of operating condition • Synthetic function of facility
TEST RESULT	• Quantiative feed has adequate accuracy to satisfy product quality • HAW concentration can be estimated with adequate accuracy • Waste content in product can be controlled in limit with enough accuracy	• DF can satisfy design in both Melter off-gas treat. process and evaporator • Equipment has safety function as expected in design	• Possible to make stable melter operation • Possible to treat noble metal by using low bottom temperature mode • Possible to start stable pouring by heating mode and to control pouring	• Confirm effect of change in operating condition on melter, evaporator • Confirm stable operation of TVF process

2.3 Three dimensional thermal-hydraulic analyses by physical and mathematical modelings

Three dimensional thermal-hydraulic analyses by phsical and mathematical modelings

Prepared for
The 12th Annual KfK-PNC Meeting on
High-Level Waste Management

by AYAME, Y.

December 7-9,1993

Power Reactor and Nuclear Fuel
Development Corporation

PNC

Background of study

The Relation between Requirement for Design of the Melter and an Item of Thermal-Hydraulic Analysis in the Melter

Requirement for Design of Melter

- Containment of Molten Glass in the Melter Structure
- Corrosion Resistance of the Electrode and the Refractory Structure
- Melting rate of the Melter
- Quality of the Glass Product

Item of Thermal-Hydraulic Analyses

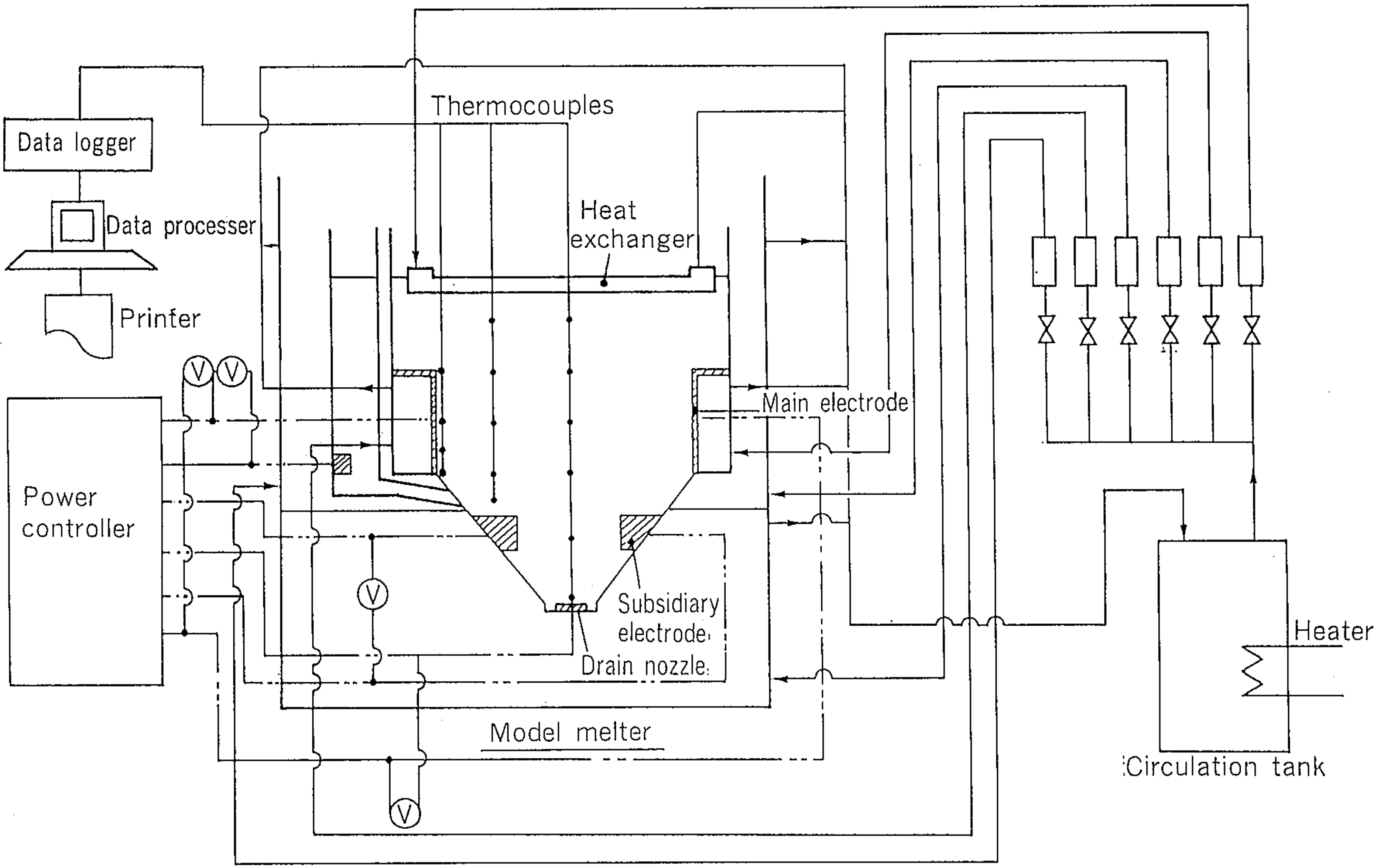
- Temperature Distribution in the Melting Cavity
- Temperature Gradient in the Electrode and the Refractory Structure
- Electrical Aspect in the Melting Cavity
- Flow Pattern in the Melting Cavity

Scope of study

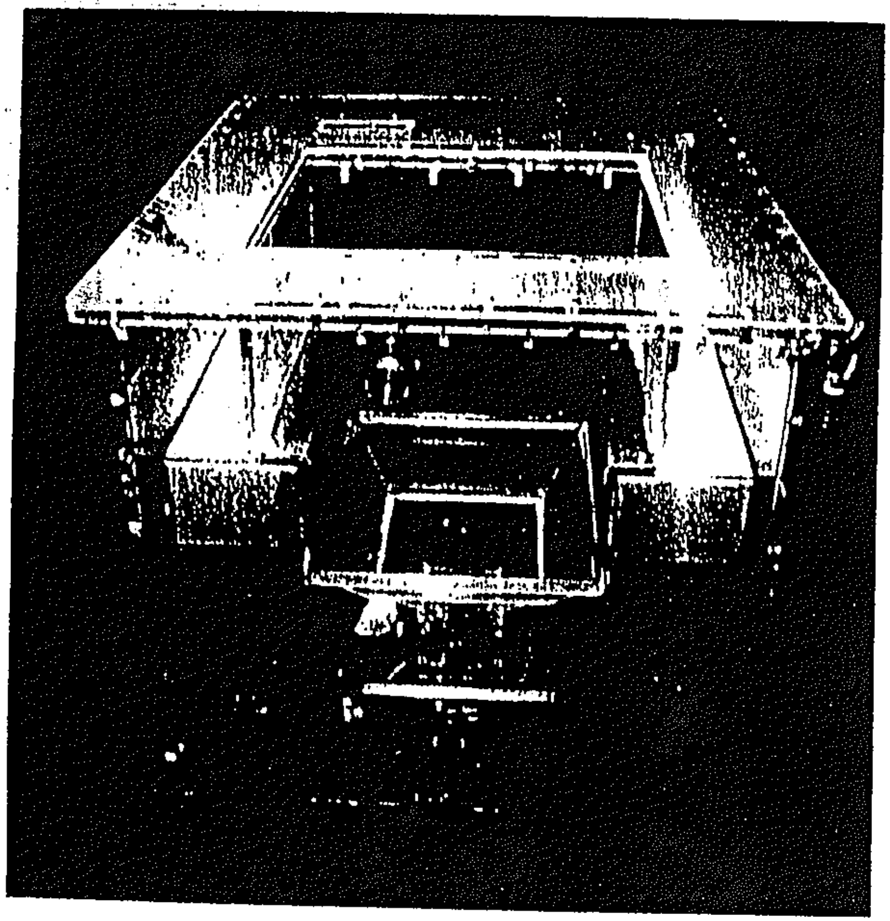
The Physical and mathematical modeling is useful means to obtain the detailed information on thermal-hydraulic behavior in the melter.

- Validation of temperature and flow pattern in the melter by means of physical and mathematical modeling

- Validation of mathematical modeling by physical modeling



Physical model system



Specification of physical model

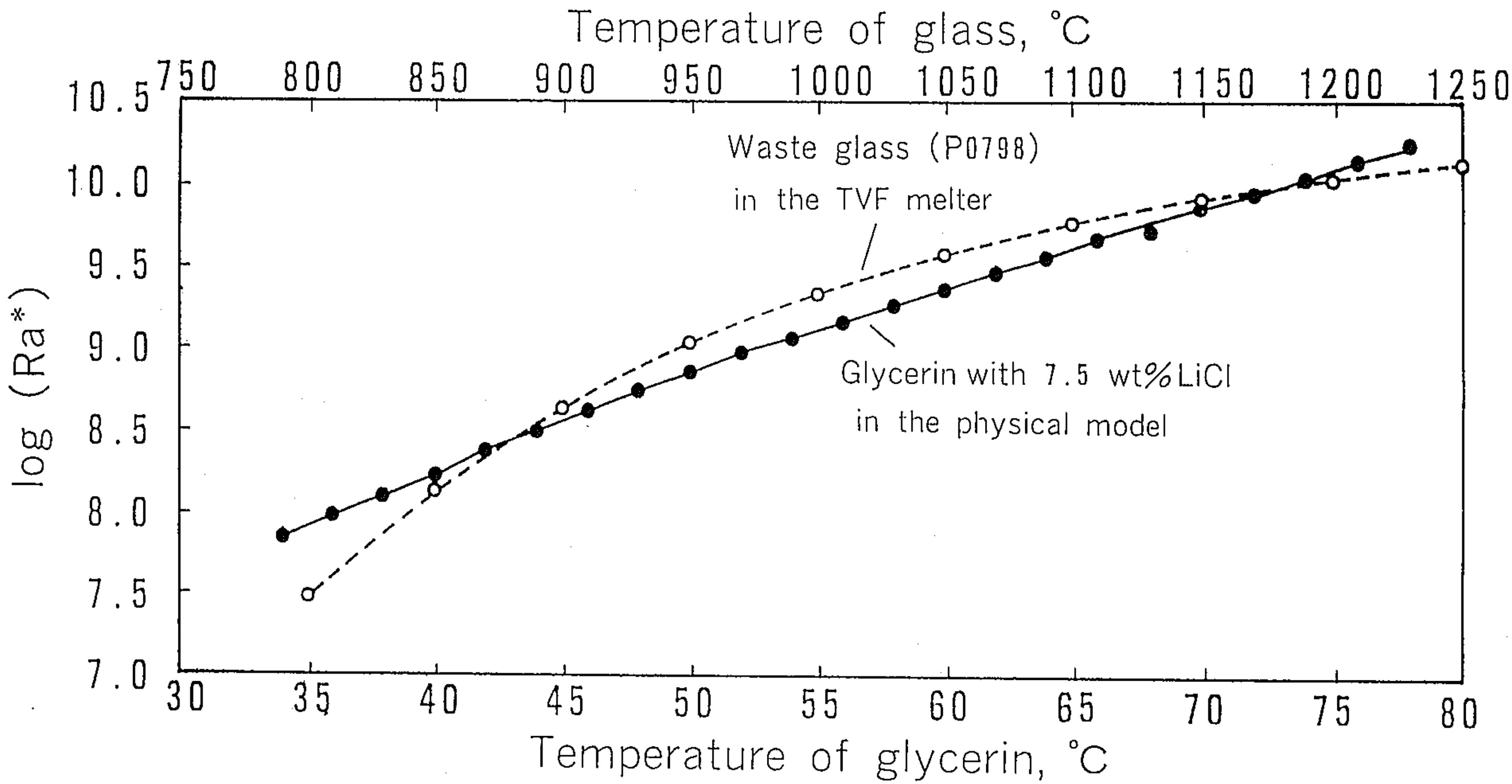
Dimension, internal	: L267×W270×H350mm
external	: L515×W425×H410mm
Floor slope	: 45° and 54.5°
Material, Wall	: Polymethylmethacrylacrylate (PPMA)
electrode	: copper plate
Fluid	: Glycerin with 7.5 wt% LiCl
Analogy	: one-third scale of TVF melter equivalent modified Rayleigh number

Modified Rayleigh Number : Ra*

$$Ra^* = g \beta \sigma V_0 L^3 / \alpha \nu \lambda$$

$$(= Gr\ Pr)$$

Gr : Grashof Number , Pr : Prandtl Number ,
g : Gravitational Constant , L : Length ,
V_0 : Electrode Voltage , α : Thermal Diffusivity ,
β : Thermal Coefficient of Volumetric Expansion ,
σ : Electrical Conductivity of Fluid,
λ : Thermal Conductivity , ν : Kinematic Viscosity .



Comparison of modified Rayleigh number, Ra*
between the physical model and the TVF melter
(P0798 : PNC's glass code)

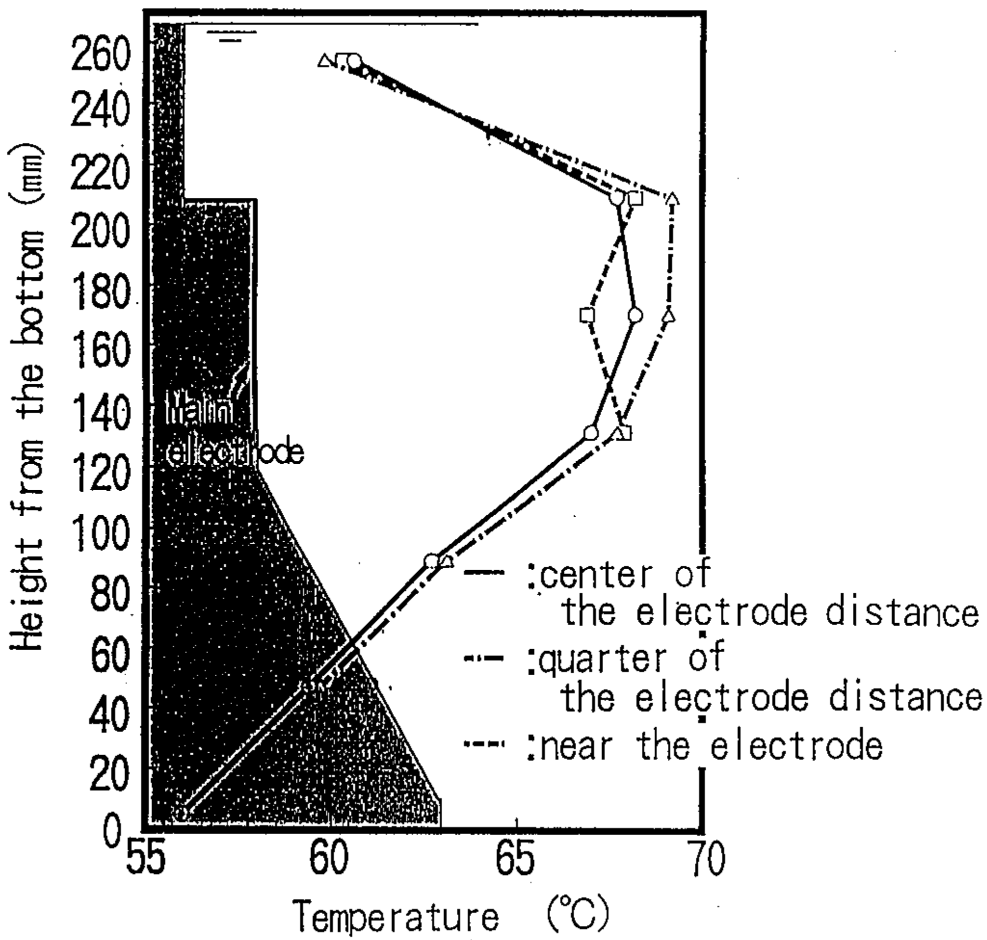
Experiment Condition of Physical Modeling

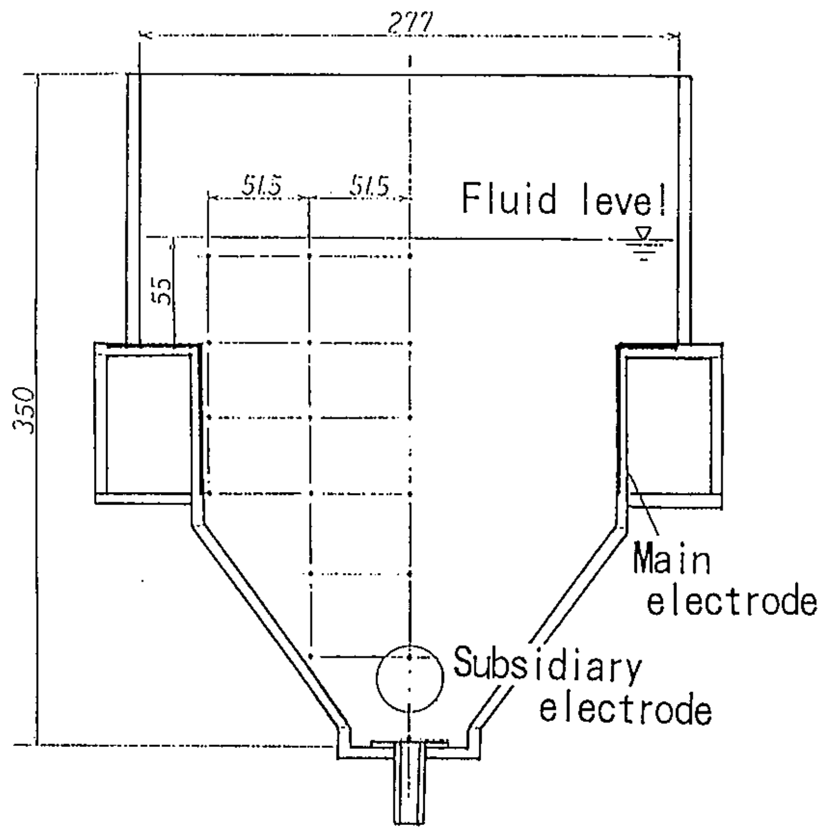
Joule heating

Electrodes	Electric power (W)		
	Case 1	Case 2	Case 3
Main electrodes	74	86	96
Subsidiary electrodes	3	3	3
Drain nozzle and main	3	3	3

Water bath temperature

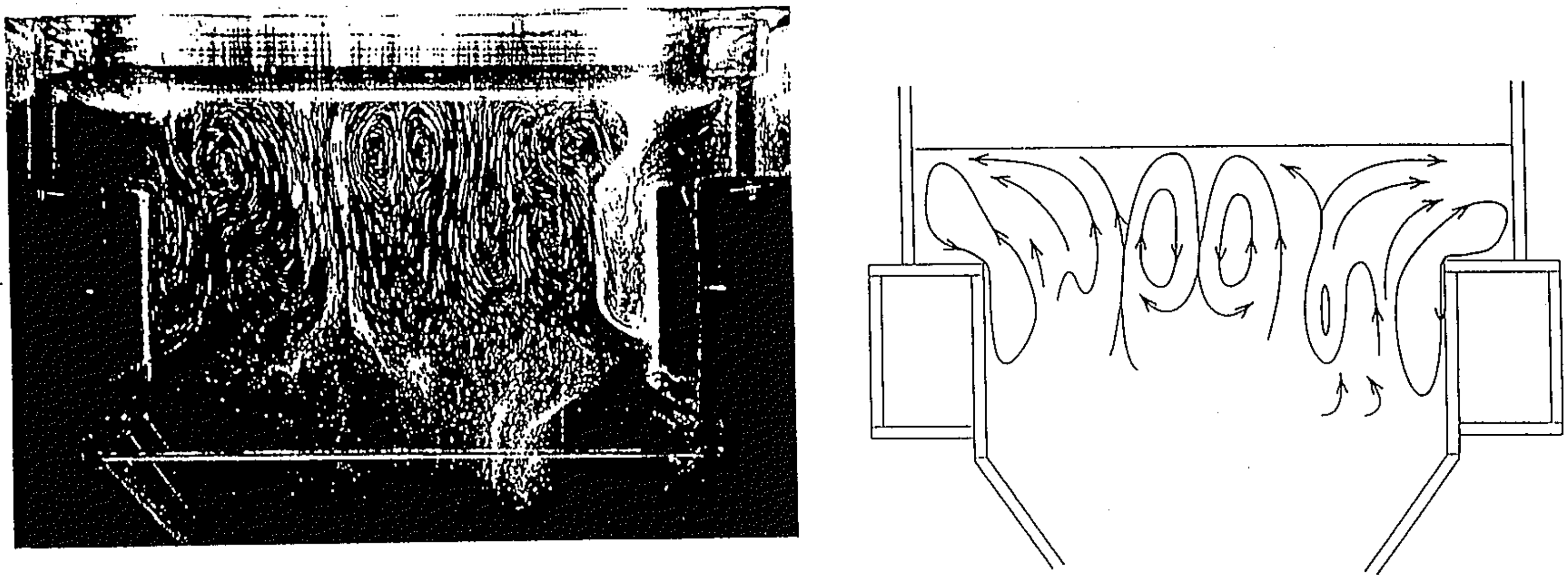
Water bath	Water temperature (℃)
Top water jacket	62
Side wall	61
Bottom	52
Main electrode	61





Measuring points of temperature and electric voltage

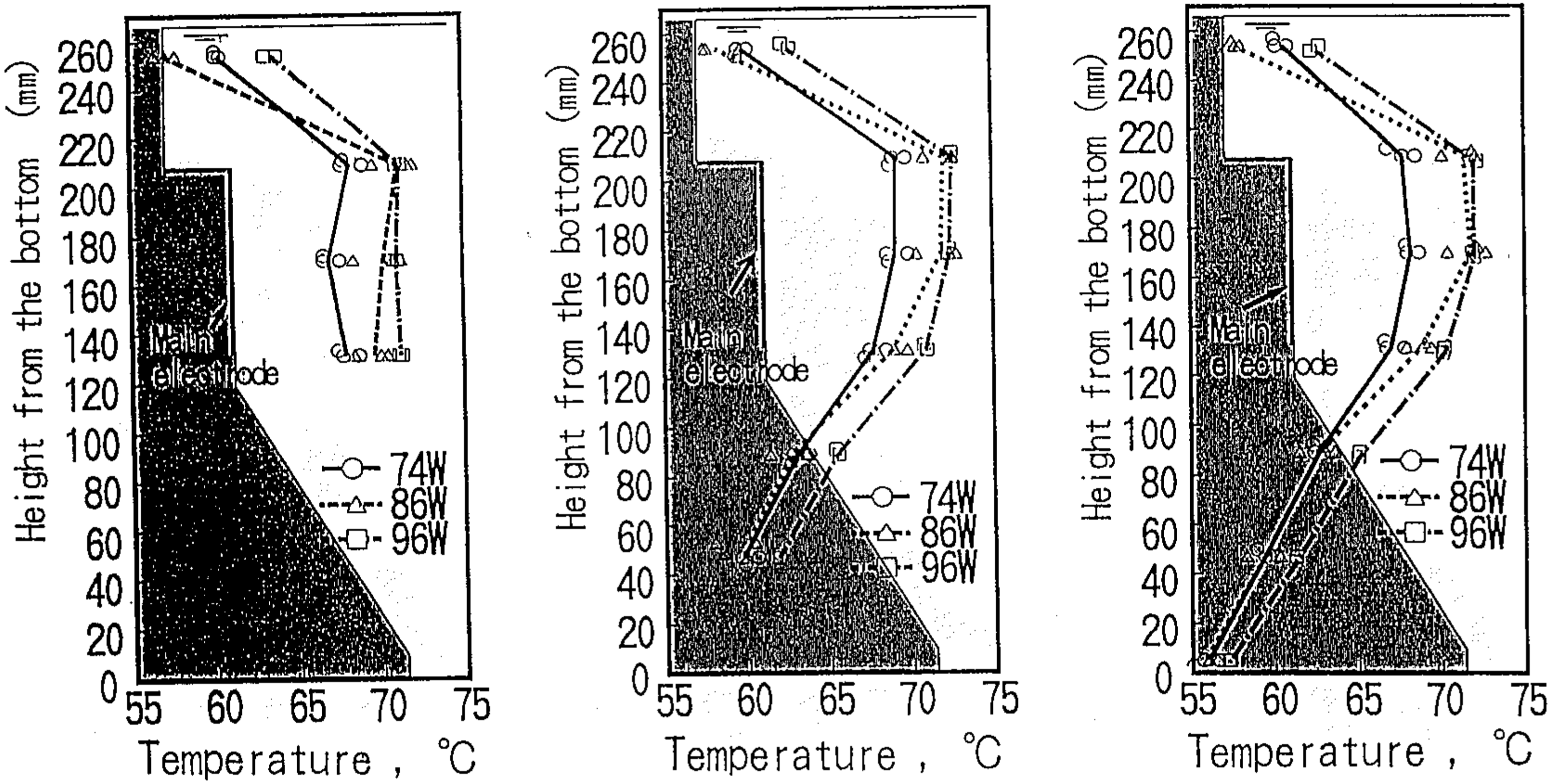
Vertical temperature profile (Case 1)



(a) Photograph of traces
(Shutter speed 20second)

(b) Illustrated patterns

Flow patterns observed in physical model for Case 1 (Main electrode power 74W)

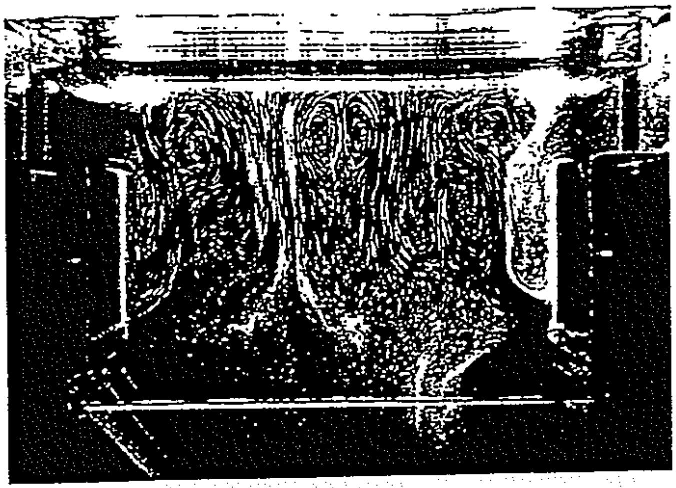


near the electrode

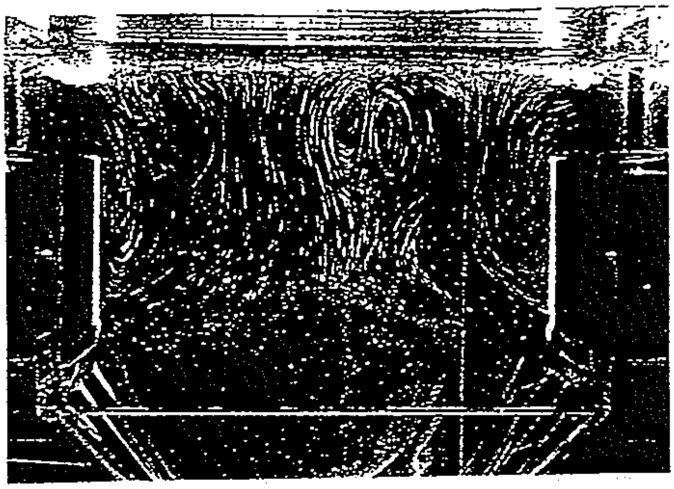
quarter of the electrode distance

center of the electrode distance

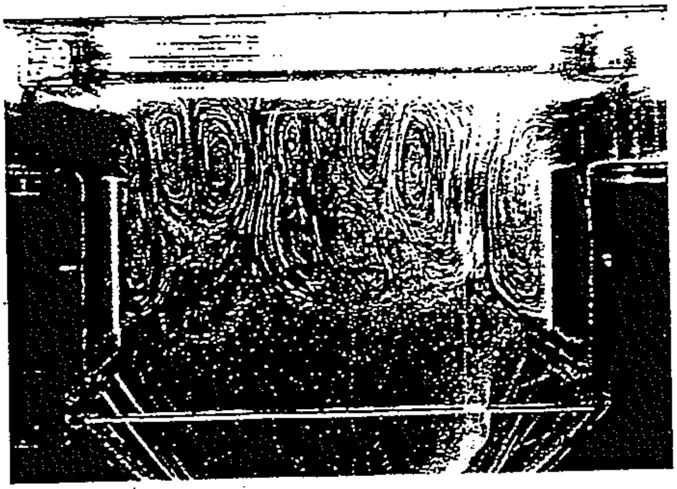
Experiment results of vertical temperature profiles
(Comparison of main electrode power)



(a) Main electrode power 74W

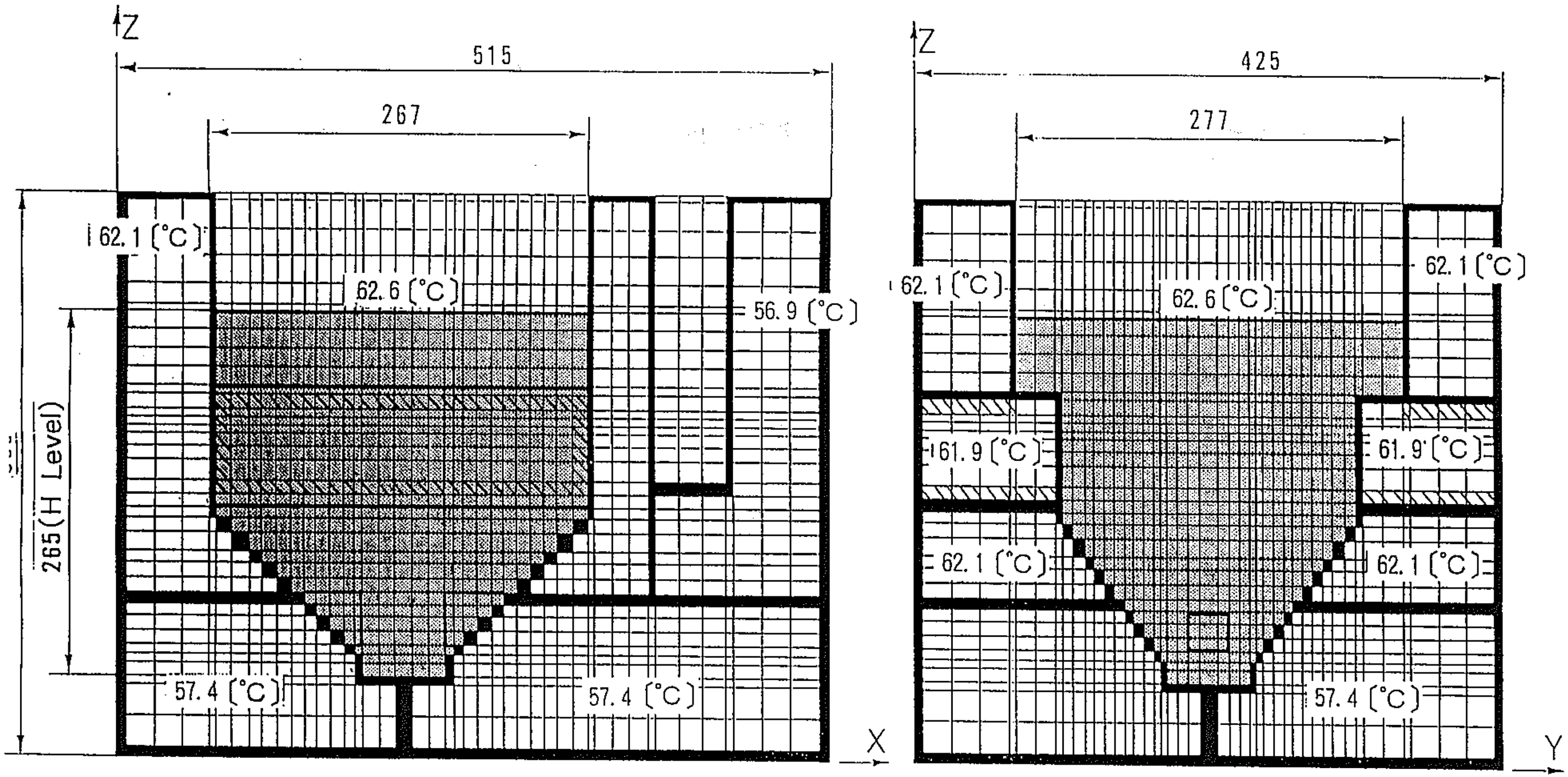


(b) Main electrode power 86W



(c) Main electrode power 96W

Flow patterns observed in physical model



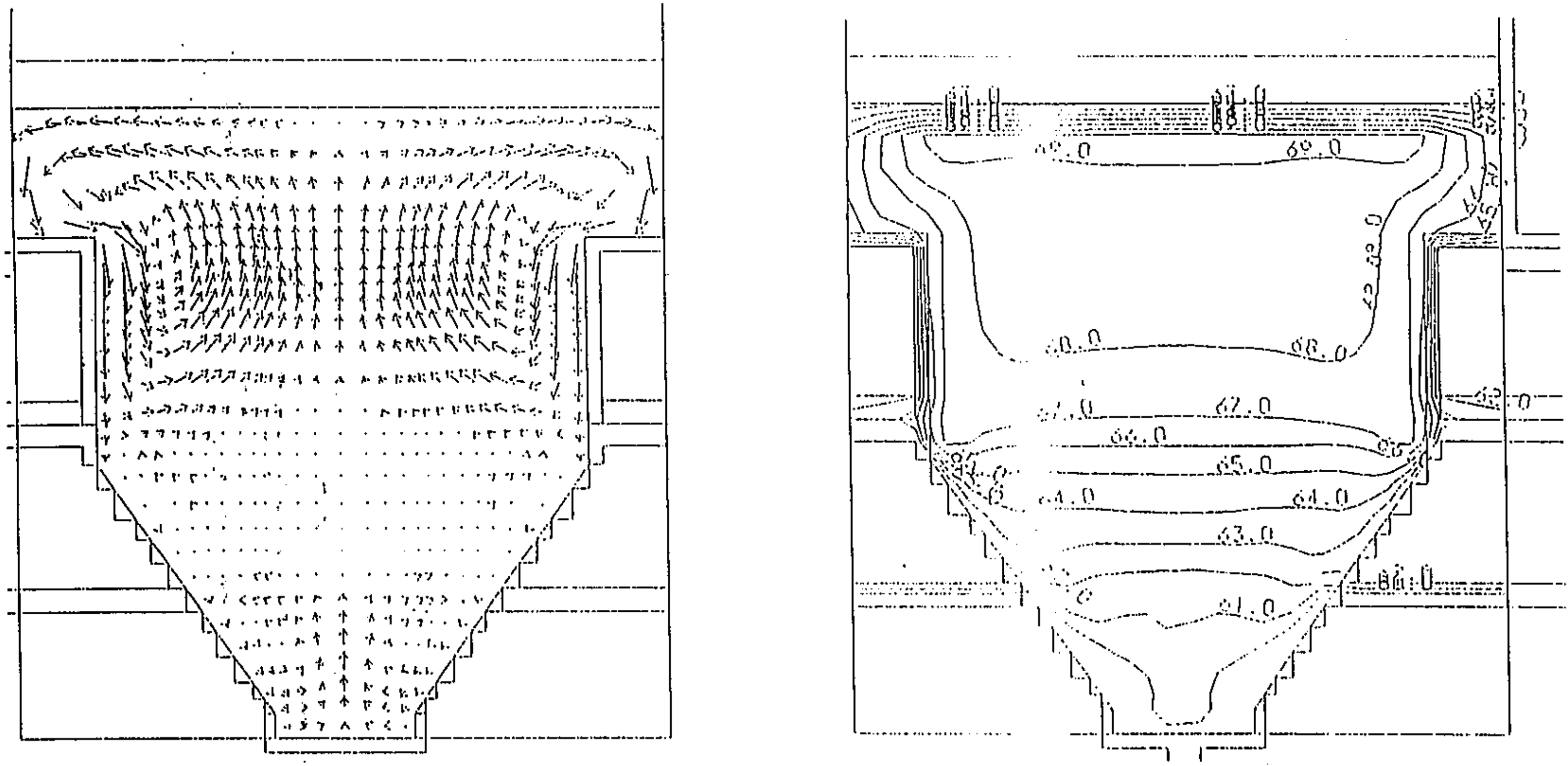
(a) X-Z plane　　　(b) Y-Z plane

Mesh geometry of physical model for computation

(Mesh size : 46×46×38 with 28×36×28 Internal domain)

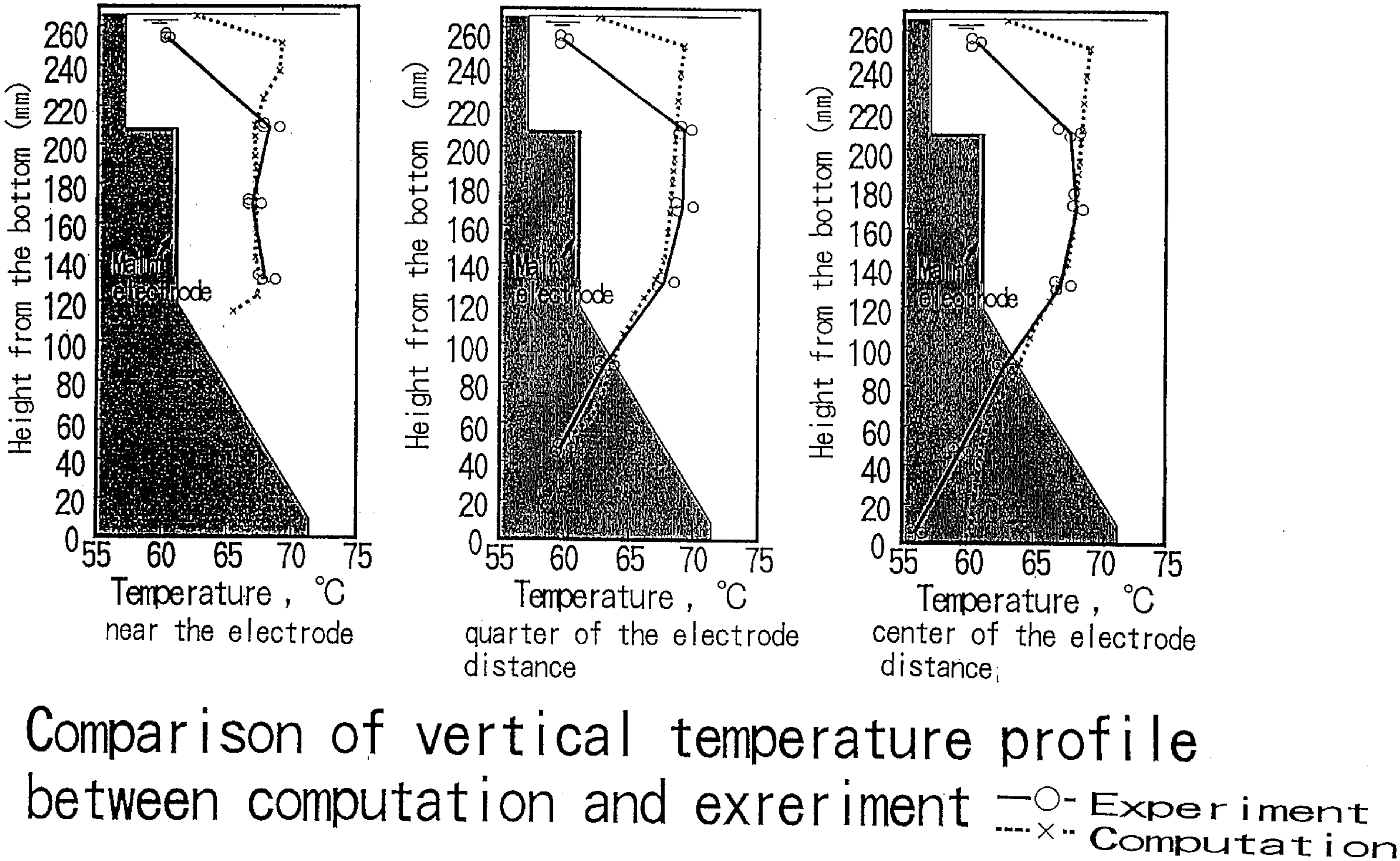
: External domain

: Internal domain



(a) Flow pattern (b) Temperature distribution, ℃

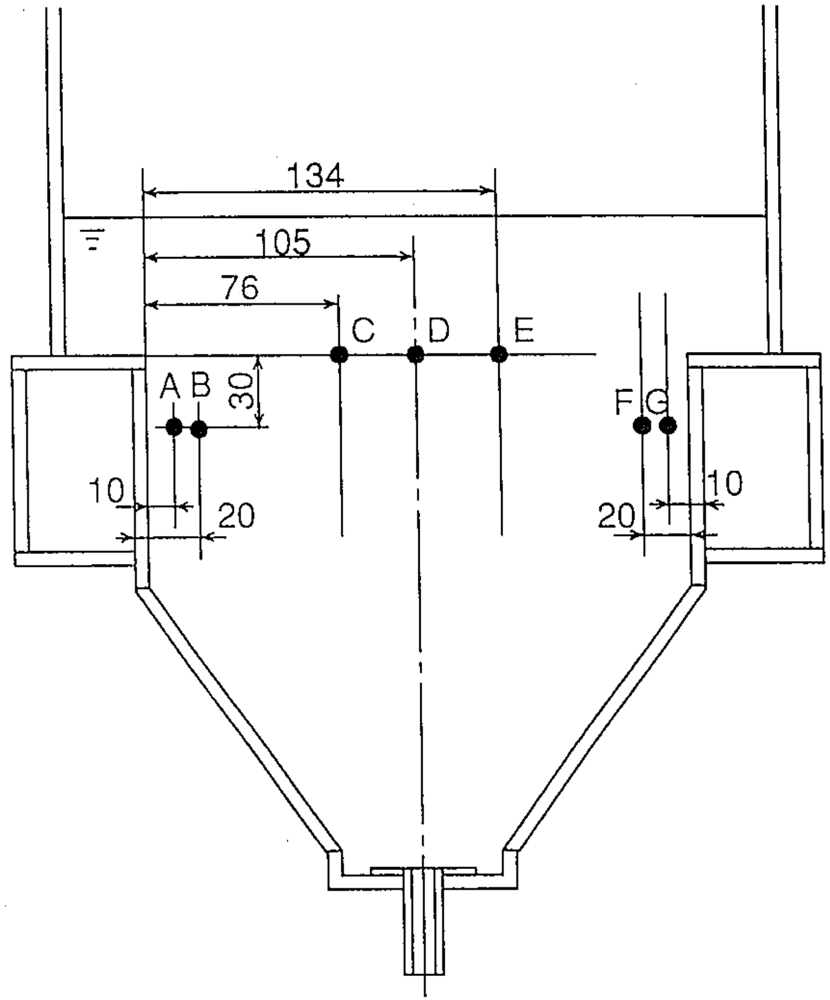
Computational result by mathematical model



Comparison of vertical temperature profile between computation and exreriment

Comparison of vertical velocity components between computation and experiment , mm/s

Measuring points	experiment		computation
	velocity	standard deviation	
A	-0.32	0.060	-0.56
B	0.40	0.063	-0.03
C	0.67	0.146	0.21
D	-0.50	0.070	0.20
E	0.71	0.120	0.21
F	0.40	0.066	-0.03
G	-0.39	0.088	-0.56



Measuring points of velocity in physical model

Conclusion

- Influence which the electric power exerts the flow patterns and temperatuer profile was clearly by physical modeling.
- The flow patterns and temperature behavior was proved by physical and mathematical modeling.
- The chief flow patterns agreed between the experiment and computational result.
- The temperatuer profile agreed qualitatively and quantitatively between the experoment and computatinal results.

2.4 Inspection technique based on LASER for melter and Dismantling of spent melter

PNC TN8100 94－003

Inspection technique based on LASER for melter and Dismantling of spent melter

Prepared for
The 12th Annual KfK-PNC Meeting
on
Cooperation in High-Level Waste Management

by KOBAYASHI, H.

December 7-9,1993

Power Reactor and Nuclear Fuel Development Corporation

PNC

Development of the In-Melter Inspection System

Purpose

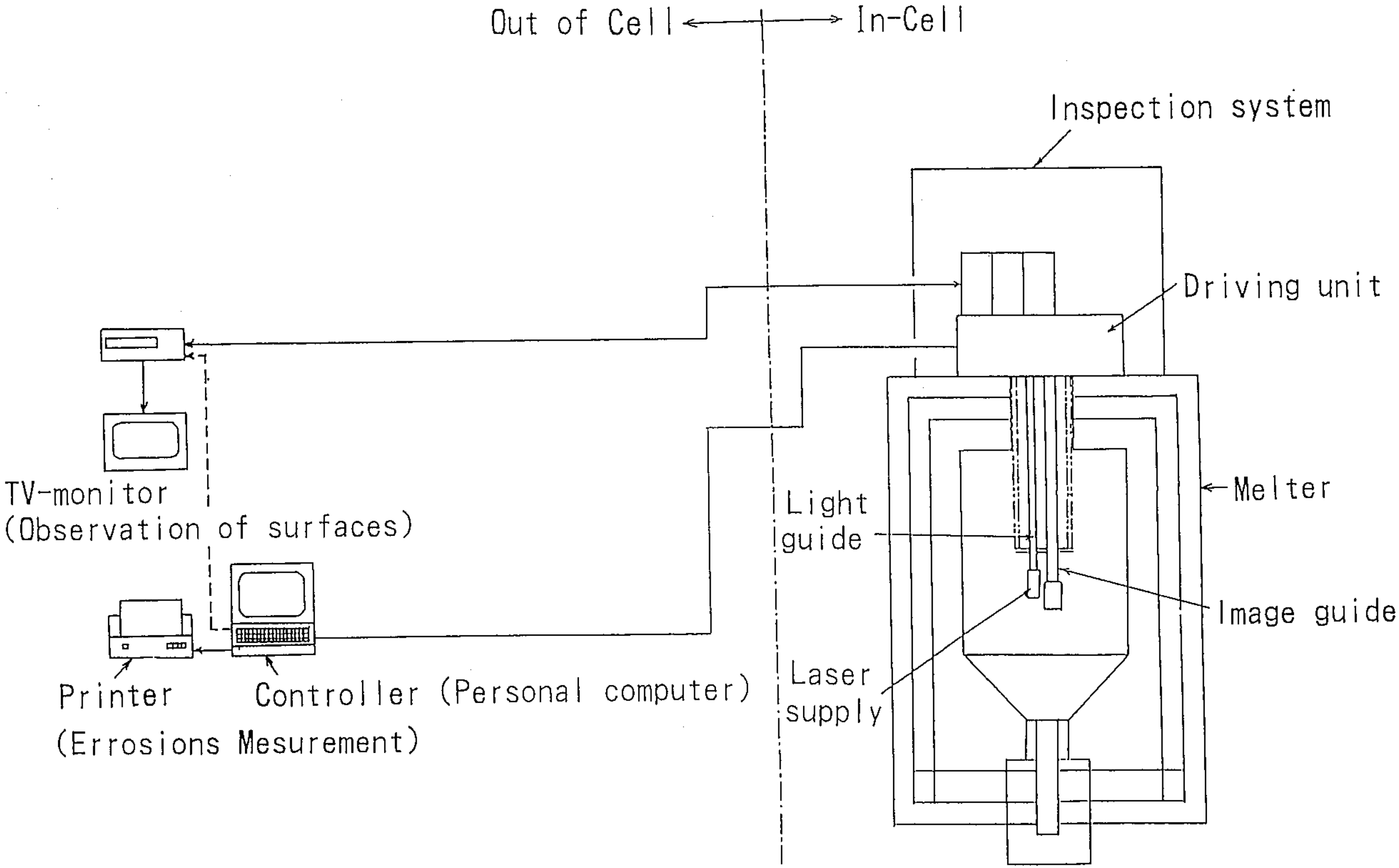
Check durability of the melter

- Observation of Surfaces
- Errosion Mesurement

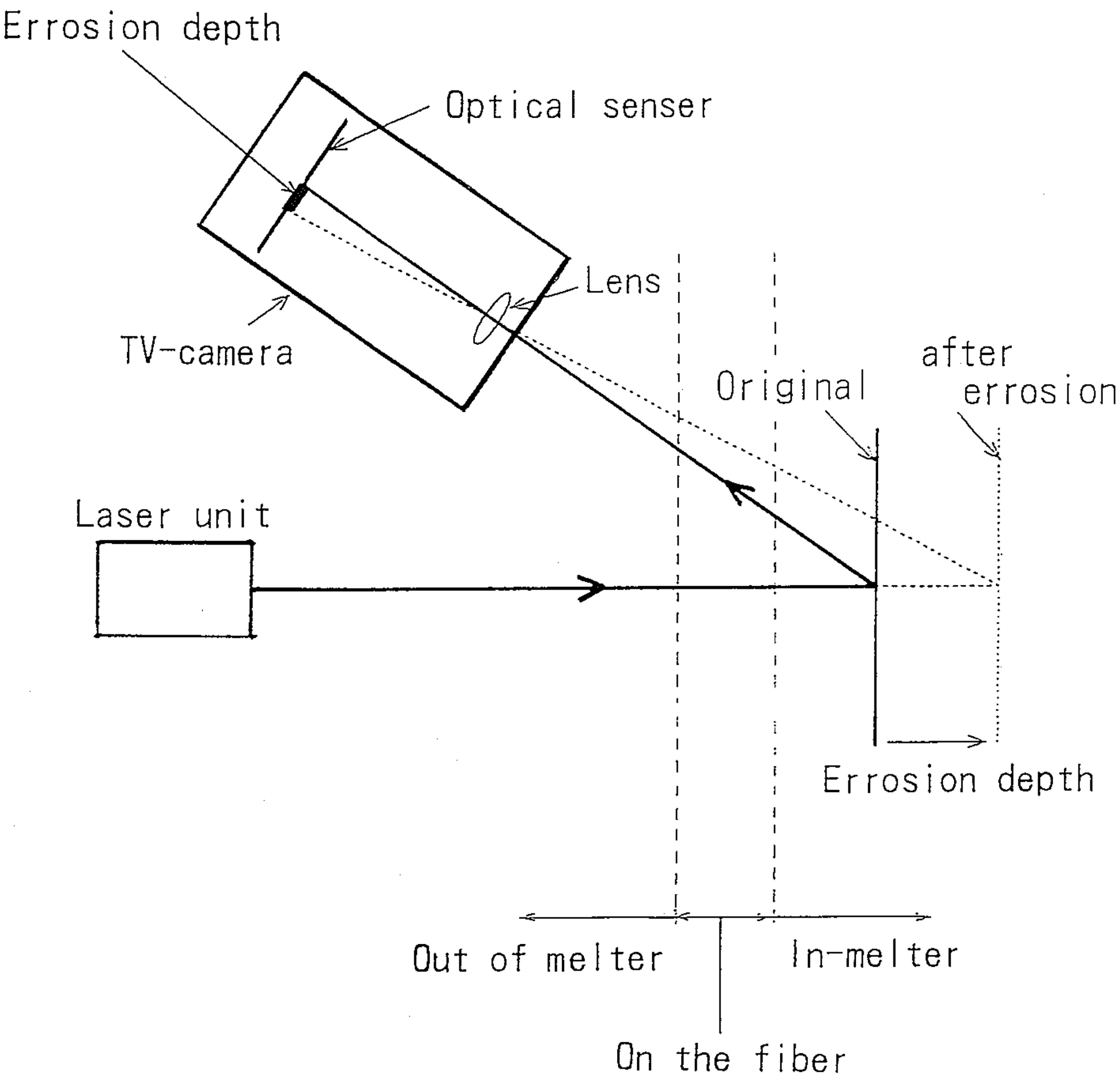
(Electrode, Refractory)

Radiation in melter

- 10^6 R/h (258C/kg·h)

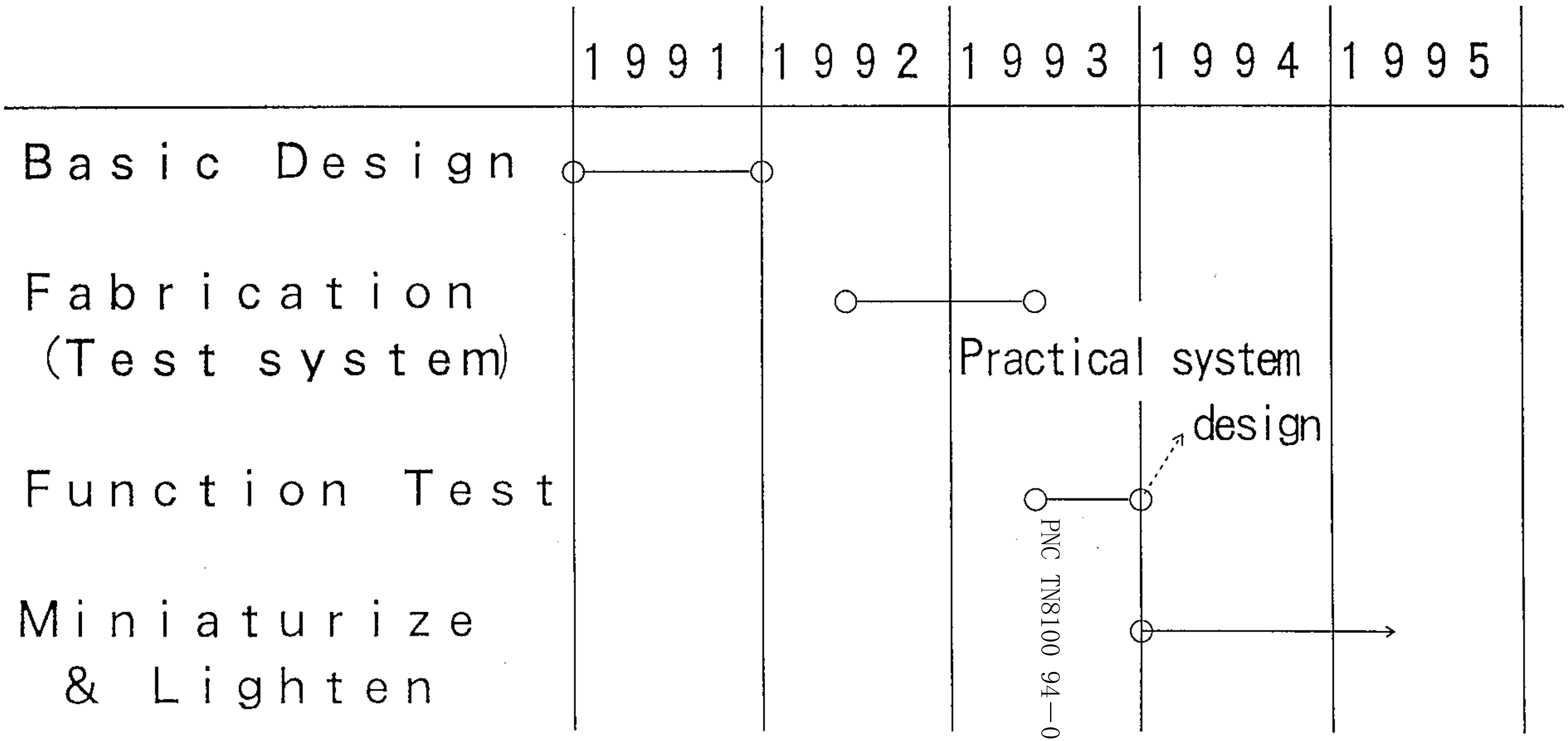


SCHEMATIC OF INSPECTION SYSTEM

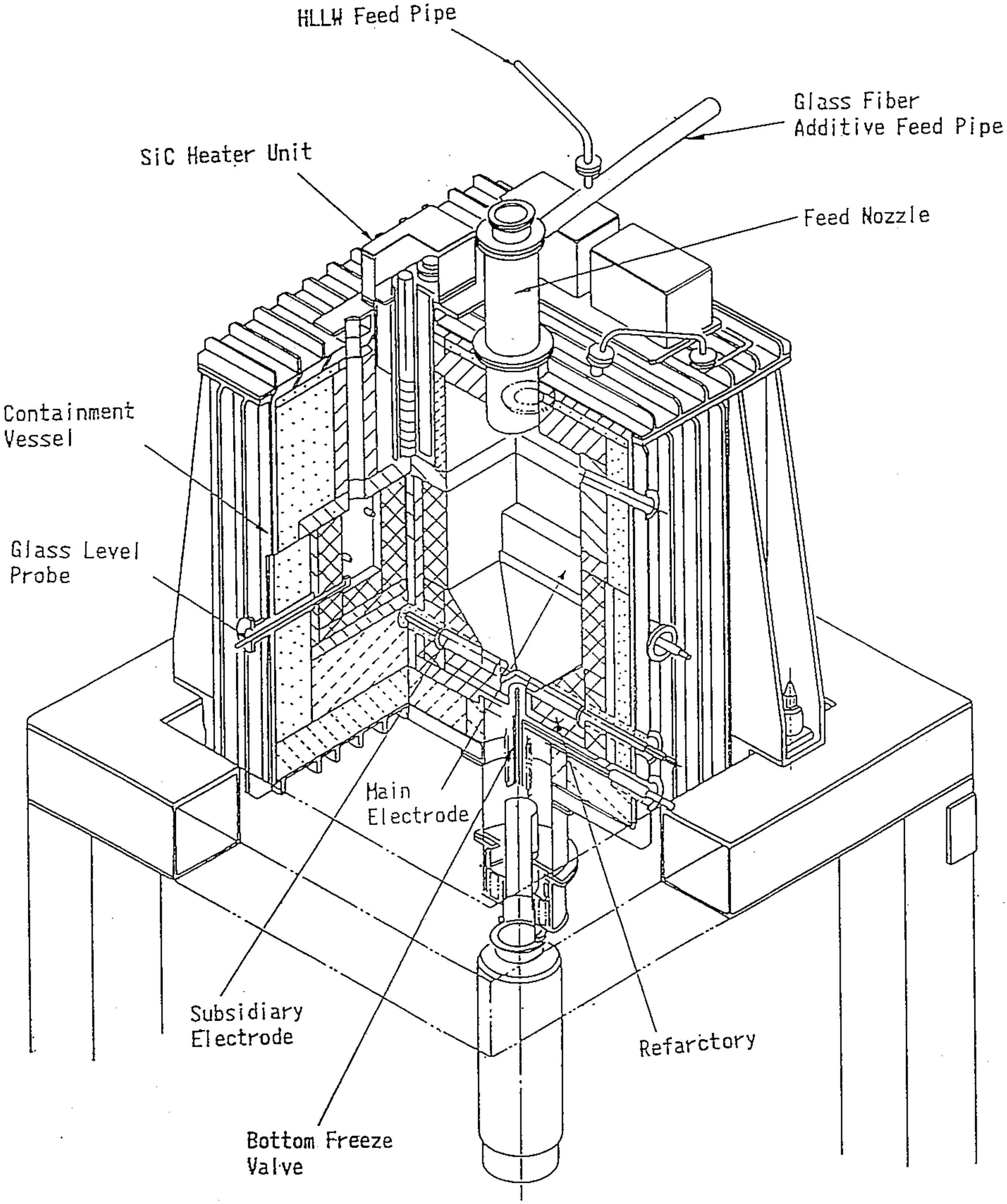


DISTANCE MEASUREMENT BY TRIANGULATION

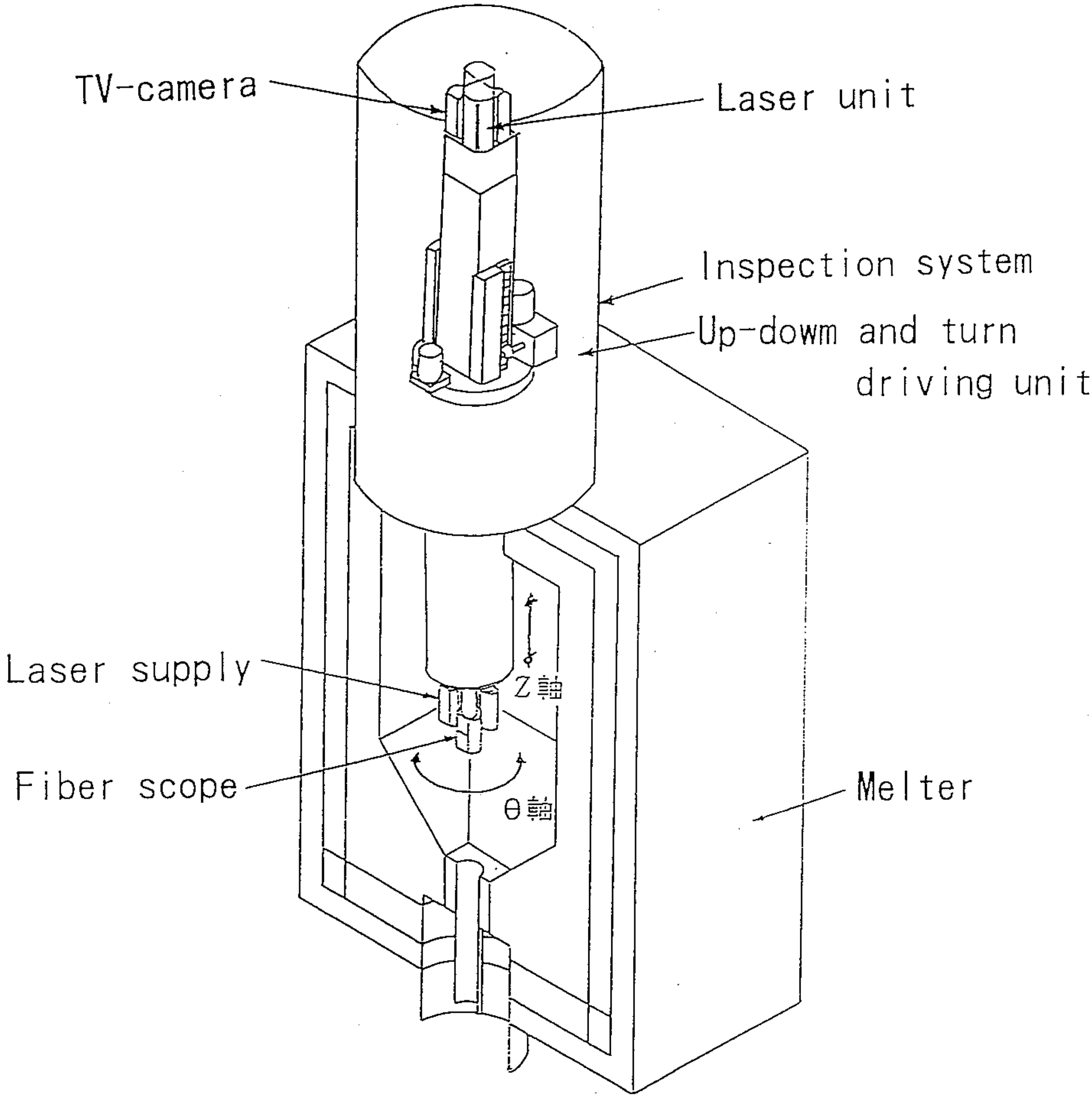
Development plan



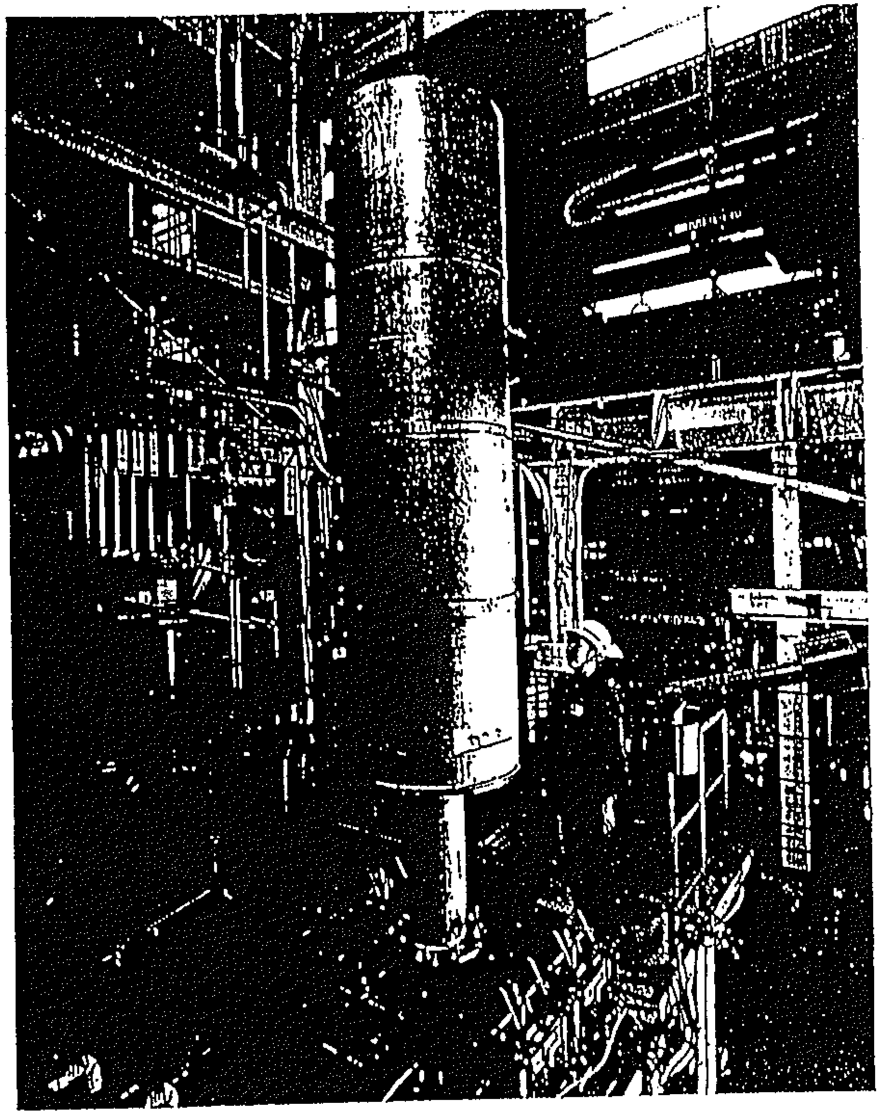
PNC TN8100 94-003



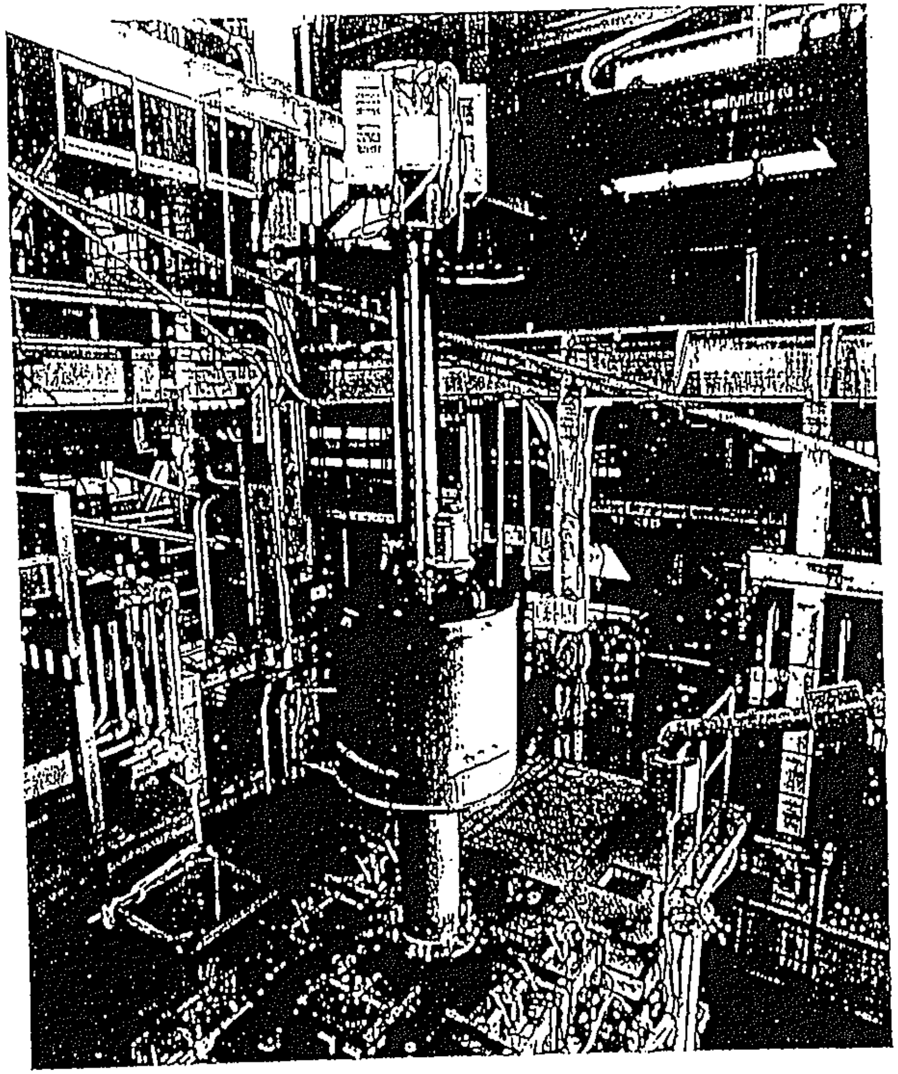
Structure of Melter



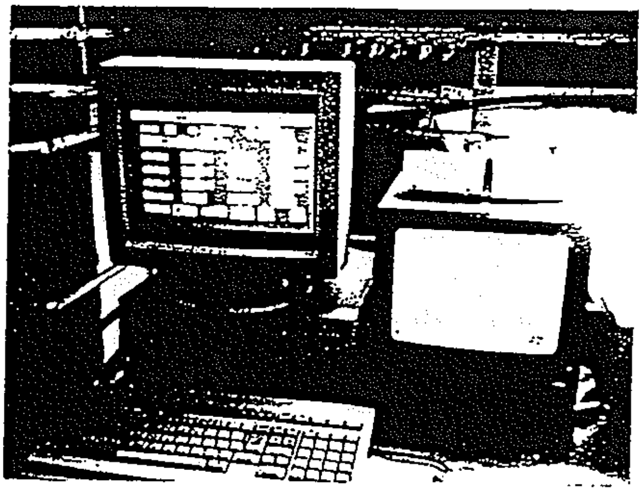
CONCEPT OF THE IN-MELTER INSPECTION SYSTEM



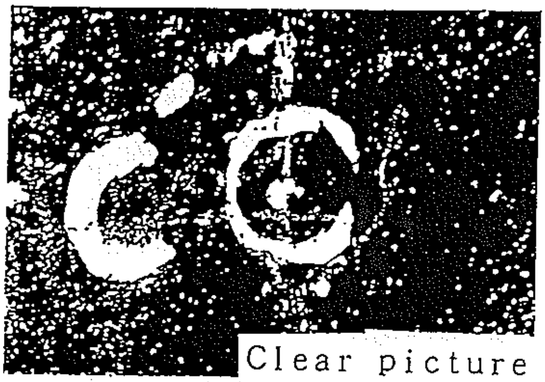
Inspection Instrument on the melter



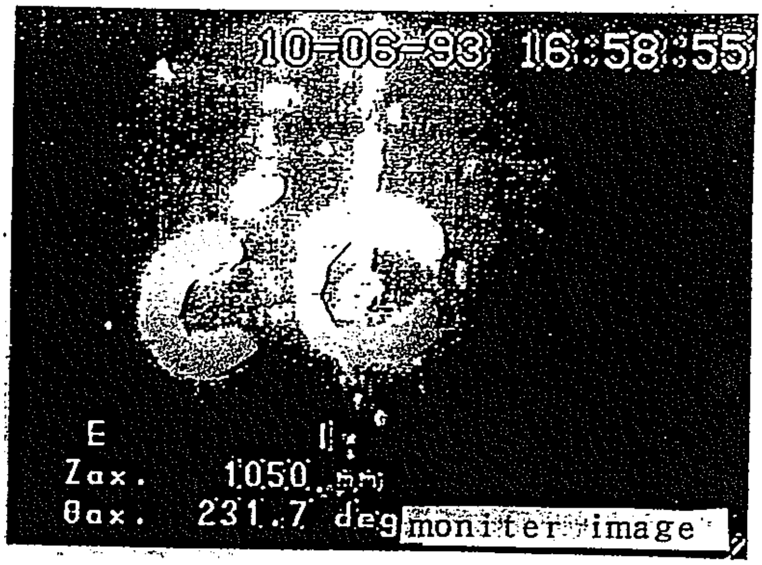
Inside of The Instrument



Control system

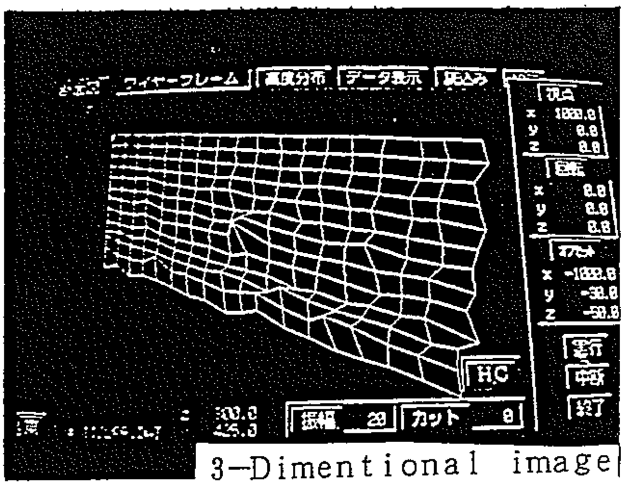


Clear picture

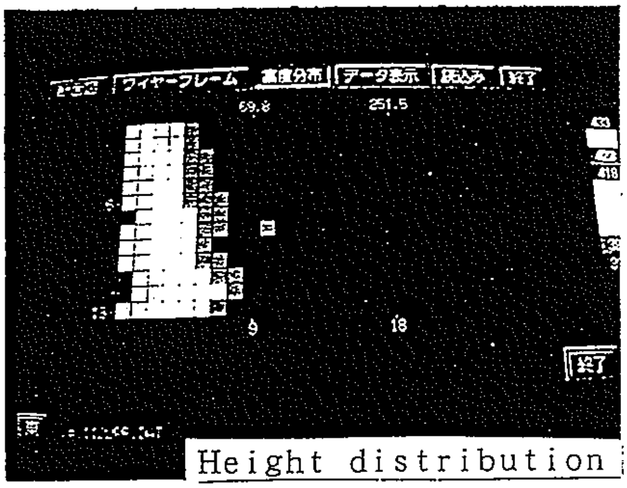


moniter image

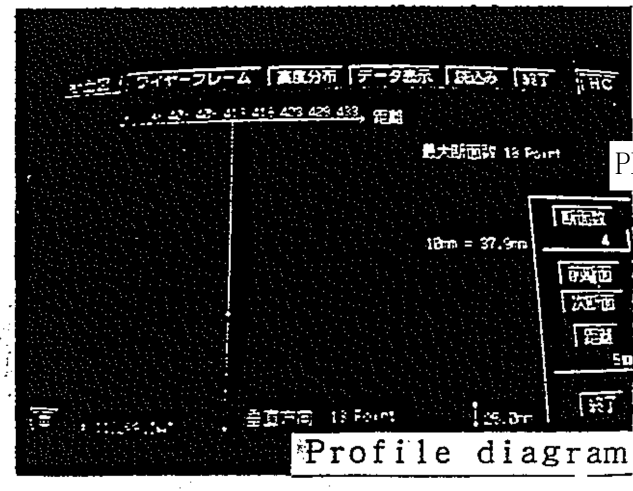
DATA DISPLAY with THE INSPECTION SYSTEM



3–Dimentional image



Height distribution



Profile diagram

PNC TN8100 94－003

DATA DISPLAY with THE INSPECTION SYSTEM

Melter Dismantling Test

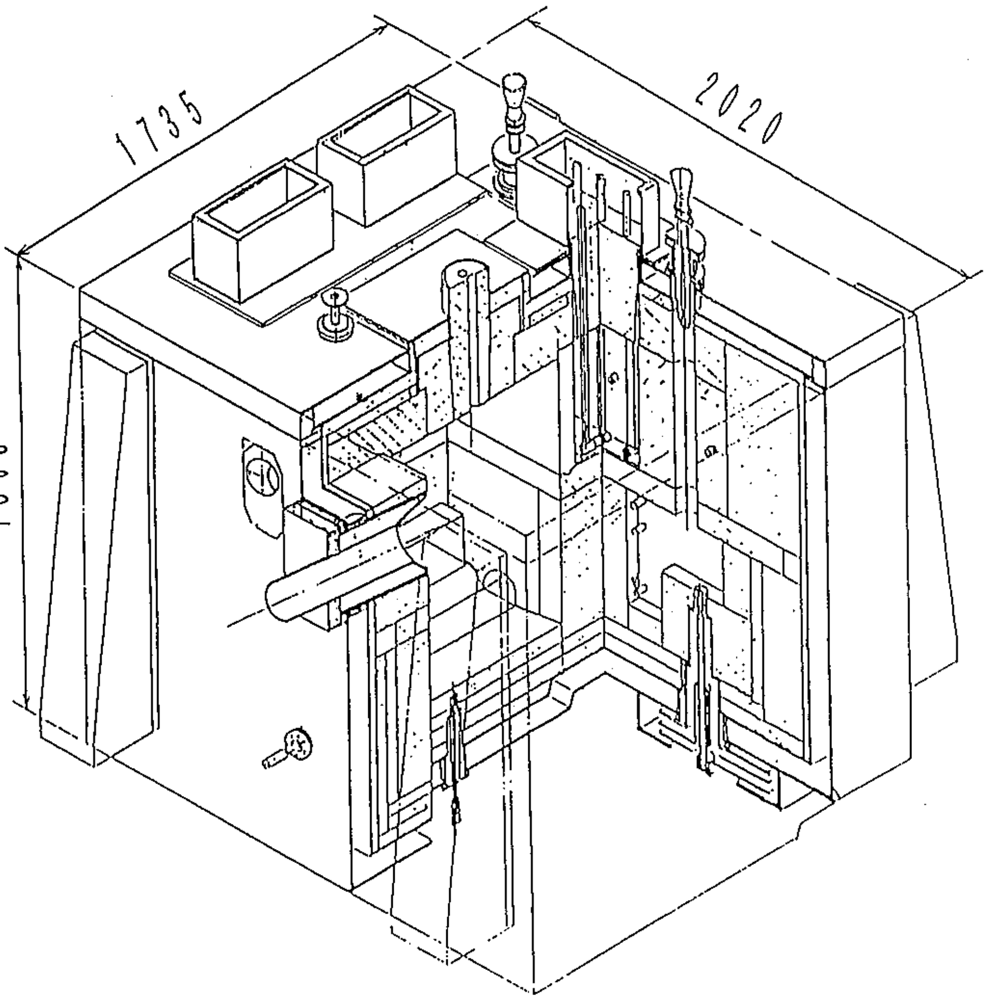
Purpose

－ Estimate of dismantling process

－ Ability test of dismantling tools

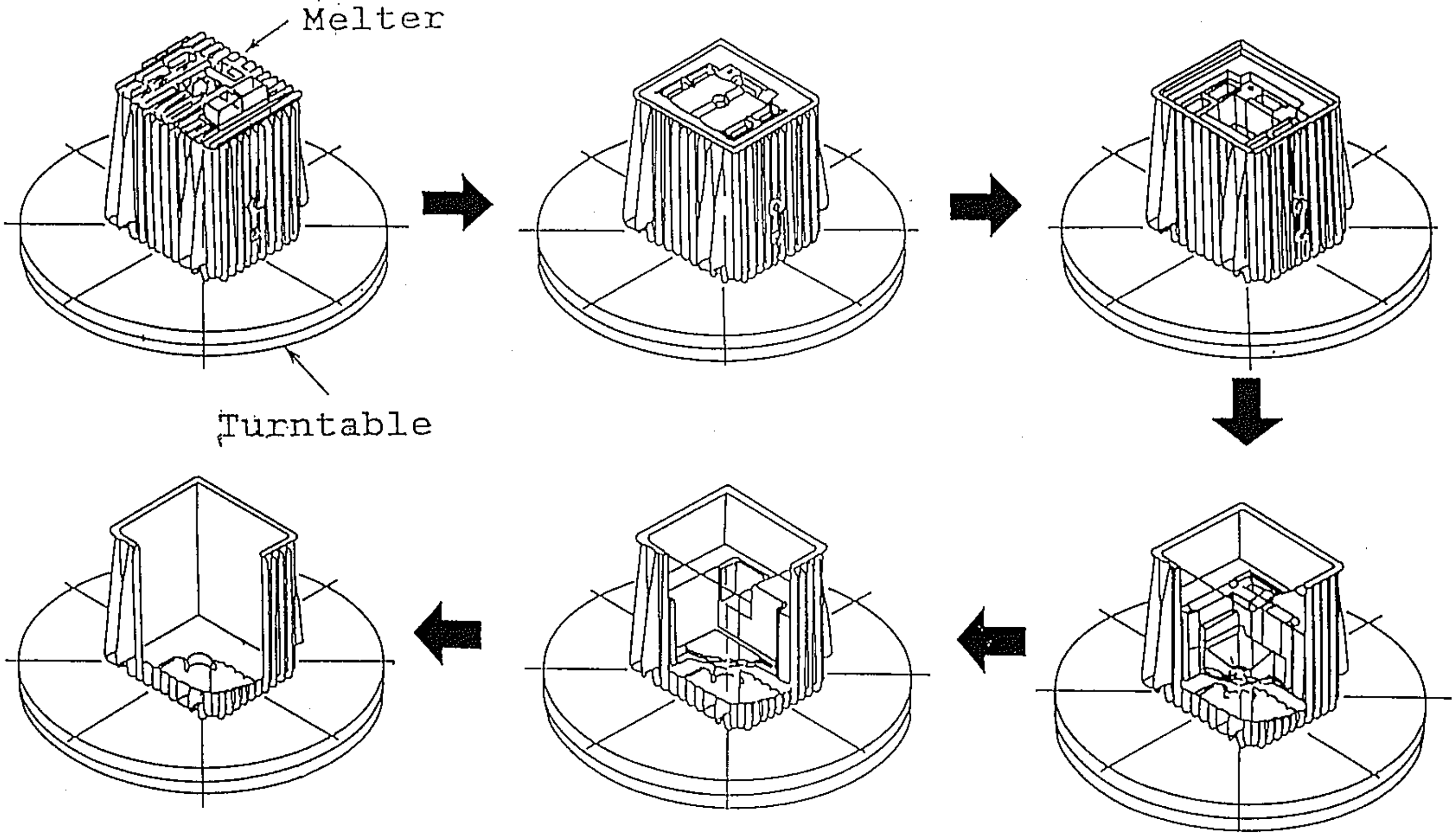
An object

－ Mock－up 2 melter

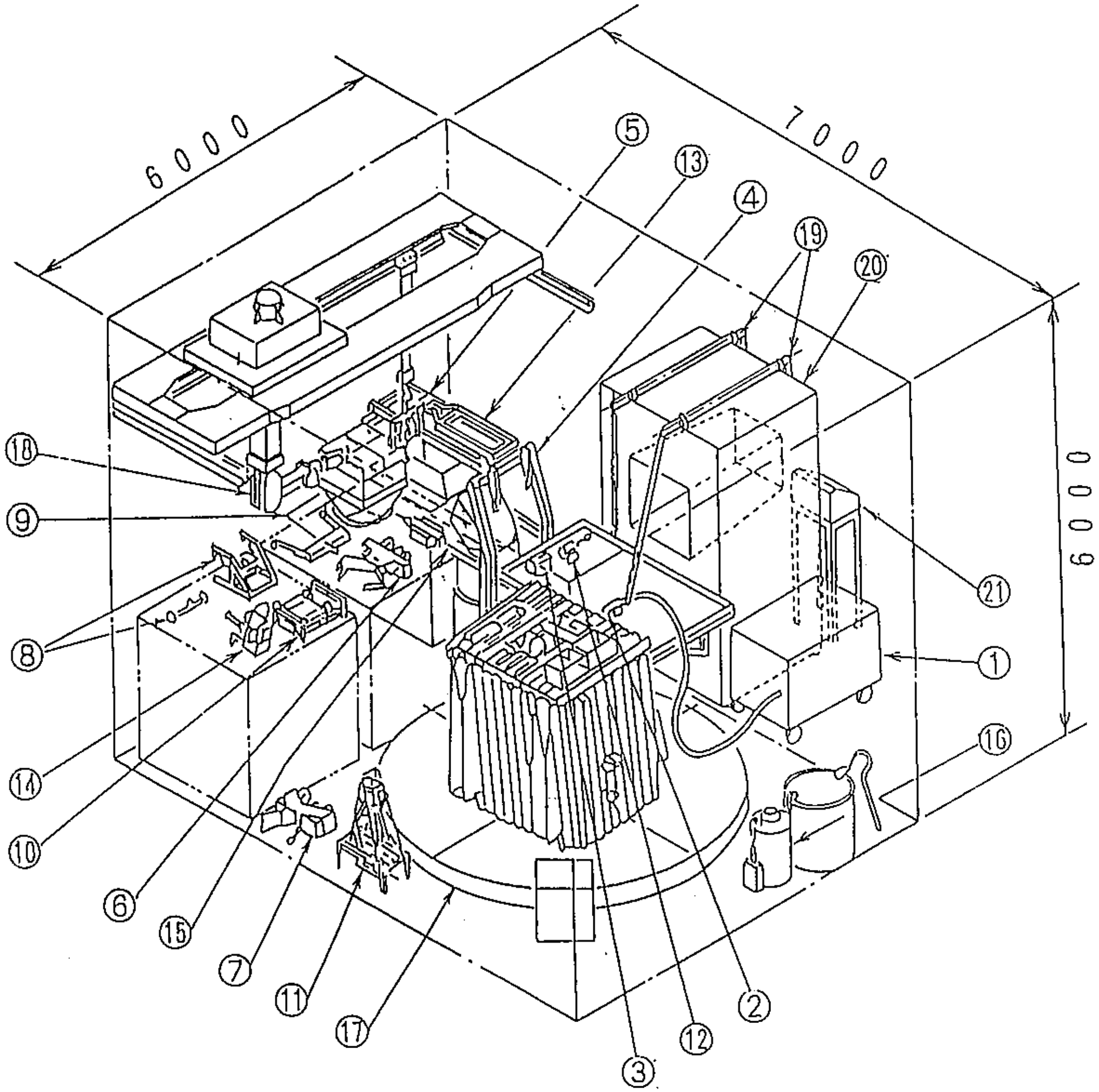


Heating	Joule-Heating
Containment Vessel	SUS 304
Electrode	Inconel 690
External Dimension	W2020×L1735×H1805
Refractory	K-3 2020kg Other 4970kg
Total Weight	16015kg

SPCIFICATION OF M/U-2 MELTER



PROCEDURE OF DISMANTLING FOR MELTER(TVF)

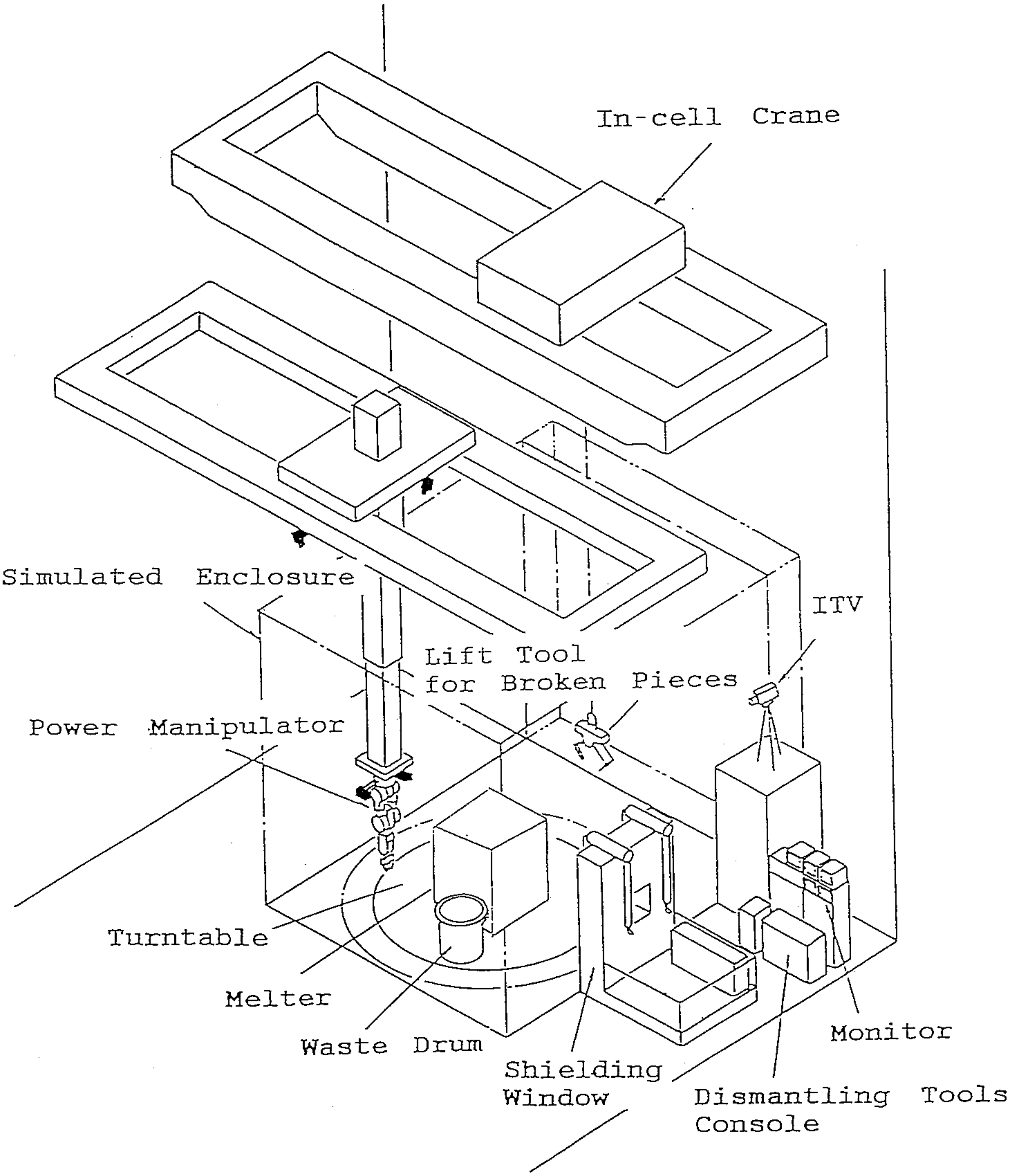


1～3	Plasma cutter
4	Hacksaw
5	Hoist scale
6～7	Handling tools of cut piece
8	Handling tools of electrode
9	Reciever
10～11	Internal dismantling breaker
12	Impact wrench
13～14	Handling tools of electrode
15	Breaker
16	Vacuum cleaner
17	Turn-table
18	Power manipulator
19	Master/slave manipulator
20	Shielding window
21	Control box

CONCEPT OF THE DISMANTLING AREA (TVF)

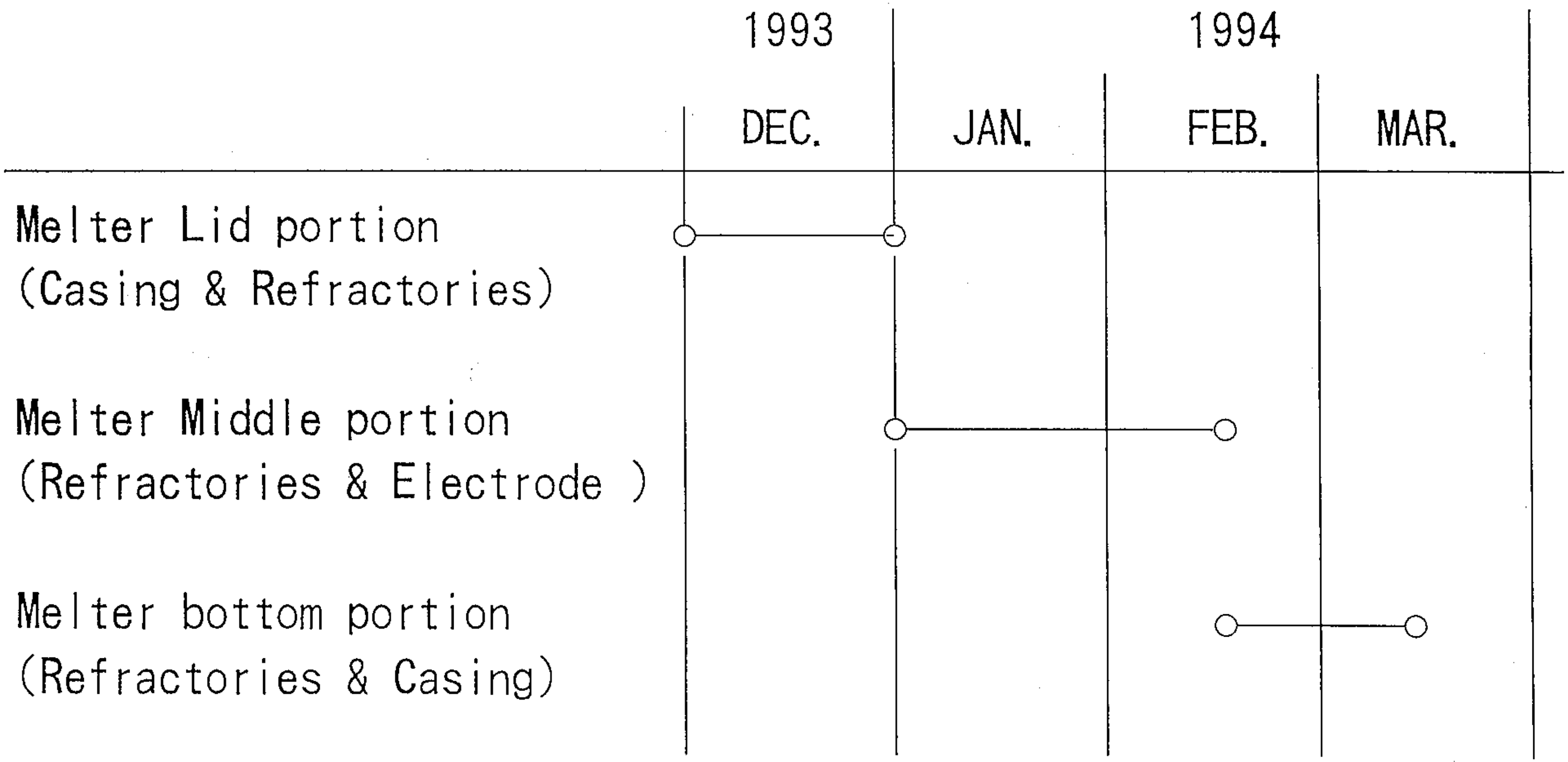
Equipment and tools used at melter dismantling

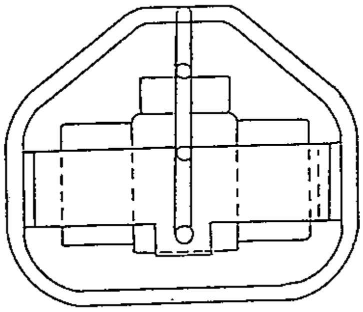
Plasma torch,	power	350A
Breaker,	electric power	system
Gripper,	electric power	system
Power Manipulator,	handoling weight	～ 100kg
Turntable,	～4m	diameter



Outline of Dismantling Test Equipments

Dismantling Test Schdule

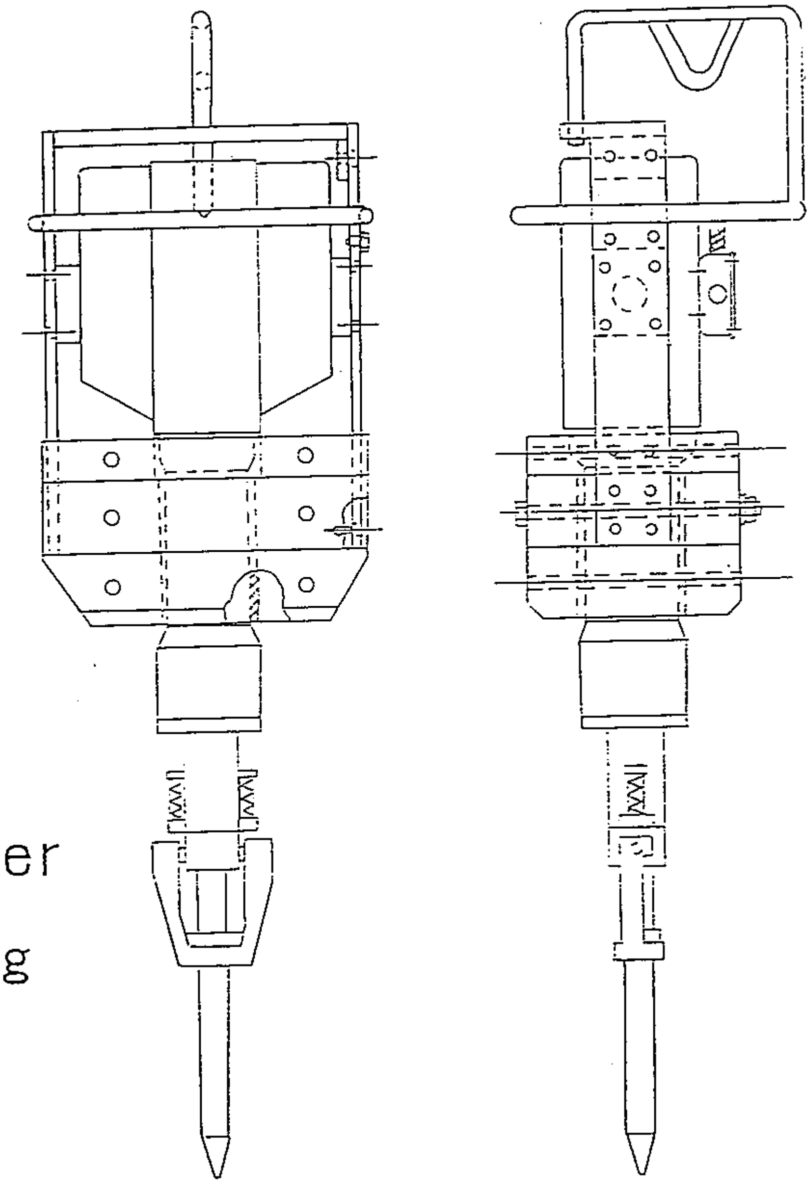




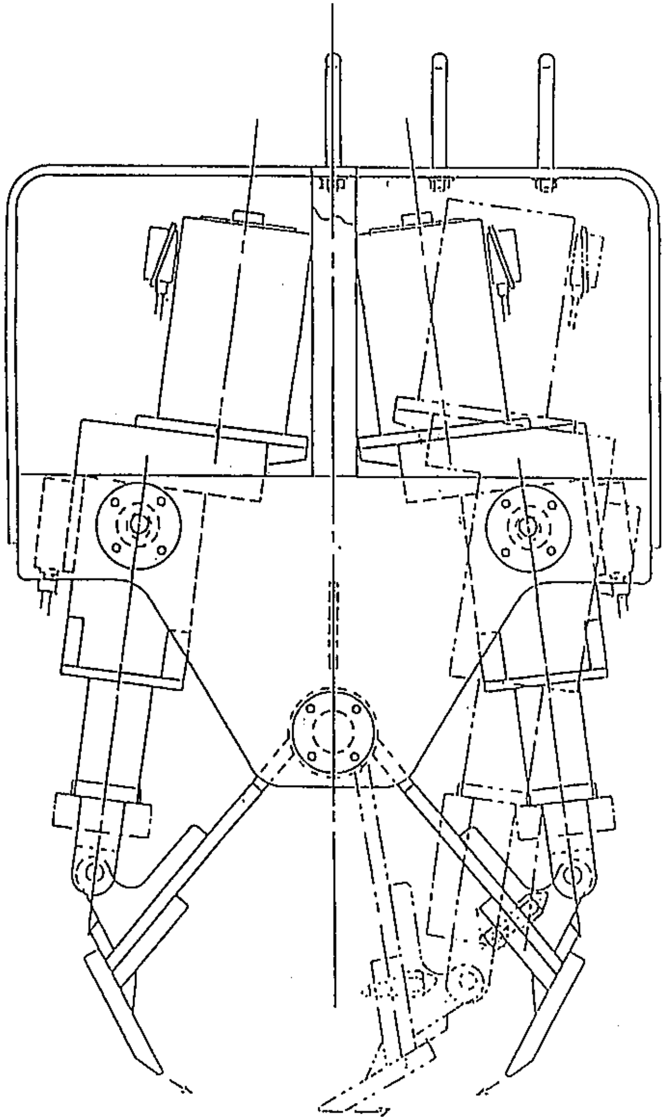
Driving force

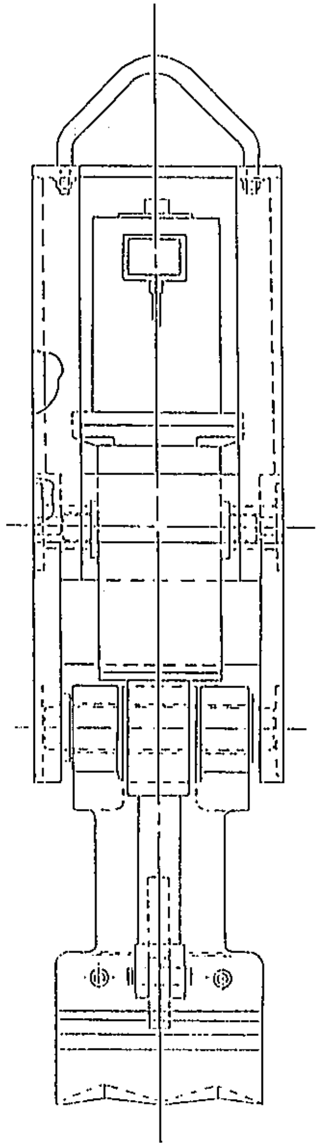
:electric power

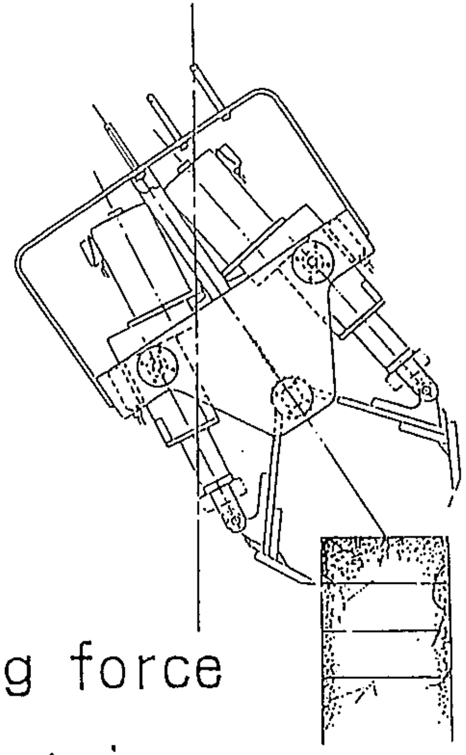
weight : 140kg



Breaker







Driving force

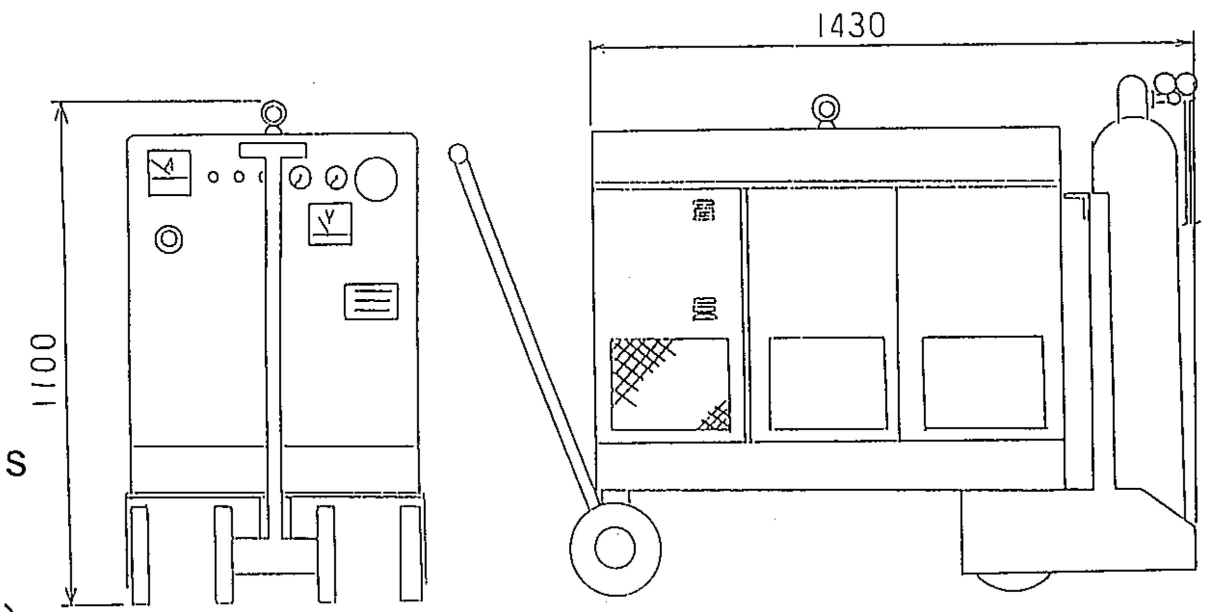
:electric power

Handling capacity

:300kg

weight : 240kg

Gripper tool

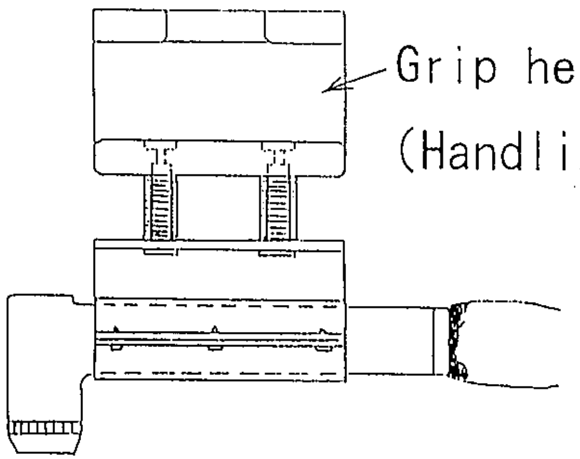


Plasma gas: $CO_2 \times N_2$ gas

Cutting speed

: 10mm/s(25mm-SUS304)

Weight :500kg



Cutting machine and Plasma torch

2.5 New glass melter

PNC TN8100 94−003

New glass melter

Prepared for
The 12th Annual KfK-PNC Meeting
on
Cooperation in High-Level Waste Management

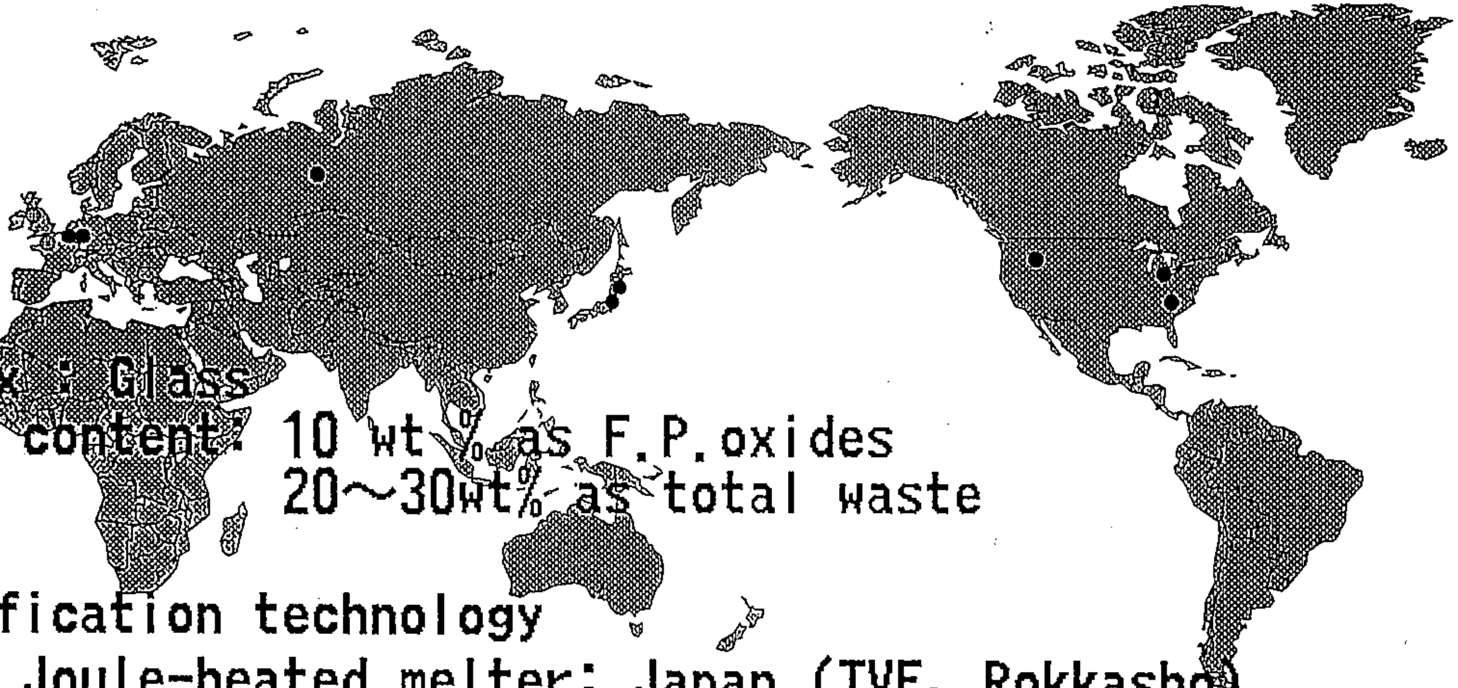
by IGARASHI, H.

December 7-9,1993

Power Reactor and Nuclear Fuel
Development Corporation

PNC

Commercialized Technology for Vitrification of HLLW



Matrix : Glass
Waste content: 10 wt % as F.P.oxides
20～30wt% as total waste

Vitrification technology

- Joule-heated melter: Japan (TVF, Rokkasho)
  Germany (PAMELA, WAK)
  USA (SRP, WVDP, HWVP)
  Russia (MAYAK)
- Calcining/Induction heating
  France (AVM, AVH), UK(WVP)

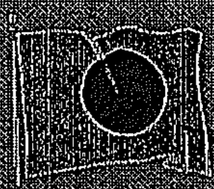
Trend of Advanced Vitrification Technology

USA: Stirred melter, High-temperature melter
(longer life, noble metals, higher-processing rate,
higher waste loading)
Application to treatment of TRU, LLW, Mixed waste

France, Russia: Cold crucible induction melting
(Higher melting temperature/ diversified glass composition
application to medium and low level waste)

Germany: Joule-heated melter with steeply sloped floor
UK: ?

Development of Advanced Melting Technology in Japan

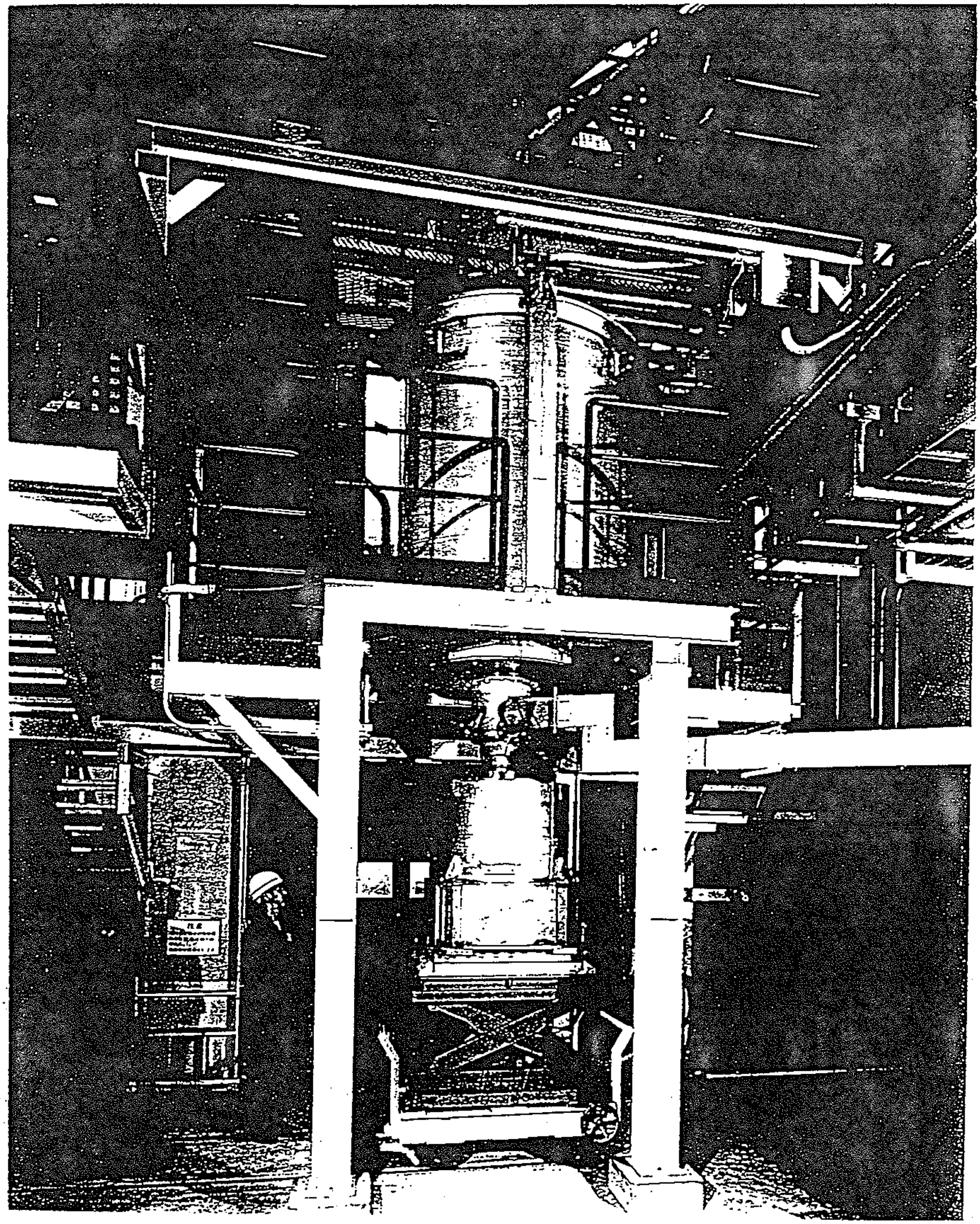


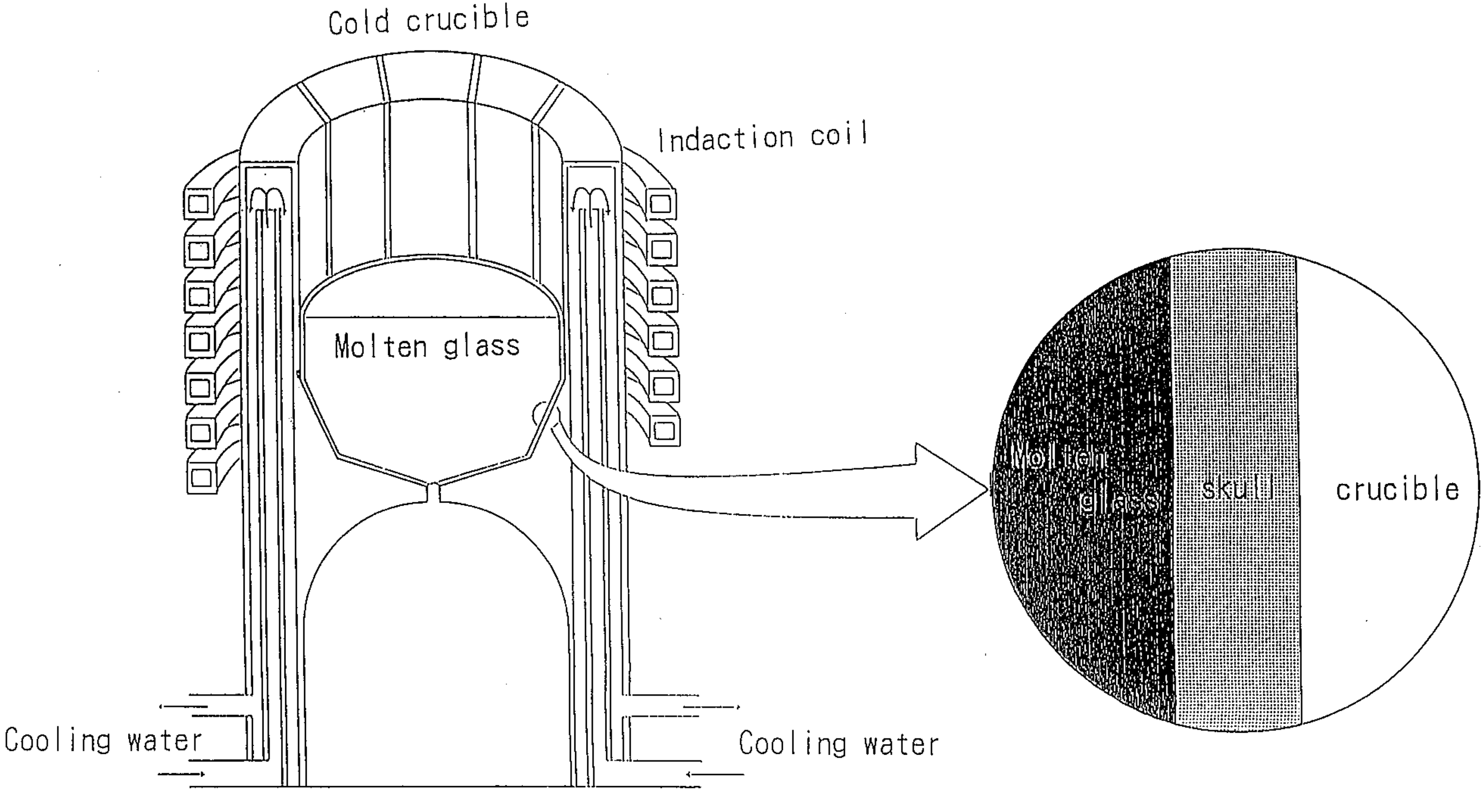
1. JCEM (Joule-heated cylindrical electrode melter)

- Reduction of dismantling waste
  - ← size reduction, longer life
  - limitation of components to be exchanged
- Compatibility with noble metals in higher concentration
  (insoluble sludges, higher burn-up, FBR reprocessing
  higher waste loading)
  - ← Development of structure (electrode arrangement)

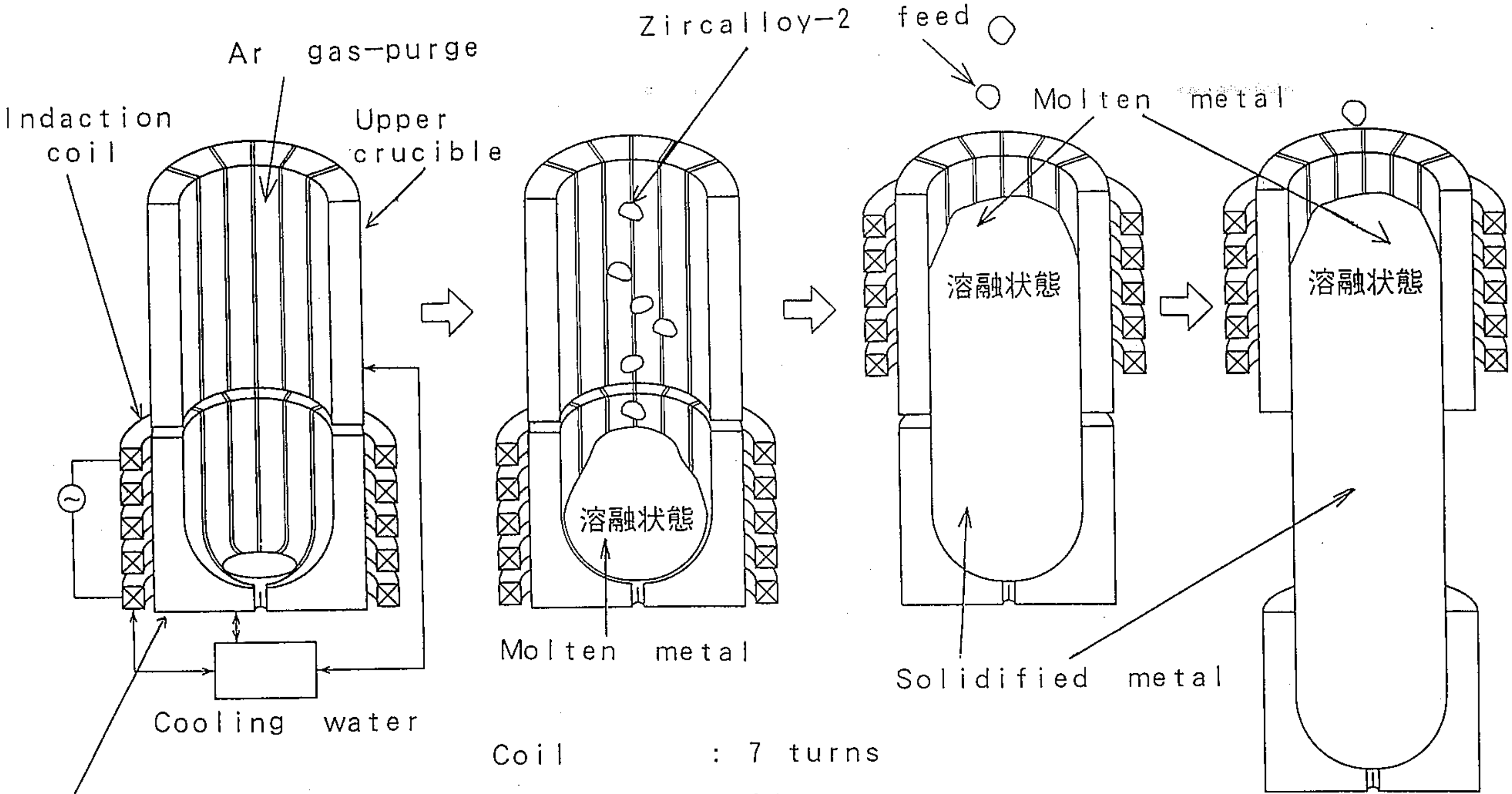
2. Cold Crucible Incuction Melting

- Higher melting temperature/flexibility of glass composition
- Small corrosion of crucible
- Application to metallic waste





Cold crucible skull melting



Coil	:	7 turns
Slit	:	24
Power	:	Max. 110kW
Frequency	:	Average 67kHz

Production of solidified Metallic wastes by crucible induction melting

Operational Results of Small Scale test Melter of JCEM

- Demonstrate technical feasibility of the JCEM concept
- Evaluate the basic operational characteristic
- Higher melting rate than conventional LFCM
- Stable operation for the waste with noble metal metals
  (good drain efficiency 95～112%)

JCEM-E1 Campaign

1) Objective:
Evaluation of basic performance of engineering scale test melter in idling operation

2) Operational condition
- Melting temperature, 900, 1000, 1100°C
- Glass level — L, M, H-level
- Electorode cooling air — 0 ~80 Nm³/h
- plenum pressure — 0 mmAq

3) Results:

- Appropriate flow rate of cooling air of electrodes
  Inner: 40Nm³/h, Outer: 20Nm³/h

JCEM-E1 Campaign (continued)

3) Results (continued)

- Heat balance

(e.g. 1100℃,-level. Iner: 40m^3N/h, Outer ; 20Nm^3/h)

Power	31 kW
Heat loss from surface	66.6 (%)
Cooling air(Inner)	7.5
Cooling air(Outer)	8.4
Off-gas	17.2
Cooling of feed nozzle	1.3

- Cooling of outer electrode promotes natural convection of moten glass.
- Effec of glass level and melting temperature
- Two tests of glass draining, evaluation of operational procedure

JCEM-E 2 Campaign

1)Objectives:

Preliminary evaluation of feeding system and operational characteristics under waste feeding

2)Operational condition:

- Feeding rate—~14ℓ/h (glass production ~8.7kg/h)
- Melting temperature—1150±50℃
- Simulated waste—SW-18 (no noble metals)
- Glass additives—Beads additives (PF798)
- Glass composition— P0798T(TVF glass)

3) Results:

- 103 hr, 1.3 m^3 of waste, 816 kg of glass
- Two glass draing test
- Maximum feeding rate was 14ℓ/h

JCEM-E3 Campaign

Objective: Evaluation of maximum melting rate

Time: Oct.18～Nov.19,1993
interrupted by mulfunction in control system
Processed amount: 6 batches, $3m^3$,1.9 ton
Maximum melting rate: less than 14kg/h
Melting temperature: 1150±50° C
Simulated waste: SW-18.23 (no noble metals)
Glass additives: Beads additives(PF798)
Glass product composition : PO798(TVF glass)

Future work

- Evaluation of maximum melting rate
- Temperature distribution of melting cavity
- Thermal balance
- Evaluation of heat resistance of electrode materials (corrosion, creep, thermal cycle)
- Confirmation of compatibility with noble metal elements
- Entrainments into off-gas
- Feasibility study of application to TVF and other waste treatment field (TRU,LLW)

2.6 High waste loading glass

PNC TN8100 94−003

High waste loading glass

Prepared for
The 12th Annual KfK-PNC Meeting
on
Cooperation in High-Level Waste Management

by SASAGE, K.

December 7-9,1993

Power Reactor and Nuclear Fuel
Development Corporation

PNC

Selection of glass composition

Effect of high Na_2O concentration

Requirements
of
high waste loading glass

Heat : Separation of Cs &Sr

Yellow phase :

Separation of Mo

Operatability :

Separation of noble metals

Objective

Waste loading

Waste 45wt.% and No yellow phase

Leaching rate

Equivalent to 25wt.% waste glass

Producibility

Possible to melt and drain by LFCM

Plan

Increase MoO_3 solubility

Increase Cr_2O_3 solubility

Increase chemical durability

Sample compositions

Glass code		P1029	P1030	P1031	P1032	P1033	P1034	P1035
Glass frit	SiO_2	32.27	31.27	30.27	30.27	30.27	30.27	30.27
	B_2O_3	11.45	12.45	12.45	12.45	12.95	12.45	12.45
	Li_2O	2.2	2.2	2.2	1.2	0.2	1.2	0.2
	CaO	2.2	2.2	2.2	2.2	2.2	3.2	4.2
	ZnO	2.2	2.2	2.2	3.2	4.2	2.2	2.2
	Al_2O_3	4.69	4.69	5.69	5.69	5.19	5.69	5.19
Waste	MoO_3	1.62	1.62	1.62	1.62	1.62	1.62	1.62
	Na_2O	11.75	11.75	11.75	11.75	11.75	11.75	11.75
Total Waste		45.01	45.01	45.01	45.01	45.01	45.01	45.01

Result

Melting temperature : 1100℃

MoO_3 concentration : 1.62wt.%

Glass code	P1029	P1030	P1031	P1032	P1033	P1034	P1035
Yellow phase	Nothing (Good)	Nothing (Good)	Nothing (Good)	Nothing (Good)	Nothing (Good)	Nothing (Good)	Nothing (Good)
Leaching rate ($\times 10^{-4}$ kg/m^2d)	3.5	4.2	3.1	2.8	2.5	2.9	2.5

Result

Melting temperature : 1100℃

MoO_3 concentration : 2.50wt.%

Glass code	P1029	P1030	P1031	P1032	P1033	P1034	P1035
Yellow phase	Nothing (Good)	Nothing (Good)	Nothing (Good)	Nothing (Good)	Nothing (Good)	Nothing (Good)	Nothing (Good)

Result

Melting temperature : 1050 ℃

MoO_3 concentration : 2.50wt.%

Glass code	P1029	P1030	P1031	P1032	P1033	P1034	P1035
Yellow phase	Nothing (Good)	Nothing (Good)	Separated	Separated	Nothing (Good)	Separated	Separated

Objective

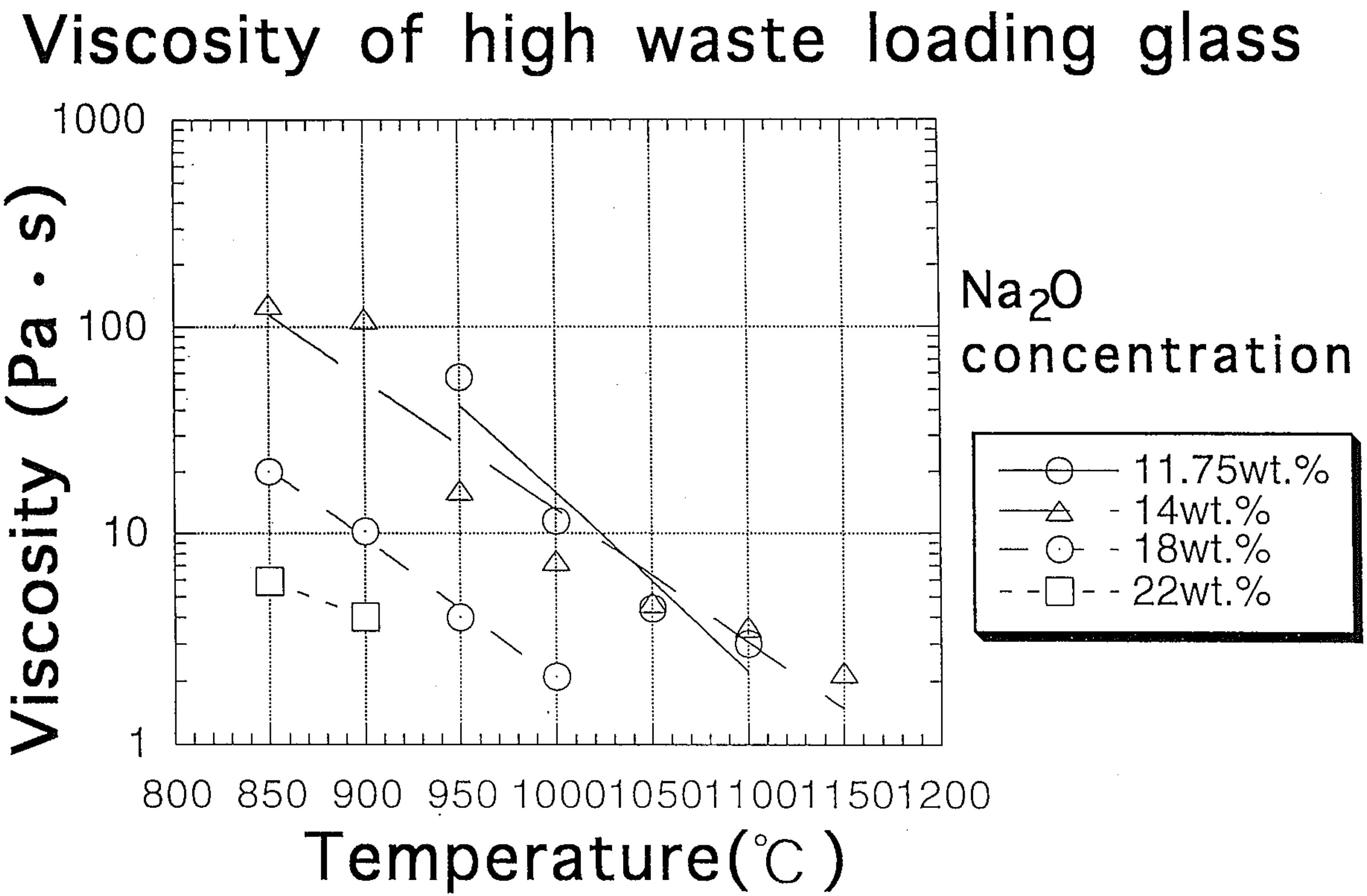
Characterization of
high waste loading glass

Evaluation items

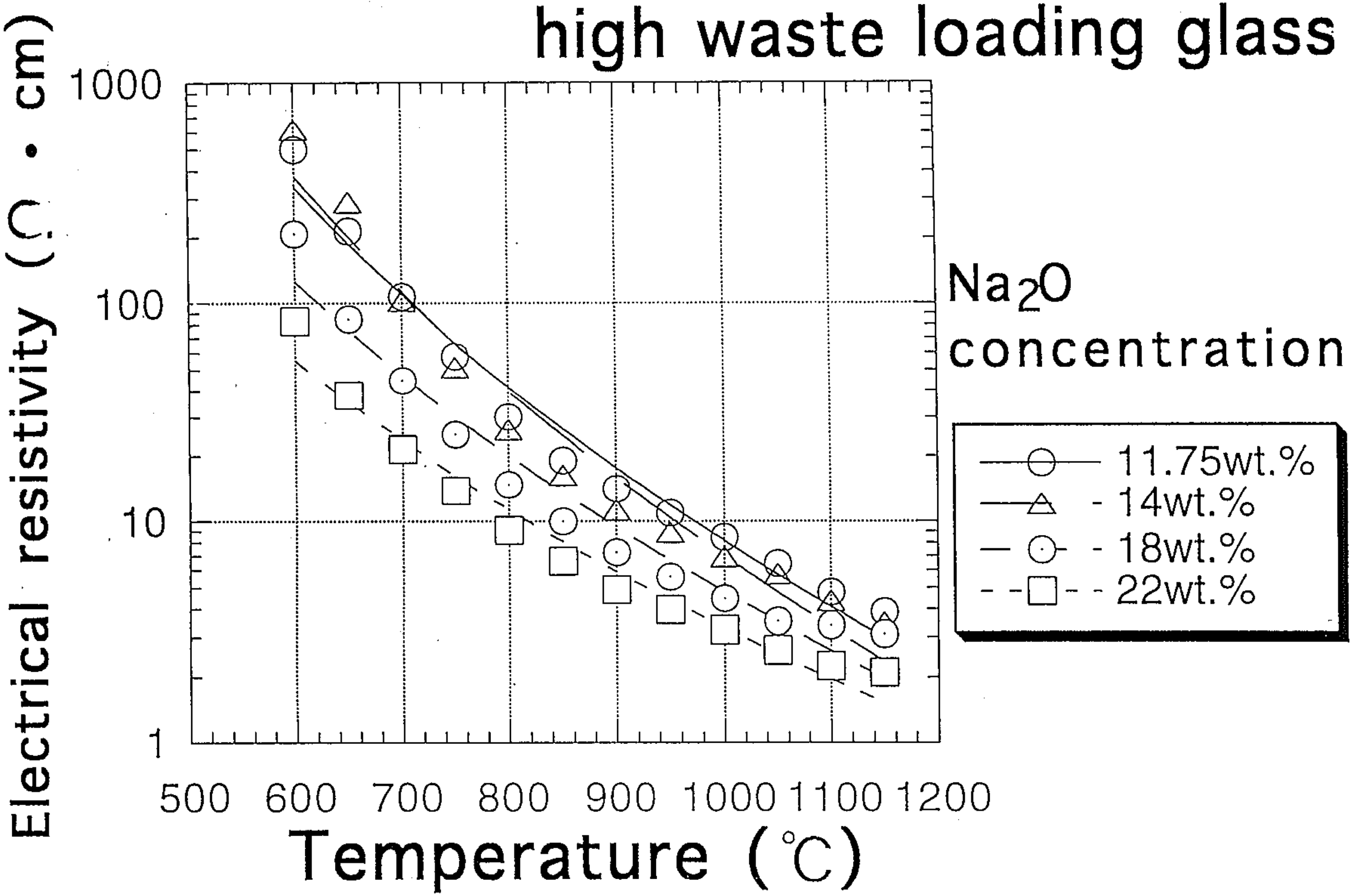
Producibility
(Viscosity and Resistivity)

Chemical durability

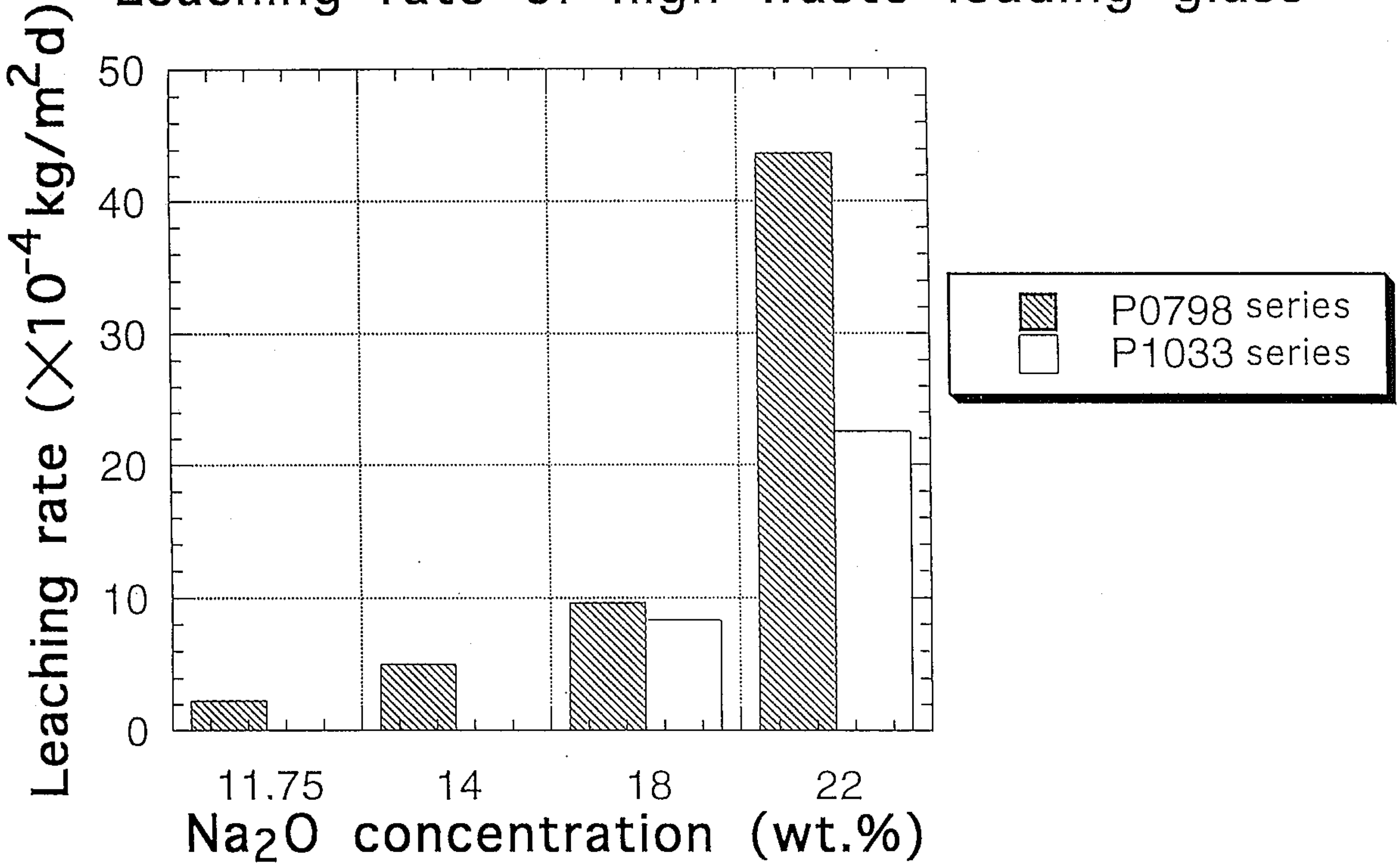
Yellow phase


Viscosity of high waste loading glass
Viscosity (Pa・s)
1000
100
10
1
800 850 900 950 1000 1050 1100 1150 1200
Temperature(℃)
Na2O concentration
11.75wt.%
14wt.%
18wt.%
22wt.%

Electrical resistivity of high waste loading glass



Leaching rate of high waste loading glass



Solubility of MoO_3

Glass code		P0798 series	P0798 series	P1033 series
Na_2O concentration (wt.%)		18	22	22
MoO_3 concentration (wt.%)	0.6	Nothing	Nothing	Nothing
	0.8	Nothing	Y	Nothing
	1.0	Y	Y	Nothing
	1.2	Y	Y	Y

Summary

We made new glass composition with
high MoO_3 solubility & high chemical durability.

If waste glass contain much Na_2O,
its MoO_3 solubility & chemical durability decreace.

New glass composition showed high MoO_3
solubility & high chemical durability.

2.7 Separation of heat-generating elements from high-level liquid waste by denitration

PNC TN8100 94－003

Separation of Heat-Generating Elements from High-Level Liquid Waste by Denitration

Prepared for
The 12th Annual KfK-PNC Meeting
on
Cooperation in High-Level Waste Management

by YONEZAWA, S.

December 7-9,1993

Power Reactor and Nuclear Fuel
Development Corporation

PNC

Heat-Generating Elements : Cs , Sr

Reason of choice

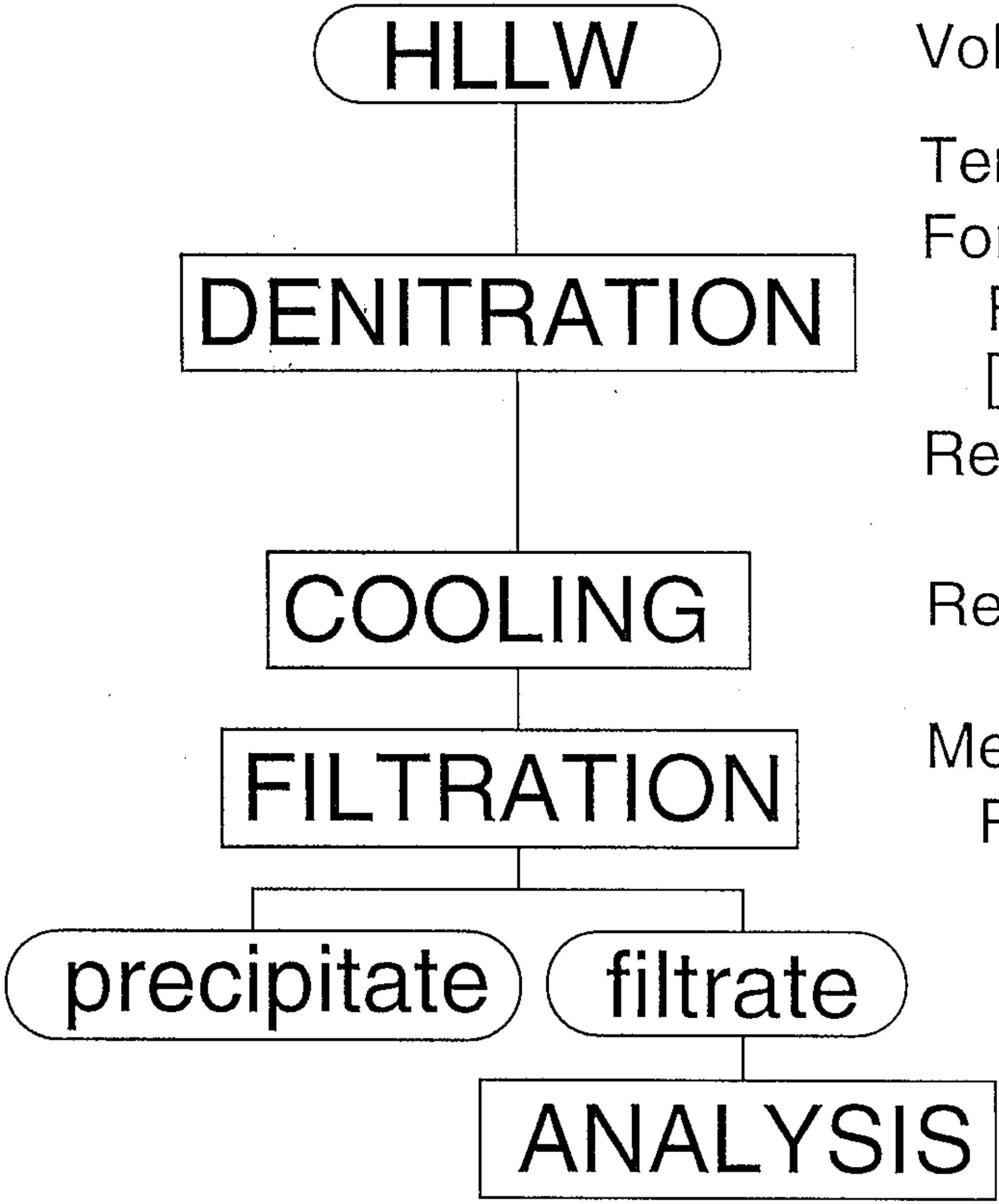
1 : No Secondary Products

2 : Based on Experience

Purpose

Behavior of Elements in HLLW

Best Condition for Separation

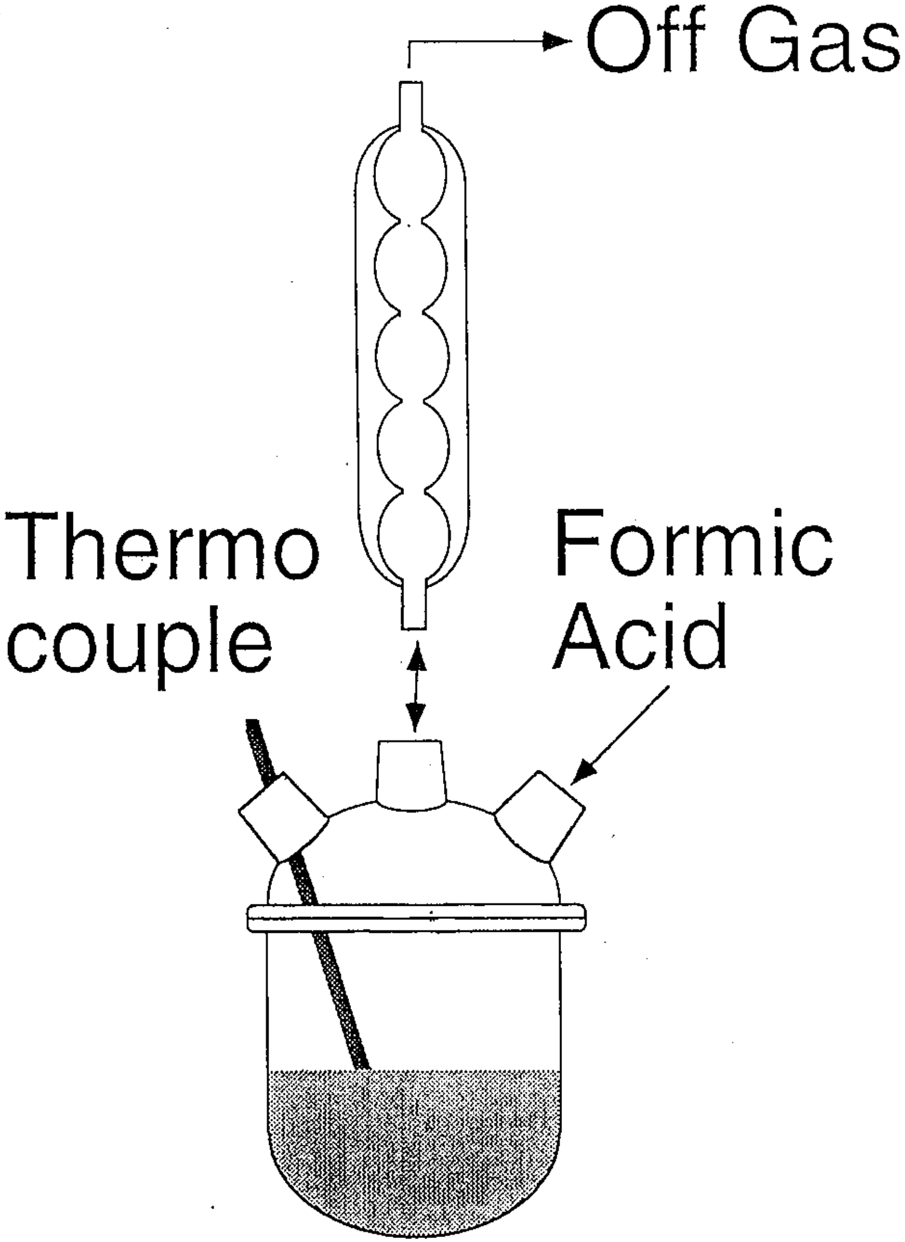


Volume : 100 mℓ

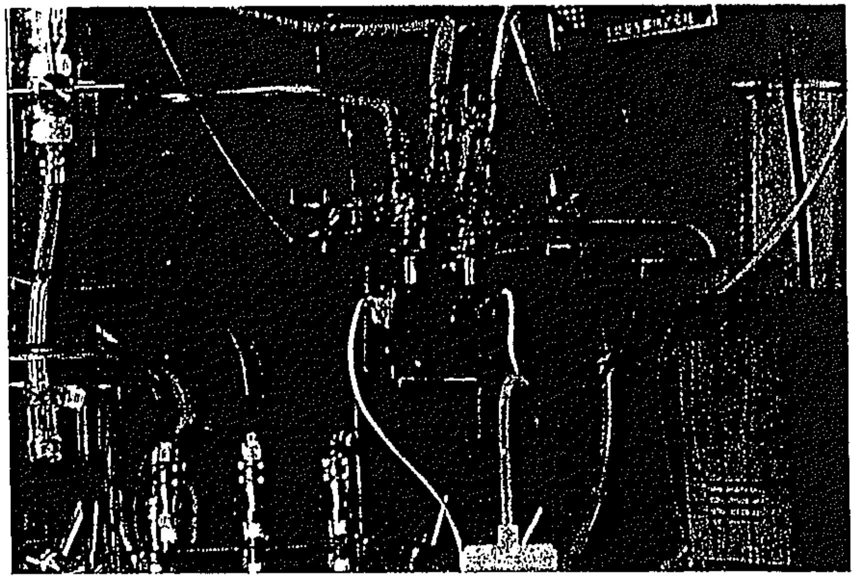
Temp. : 95℃
Formic Acid
Feed Rate : 0.4 mℓ/min
[HCOOH] / $[HNO_3]$ = 1.9～2.1
Retention Time : 6 hr

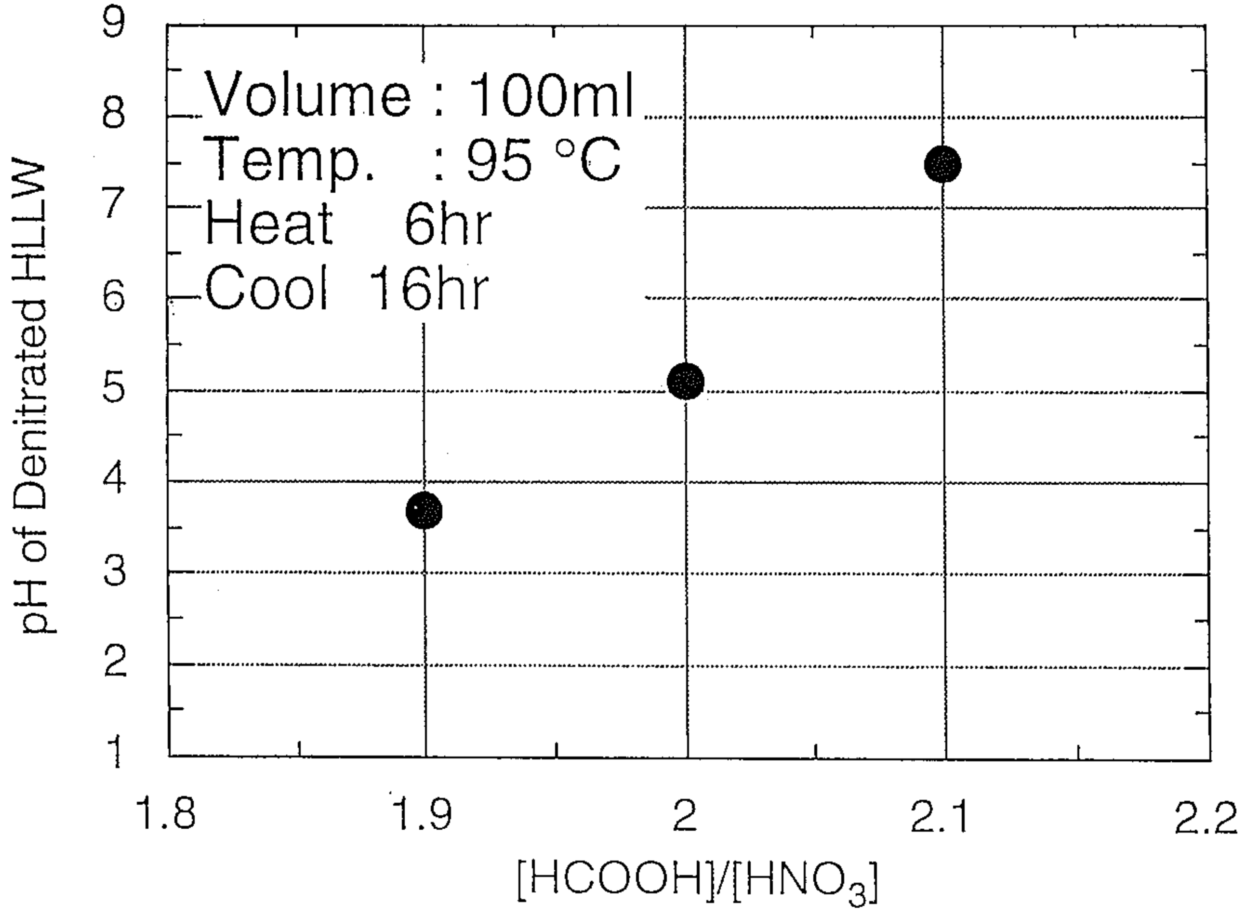
Retention Time : 16 hr

Membrane Filter
Pore Size : 0.45 μm



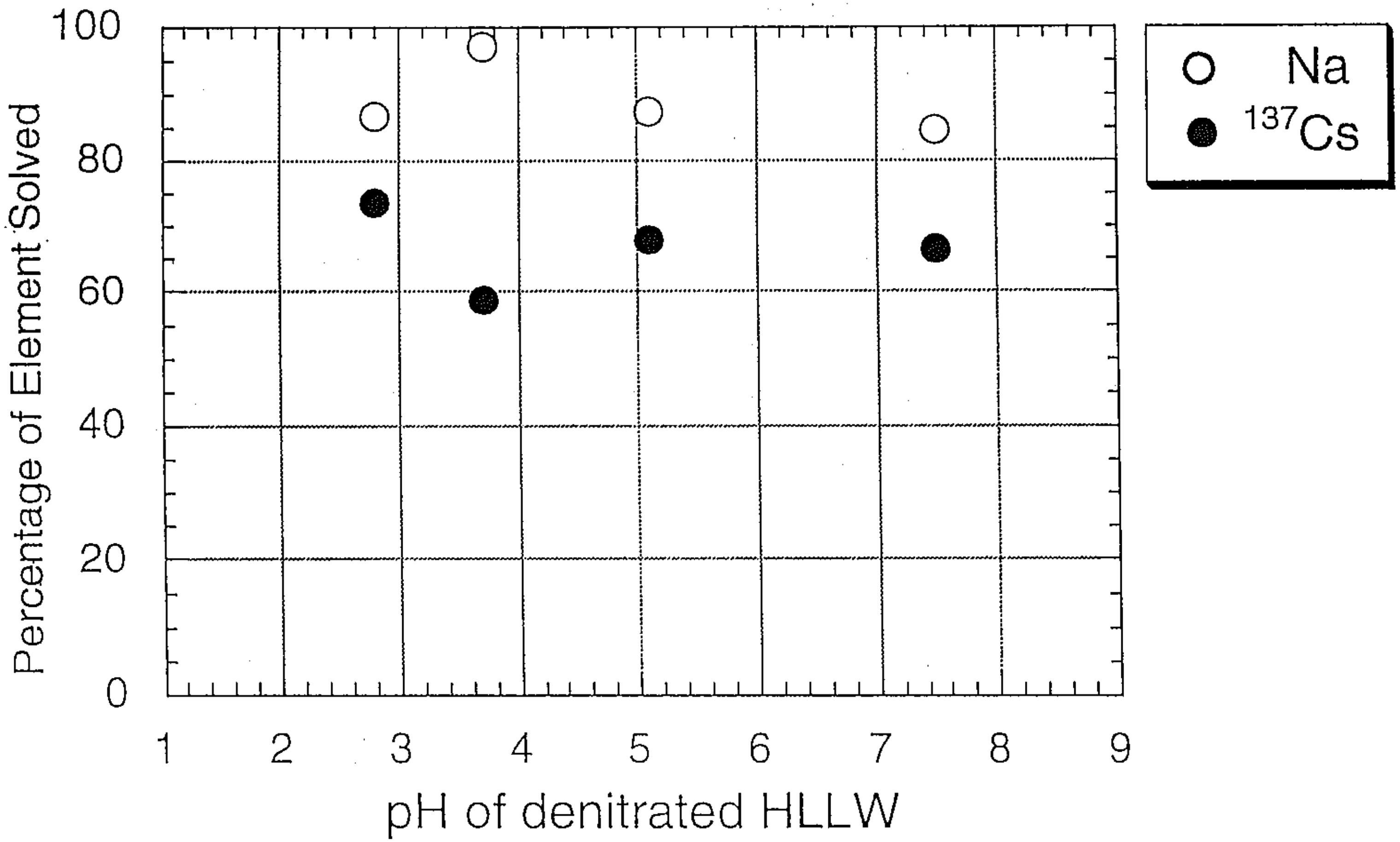
Photo



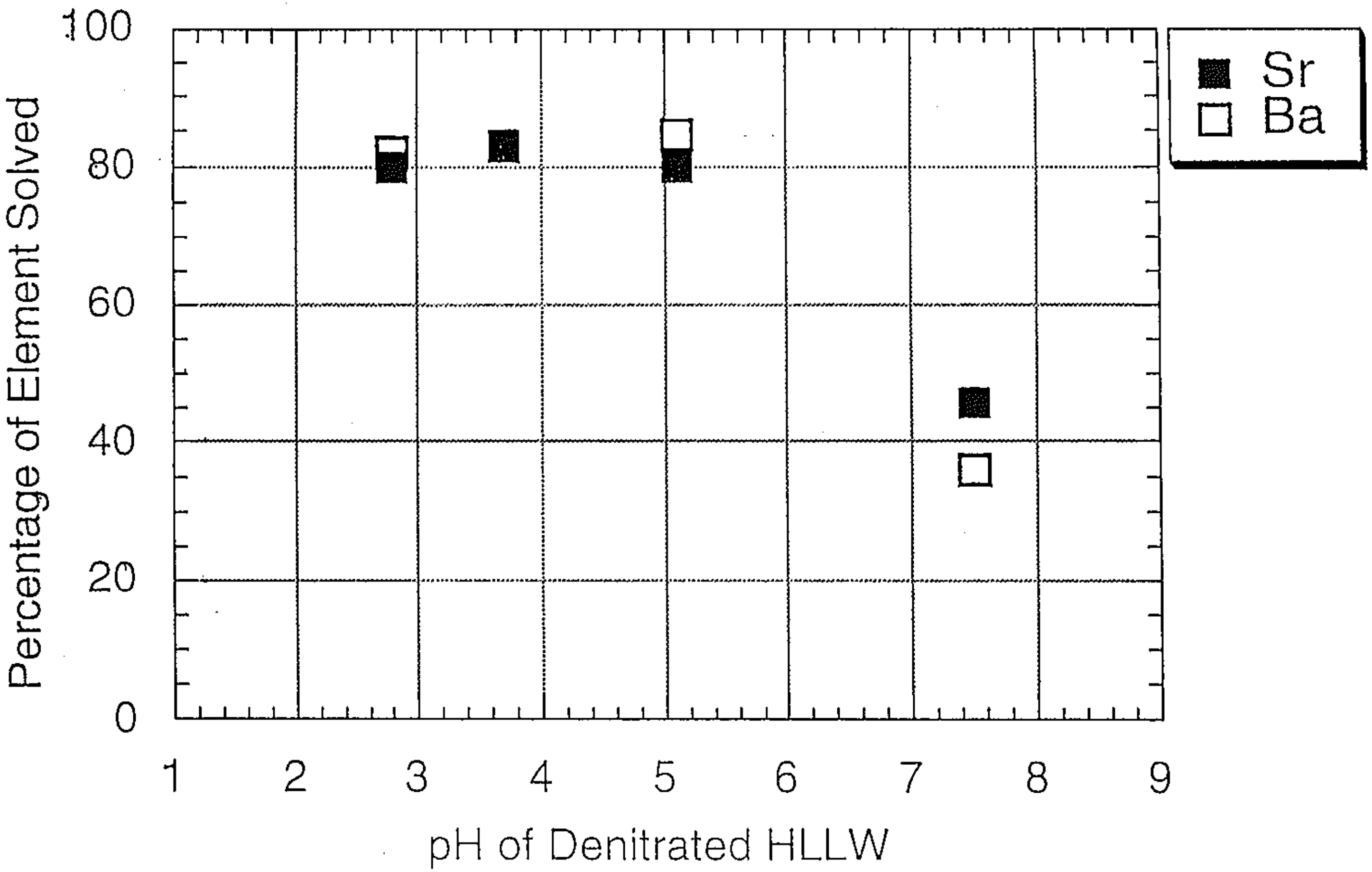


Relationship between $[HCOOH]/[HNO_3]$ and pH of Denitrated HLLW

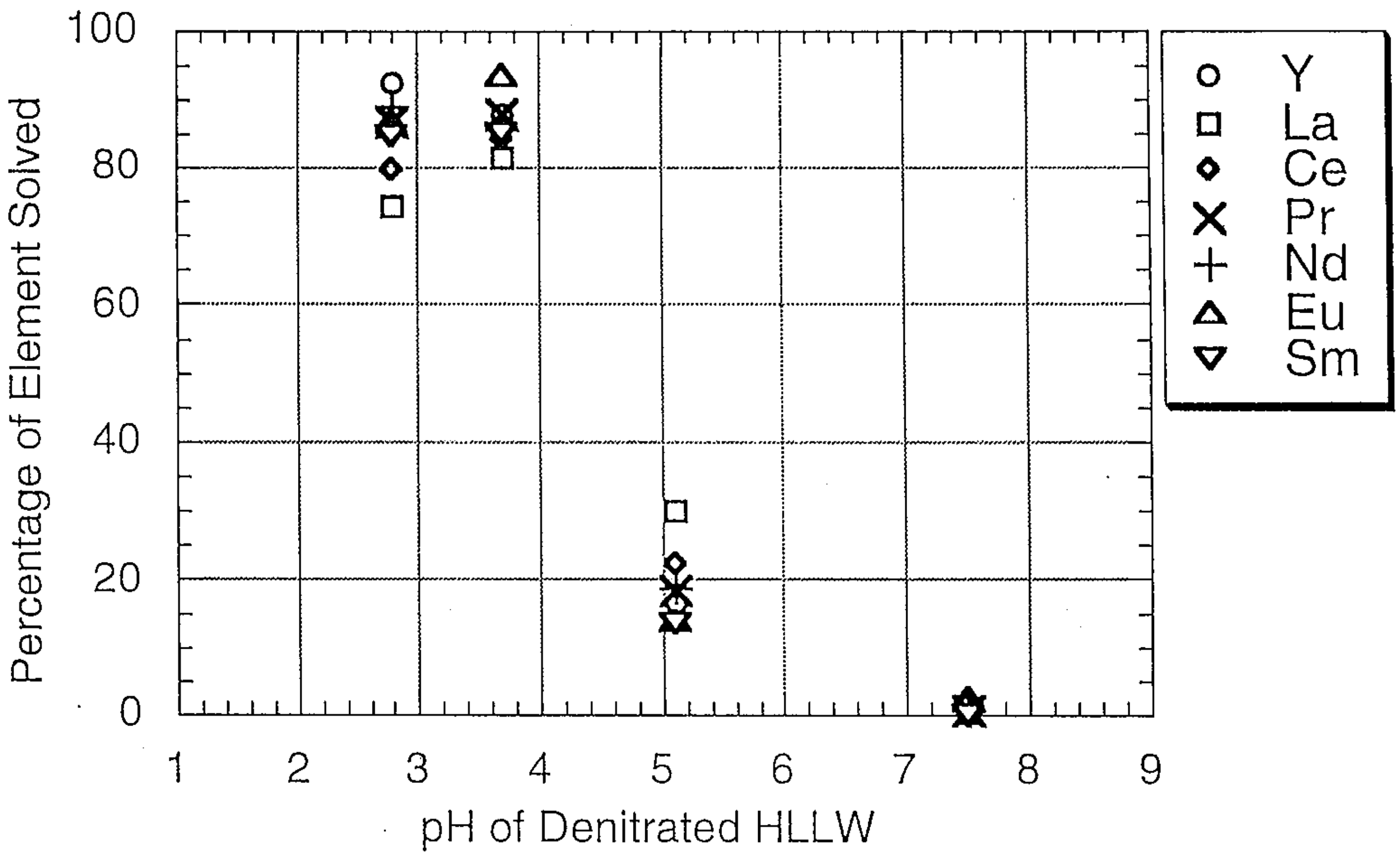
$$\text{Percentage of Element Solved} = \frac{\text{Concentration in Denitrated-HLLW}}{\text{Concentration in HLLW}} \times 100$$



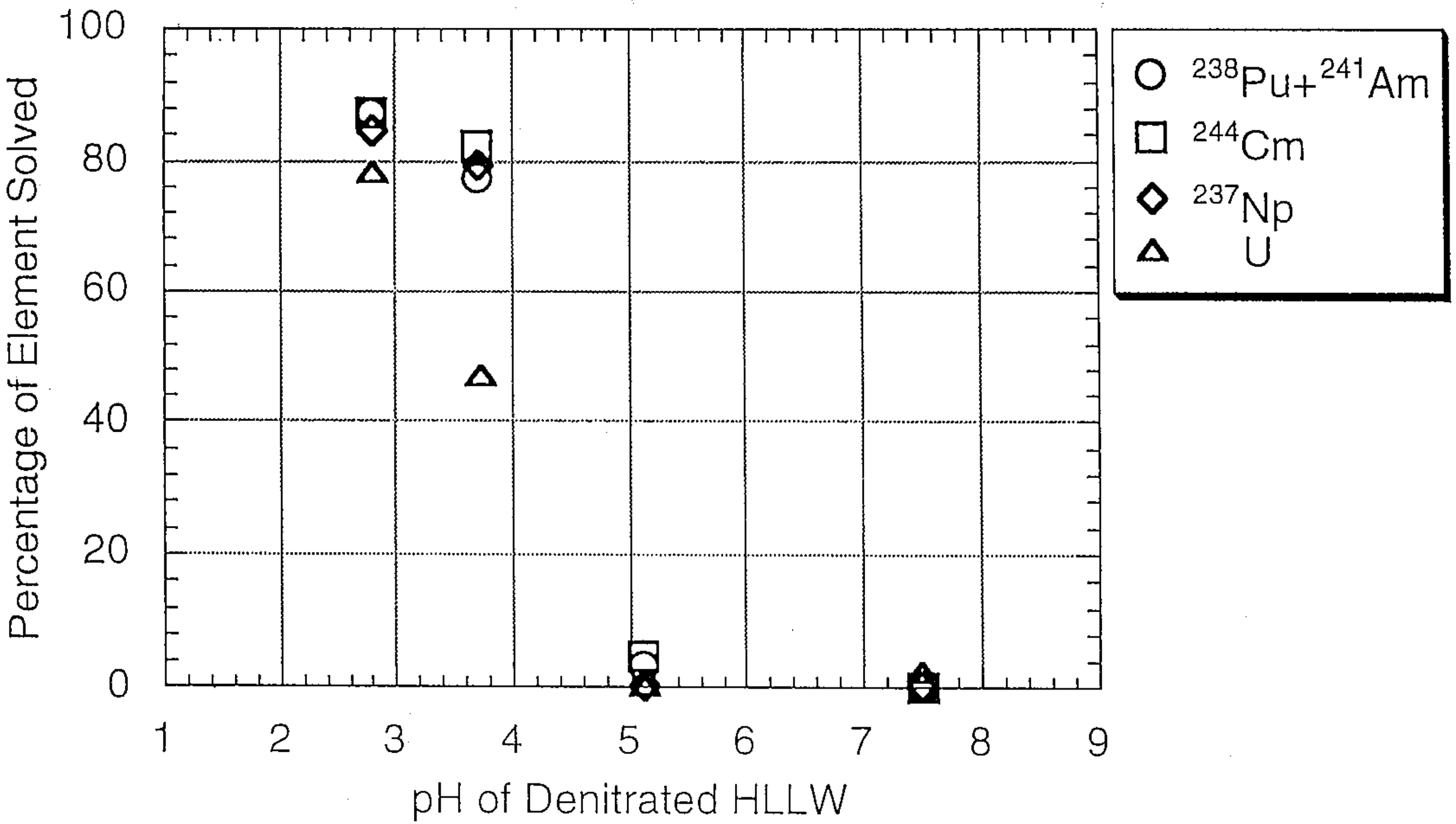
Relationship between pH of Denitrated HLLW and Percentage of Element Solved (Alkaline Metal Elements)



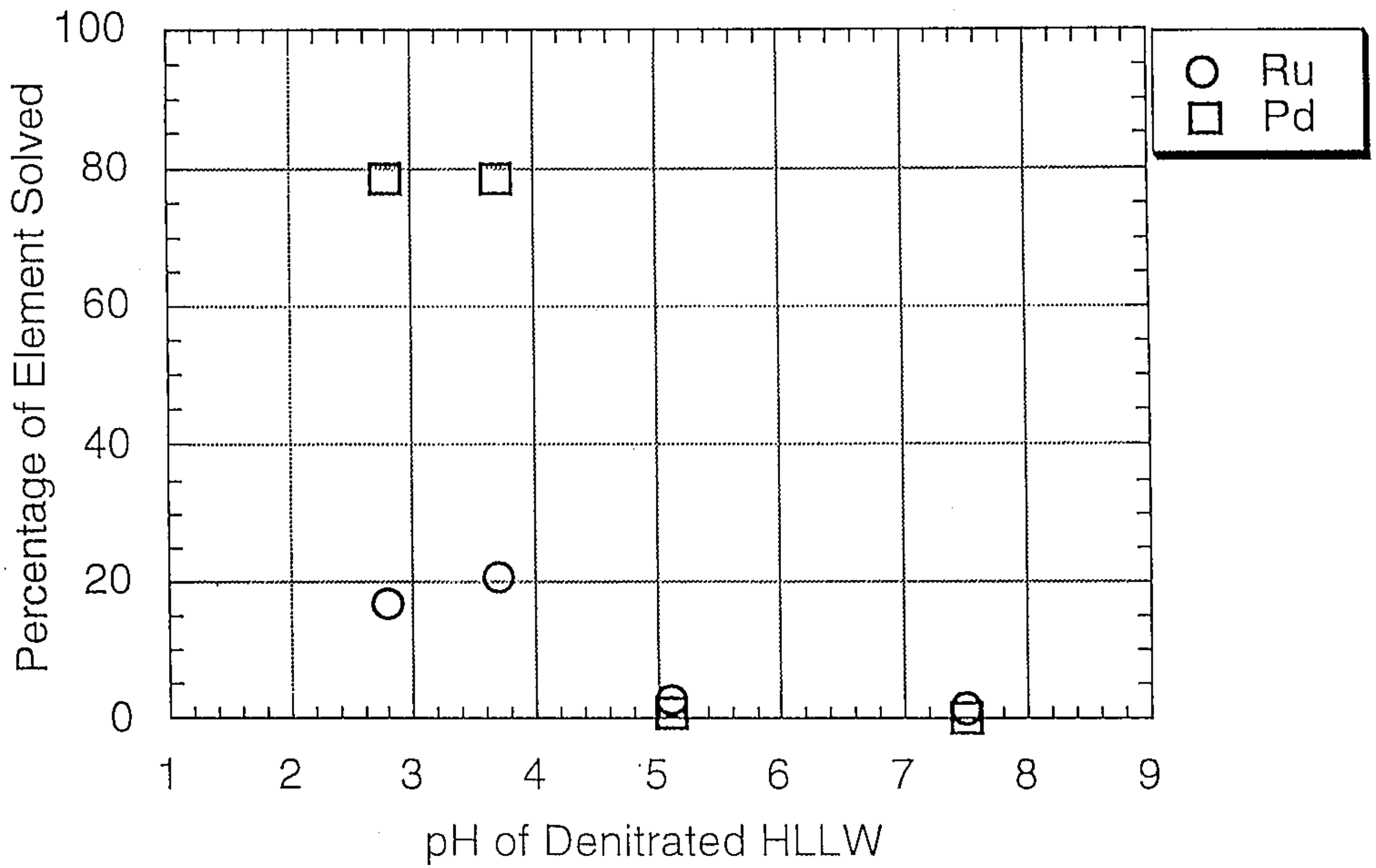
Relationship between pH of Denitrated HLLW and
Percentage of Element Solved
(Alkaline Earth Metal Elements)



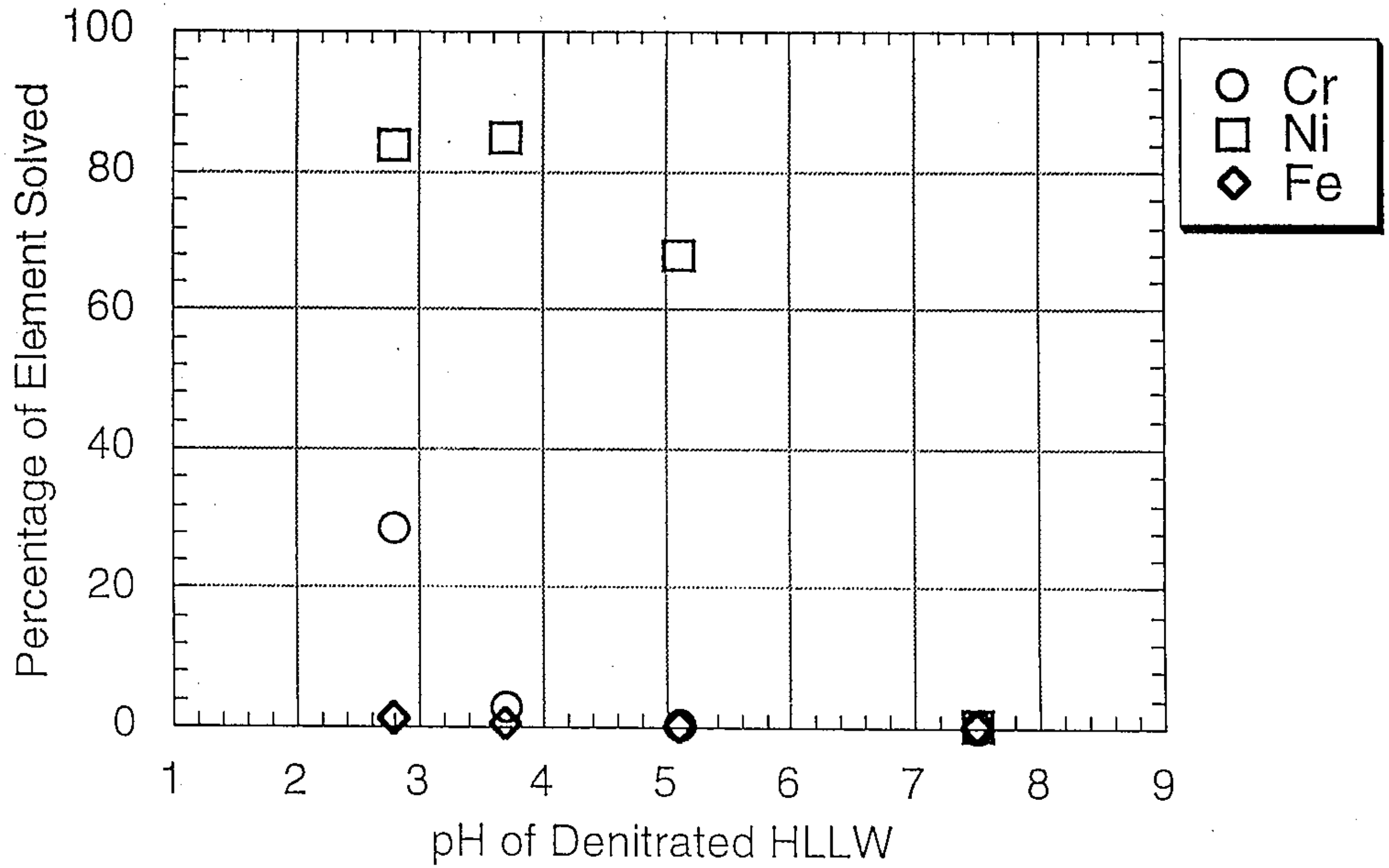
Relationship between pH of Denitrated HLLW and
Percentage of Element Solved
(Rare Earth Elements)



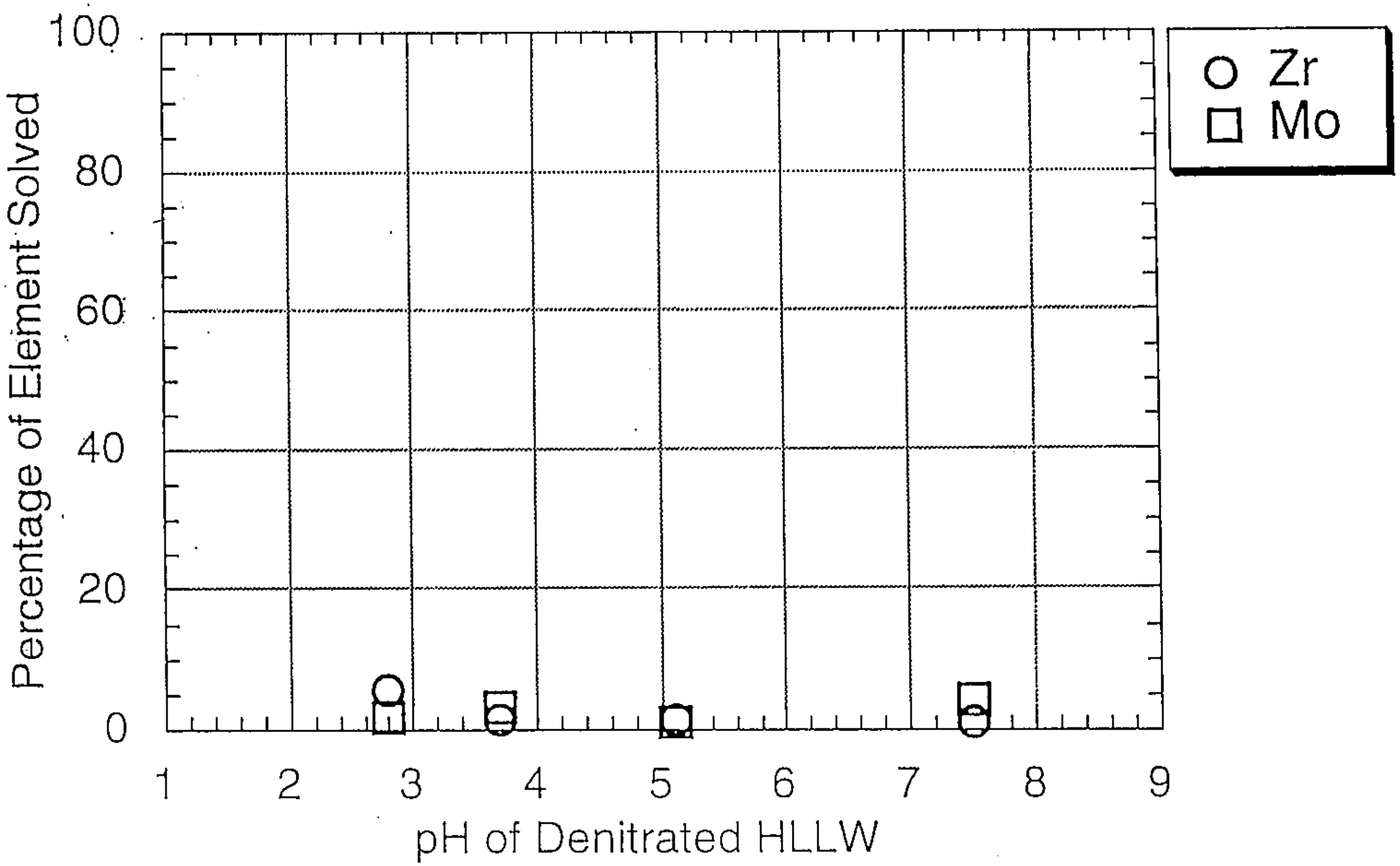
Relationship between pH of Denitrated HLLW and Percentage of Element Solved (TRU Elements)



Relationship between pH of Denitrated HLLW and Percentage of Element Solved (Noble Metal Elements)

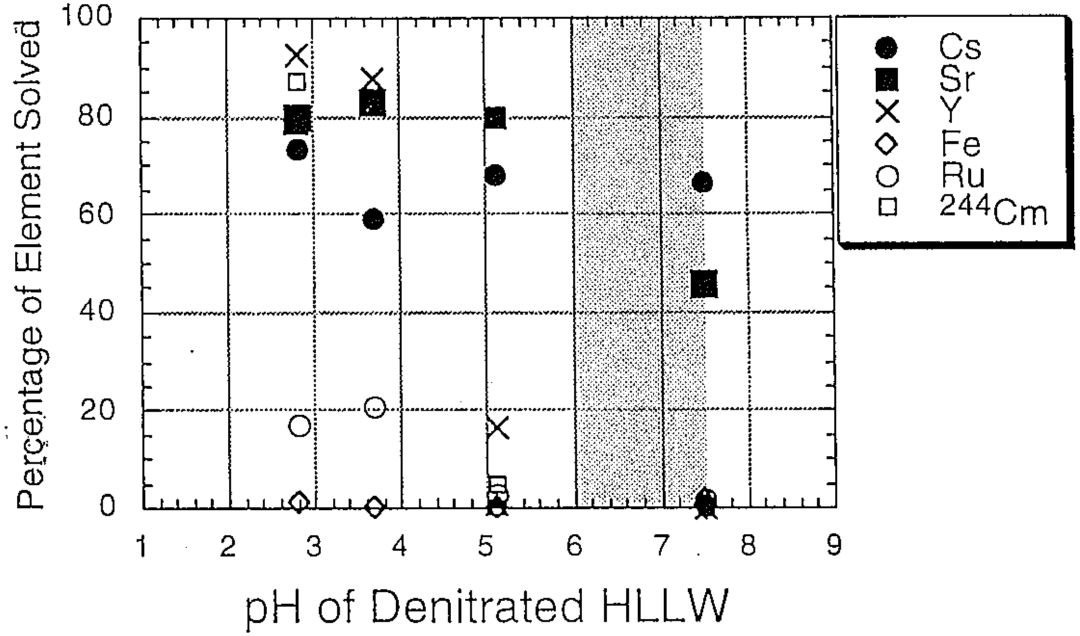


Relationship between pH of Denitrated HLLW and
Percentage of Element Solved
(Corrosion Products)



Relationship between pH of Denitrated HLLW and Percentage of Element Solved (Zr,Mo)

Conclusion



Heat-Generating elements are separated by denitoration of HLLW

The best pH range = 6 ～ 7.5

$[HCOOH] / [HNO_3] = 2.0$

2.8 Characterization of TVF glass

PNC TN8100 94-003

Characterization of TVF glass

Prepared for
The 12th Annual KfK-PNC Meeting
on
Cooperation in High-Level Waste Management

by KAWAMURA, K.

December 7-9,1993

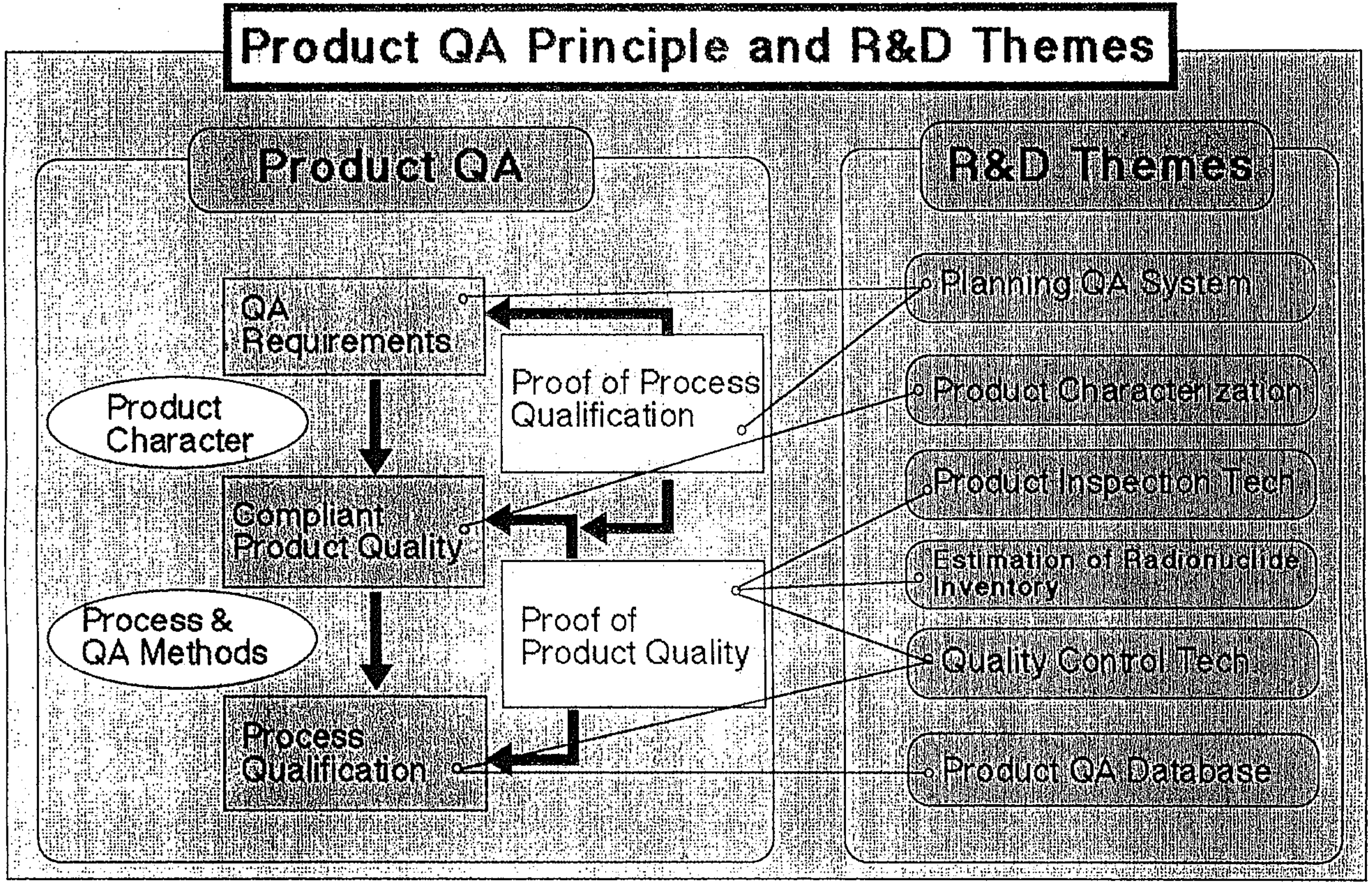
Power Reactor and Nuclear Fuel
Development Corporation

PNC

CONTENTS

PRODUCT QUALITY ASSURANCE

- QA Principle and R&D themes
- QA Requirements & methods
- Estimation of radionuclide inventory


Product QA Principle and R&D Themes
Product QA
QA Requirements
Product Character
Compliant Product Quality
Process & QA Methods
Process Qualification
Proof of Process Qualification
Proof of Product Quality
R&D Themes
Planning QA System
Product Characterization
Product Inspection Tech
Estimation of Radionuclide Inventory
Quality Control Tech
Product QA Database

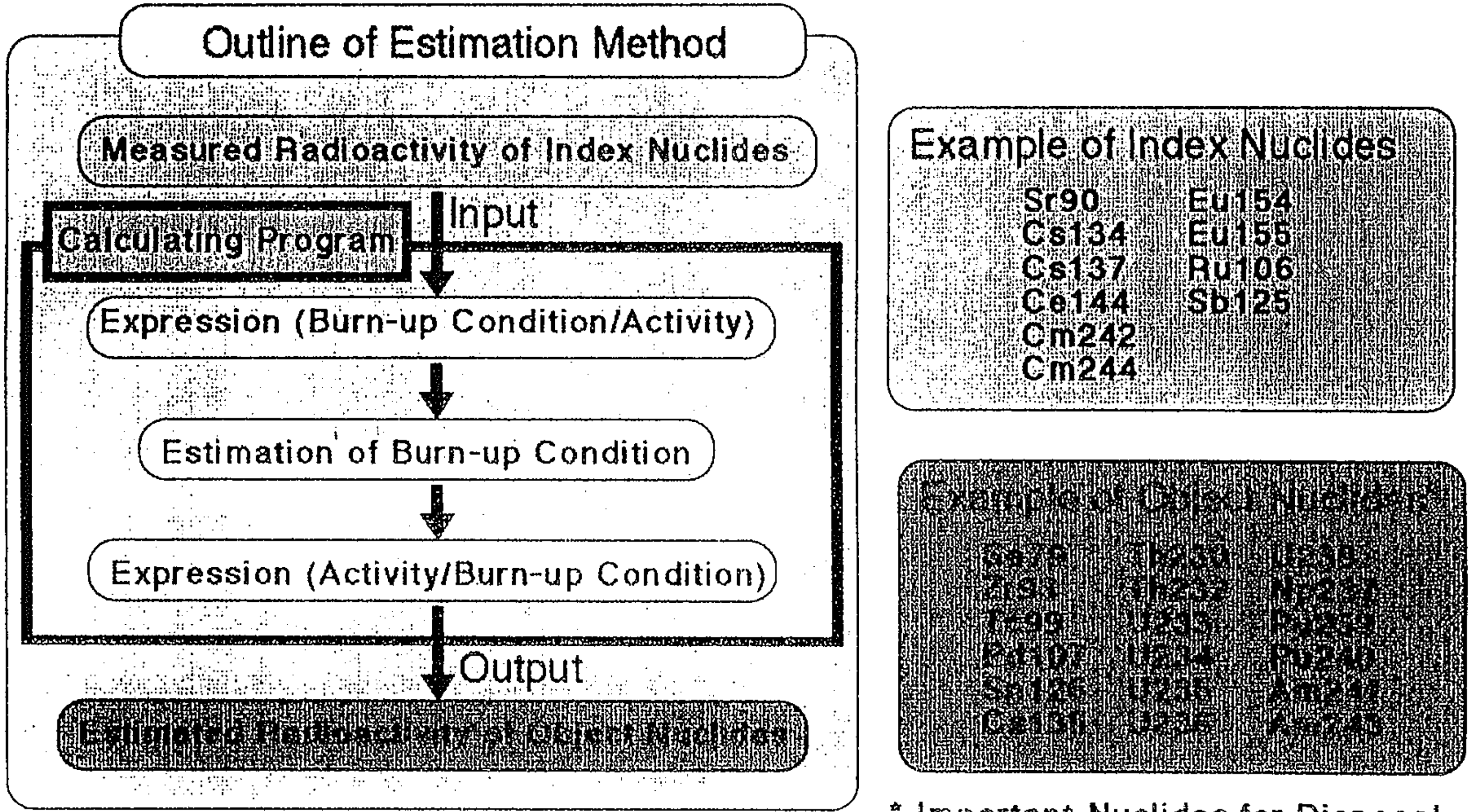
IAEA-TECDOC-680

Quality assurance requirements and methods for high level waste package acceptability

INTERNATIONAL ATOMIC ENERGY AGENCY IAEA

December 1992

Estimation of Radionuclide Inventory



* Important Nuclides for Disposal (PNC '92 Report)

CHARACTERIZATION OF TVF GLASS

- Homogeneity

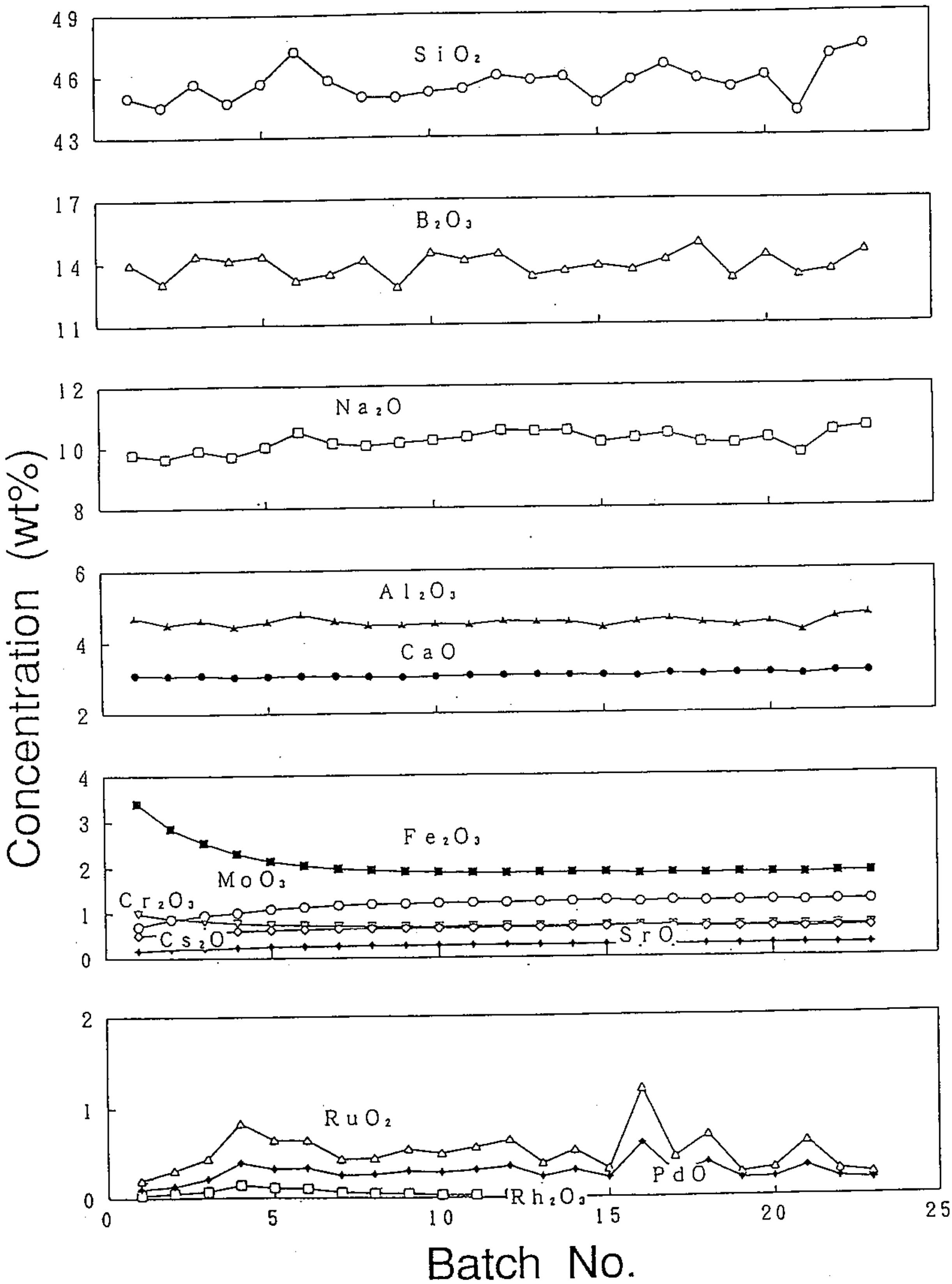
  Composition etc. (XRF, XRD, EPMA)

- Character

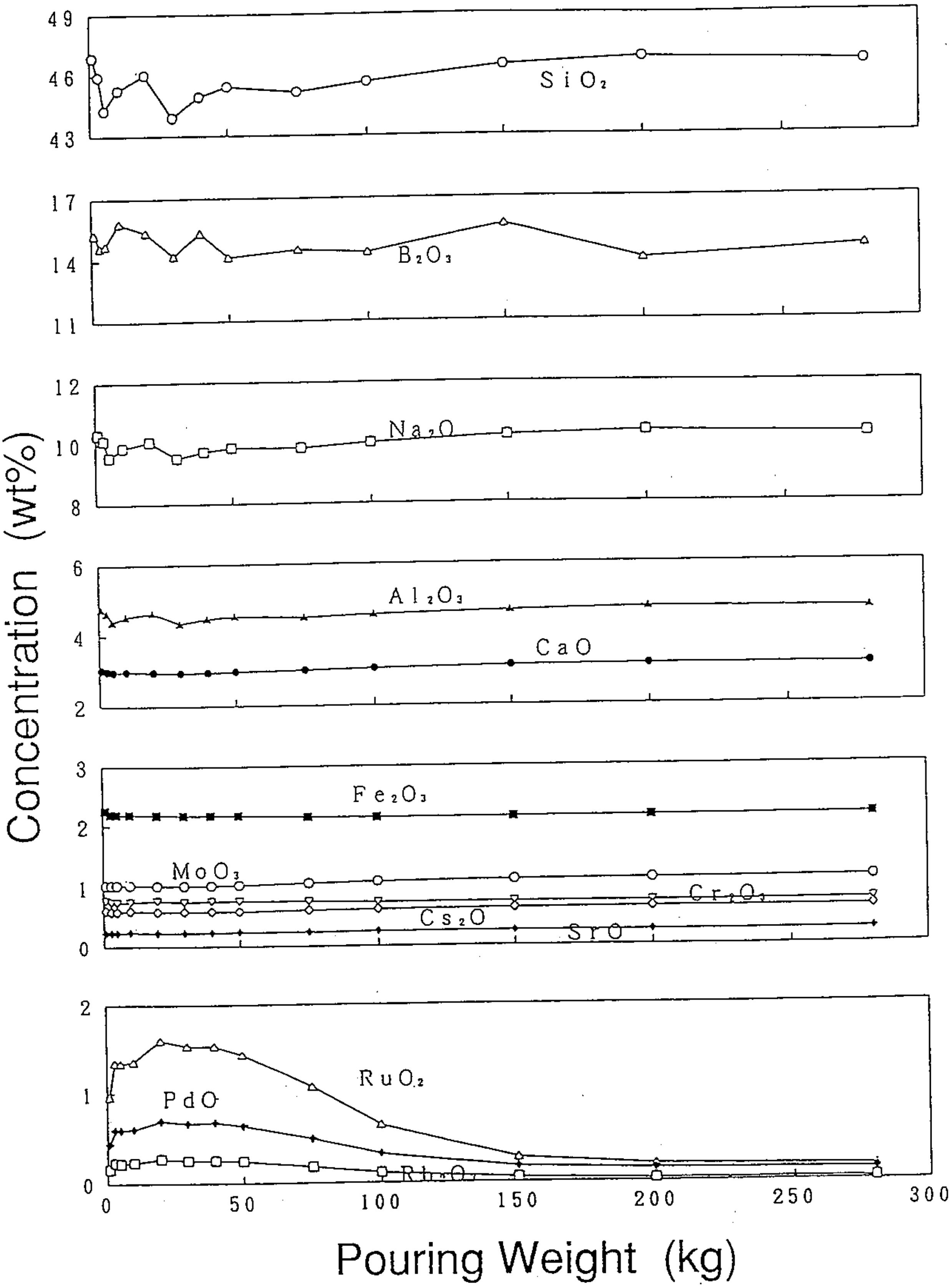
  Viscosity, E. Resistivity, Density, T. Expansion, T. Conductivity, Tg, Ts, Leaching Rate

Target Composition of TVF Glass (2nd Campaign)

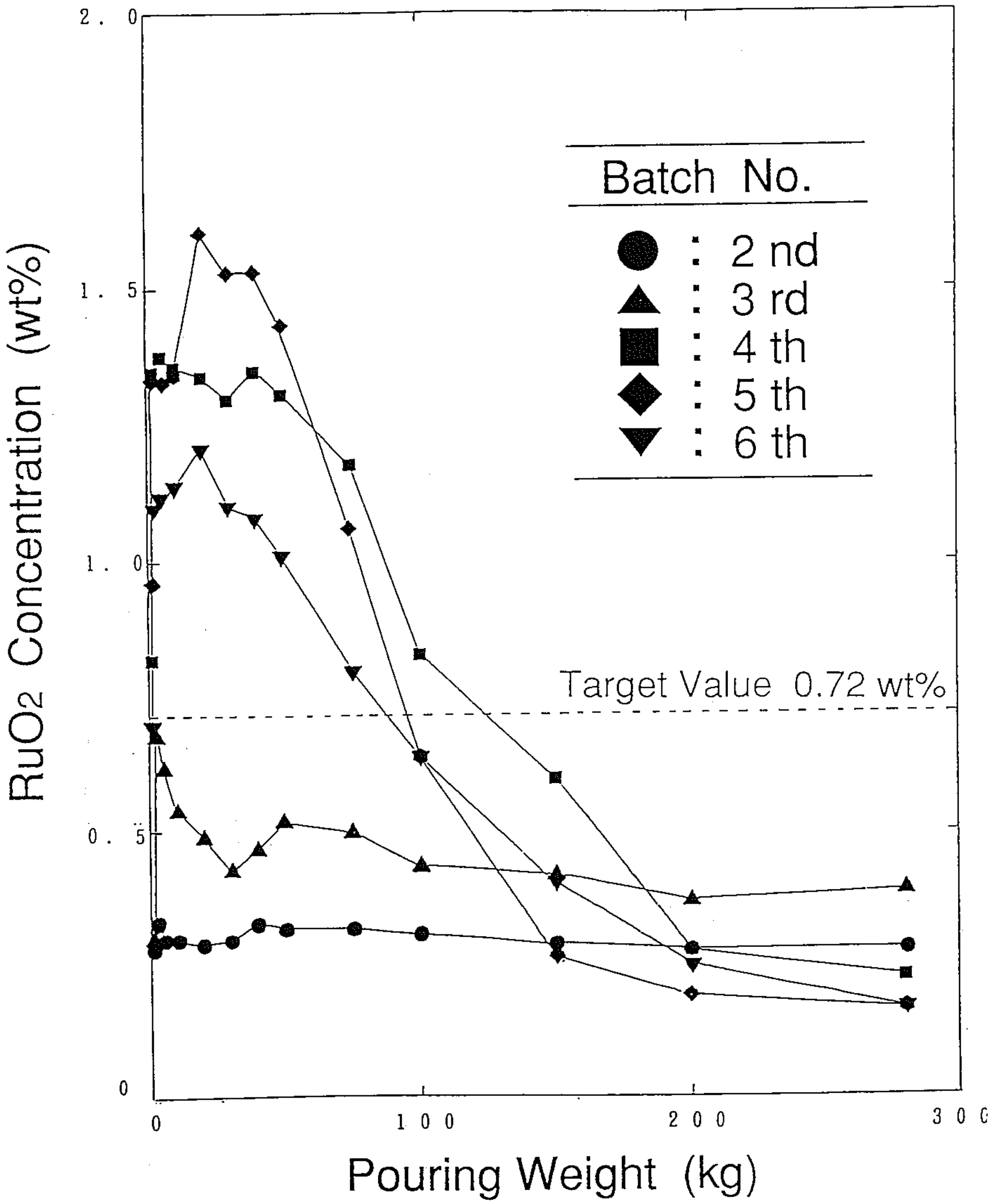
Component	wt%	Component	wt%
SiO_2	46.73	ZrO_2	1.41
B_2O_3	14.25	MoO_3	1.41
Li_2O	3.00	MnO_2	0.37
CaO	3.00	RuO_2	0.72
ZnO	3.00	Rh_2O_3	0.16
Al_2O_3	5.03	PdO	0.34
		Ag_2O	0.01
Na_2O	9.69	CdO	0.02
P_2O_5	0.29	SnO_2	0.02
Fe_2O_3	1.92	SeO_2	0.01
Cr_2O_3	0.51	TeO_2	0.15
NiO	0.45	R.E.	5.84
Rb_2O	0.11		
Cs_2O	0.75	Total	100.01
SrO	0.30		
BaO	0.52		



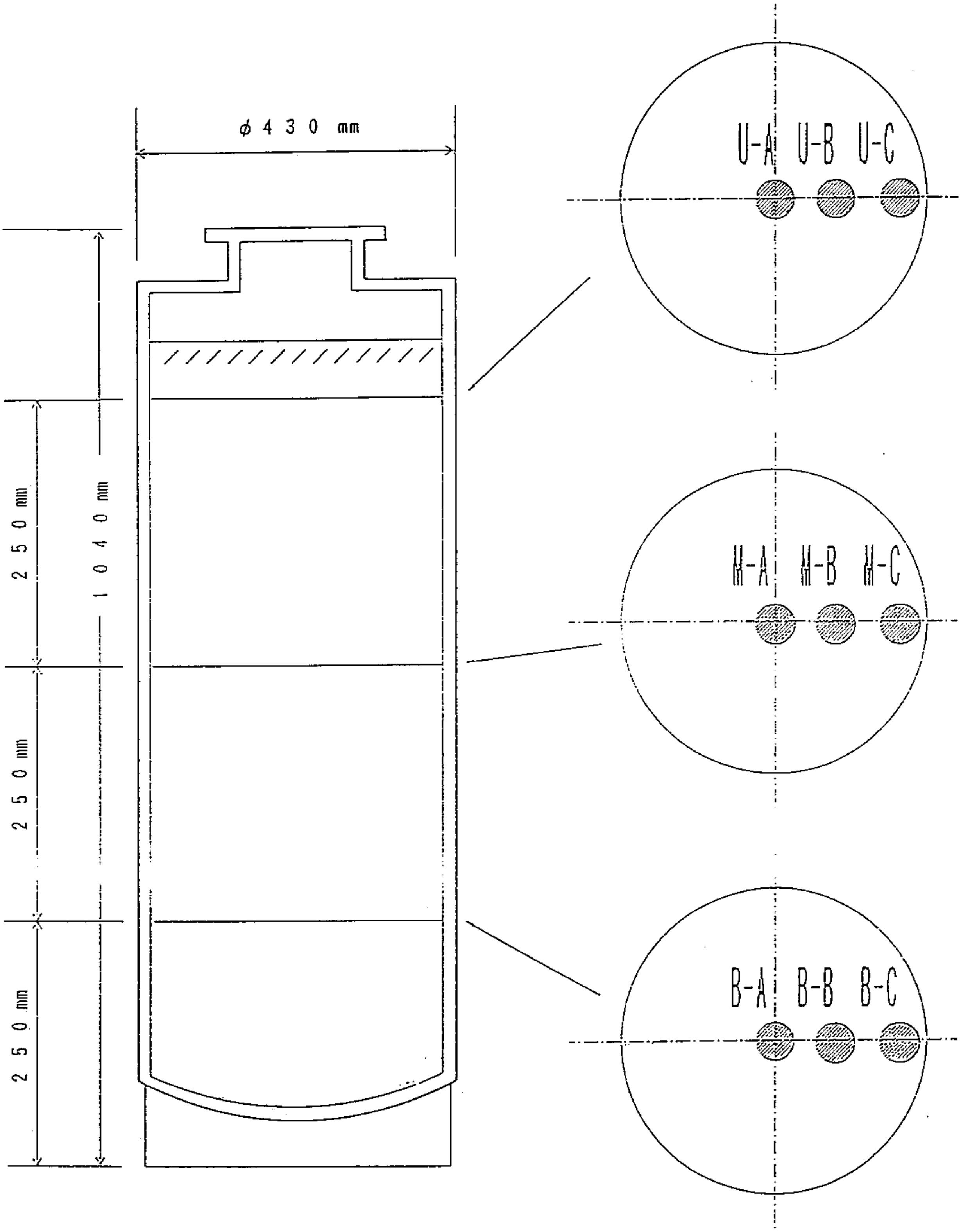
Composition of 100kg-Pouring Glass (TVF 2nd Campaign, XRF).



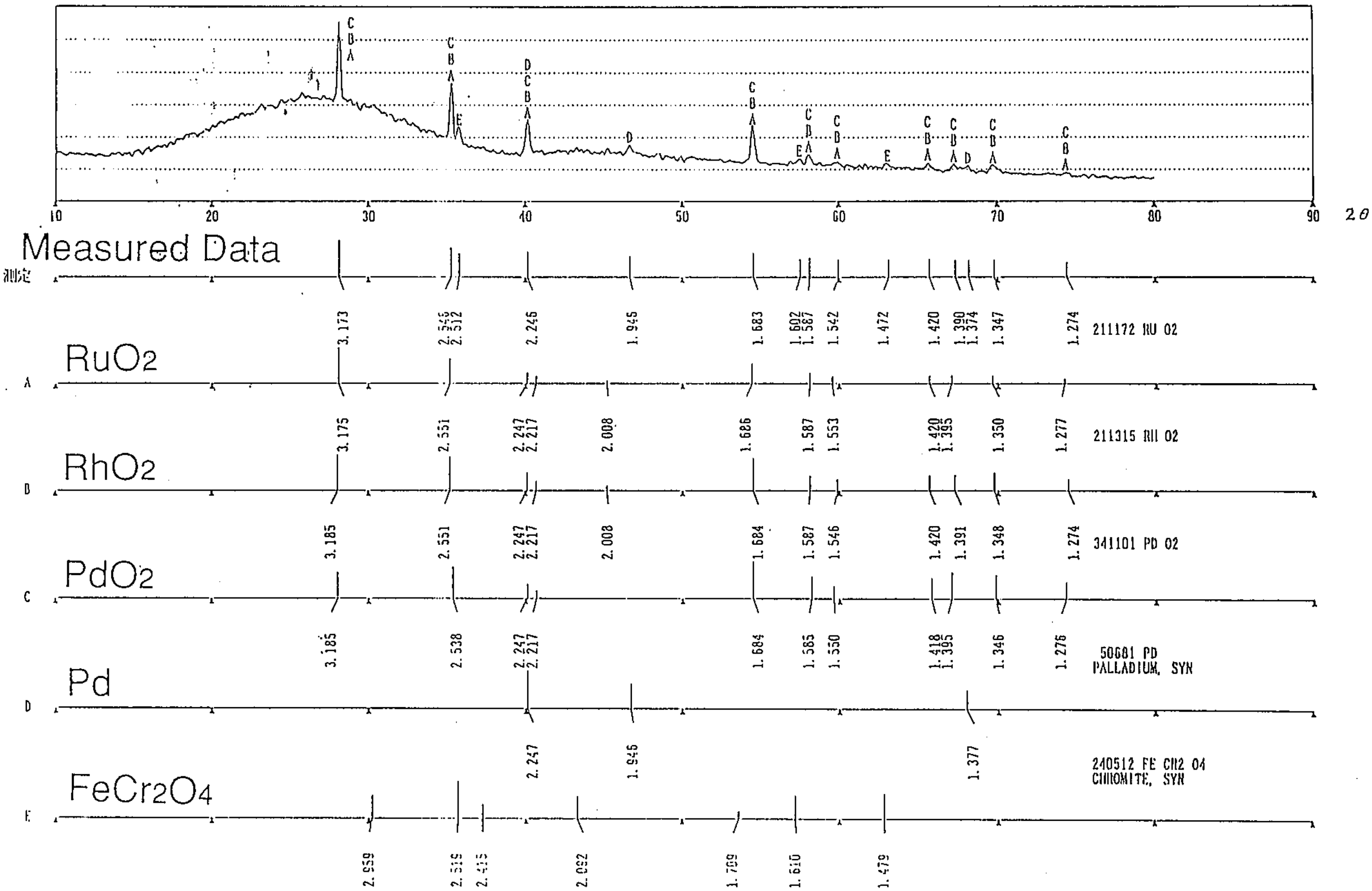
Composition of Pouring Glass (TVF 2nd Campaign, 5th Batch, XRF).



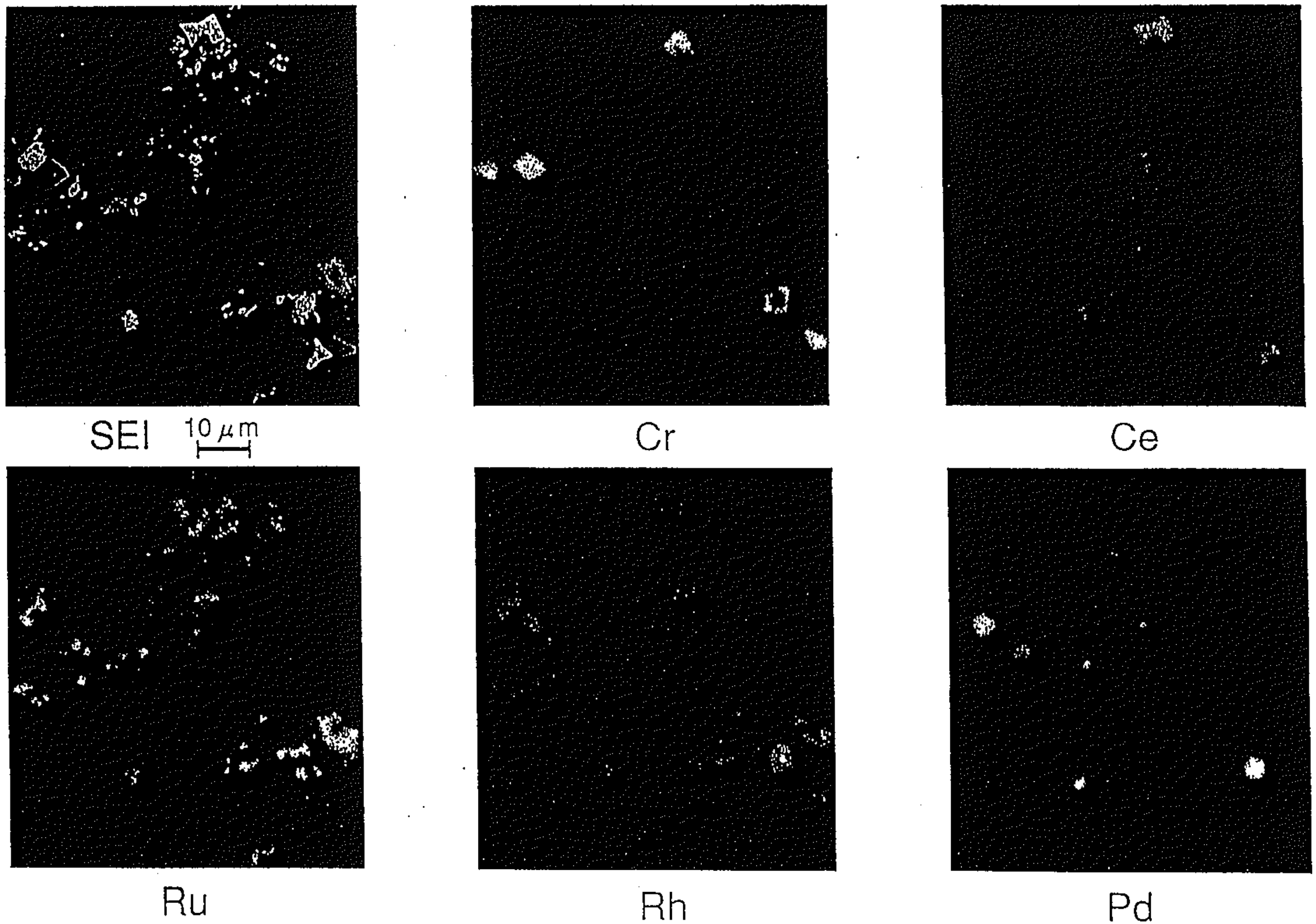
RuO_2 Concentration of Pouring Glass (TVF 2nd Campaign, 2nd-6th Batch, XRF).



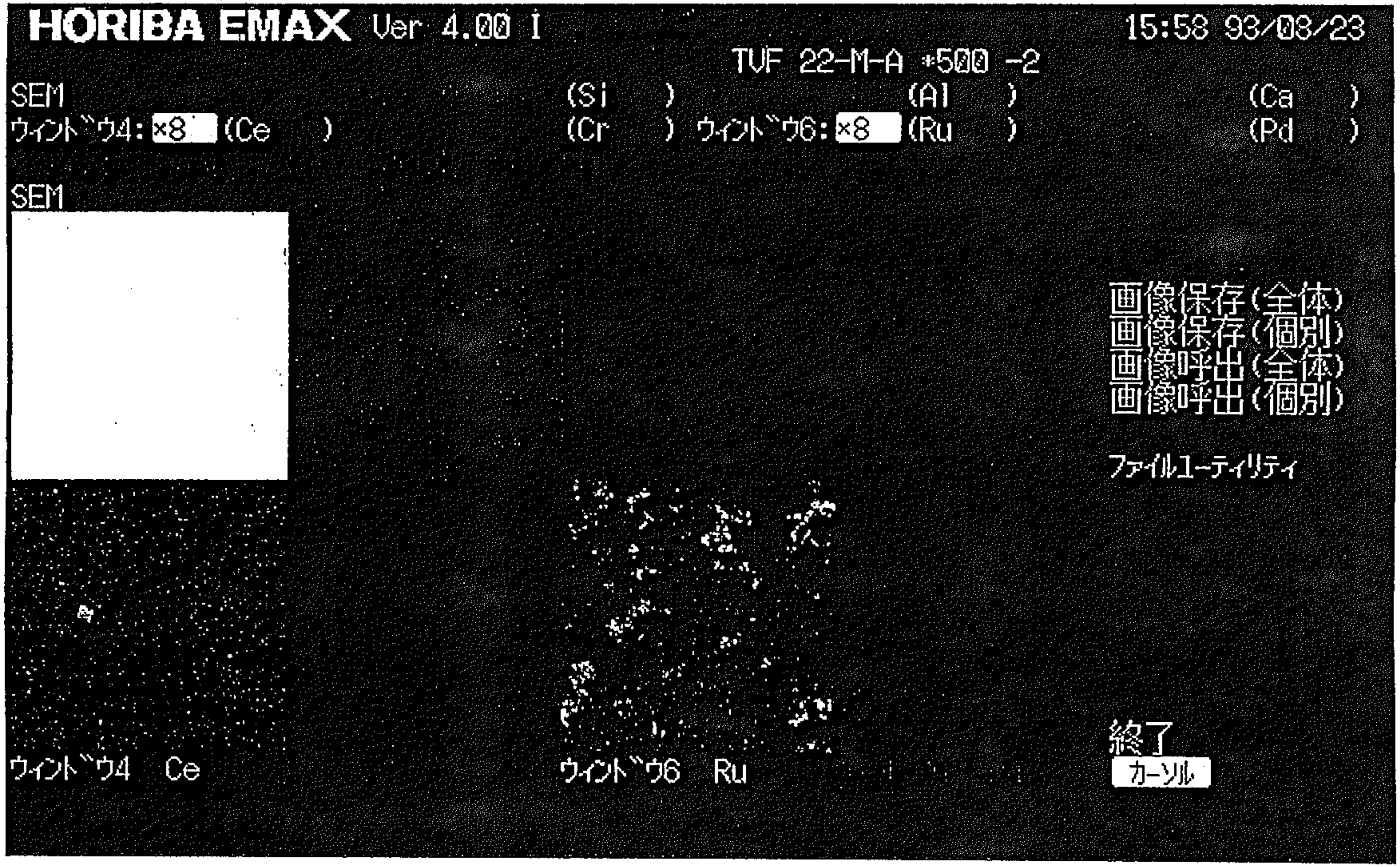
Sampling Point



XRD Data of Glass Sampled at M-A
(TVF 2nd Campaign,6th Batch).



Secondary Electron Image and Characteristic X-ray Image of Glass Sampled at M-A (TVF 2nd Campaign, 6th Batch).



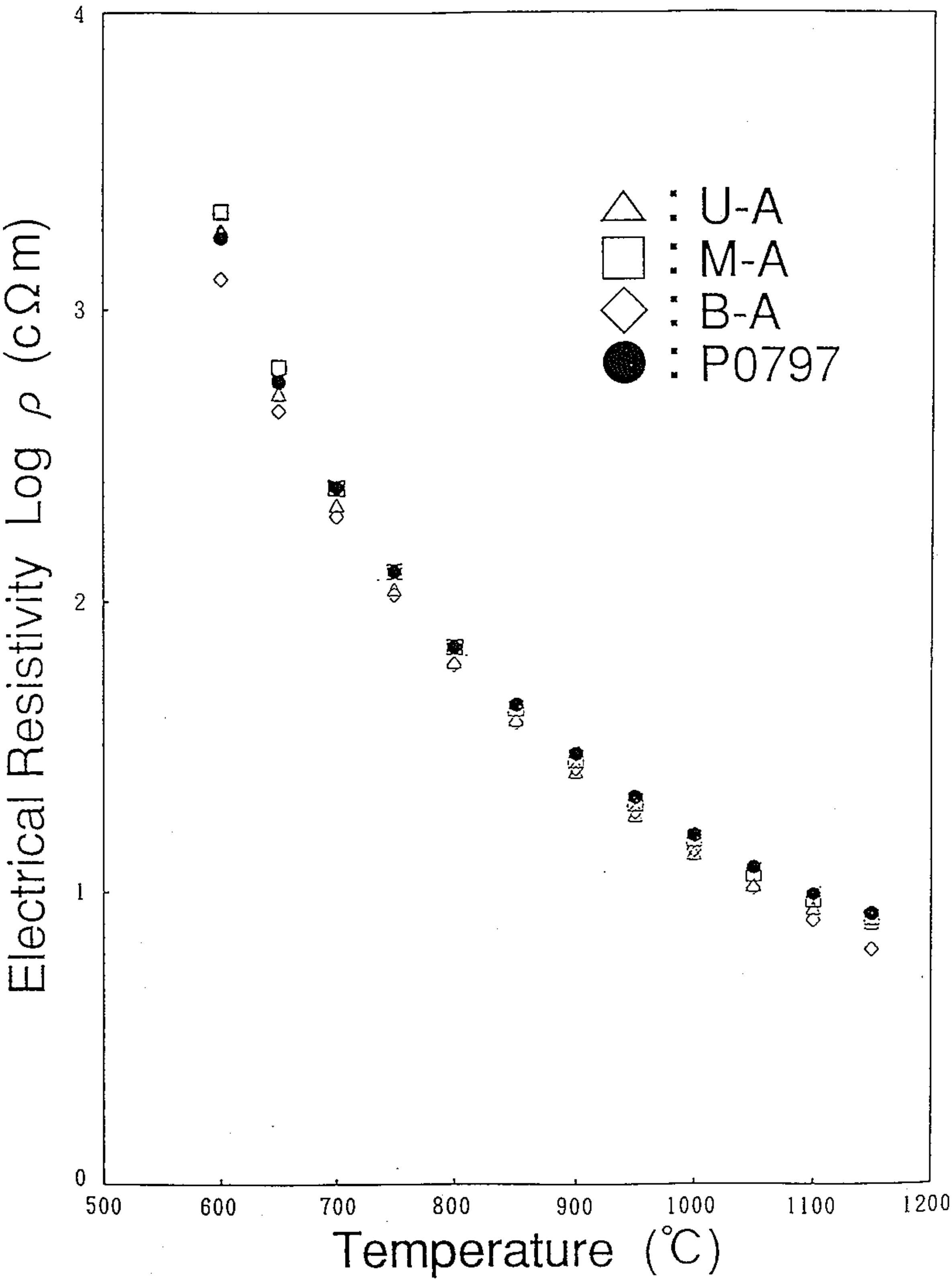
Secondary Electron Image and
Characteristic X-ray Image of Glass
Sampled at M-A (TVF 2nd Campaign, 6th batch)

Platinum Metal Content and Density of Glasses Sampled at U, M, B (TVF 2nd Campaign, 6th Batch)

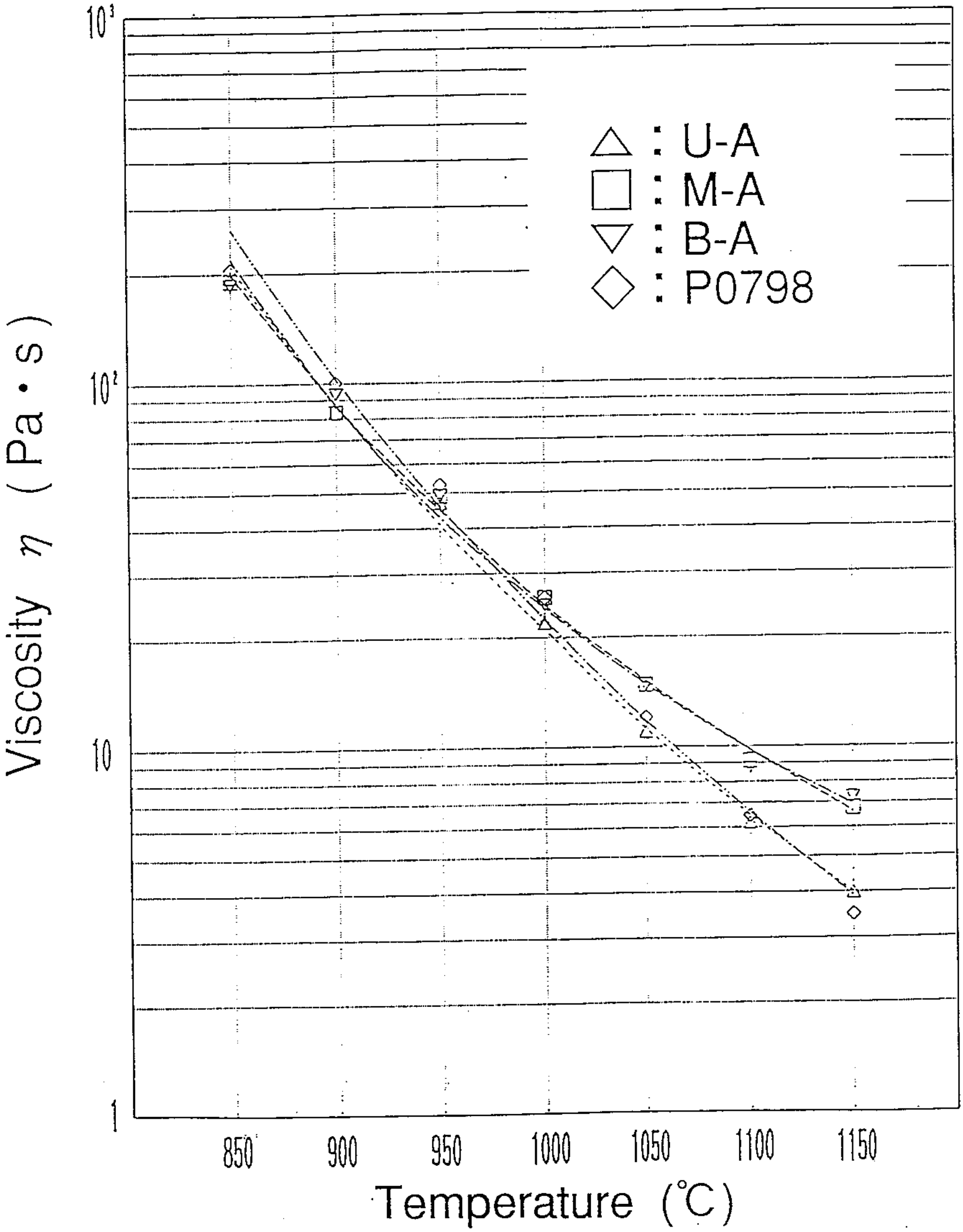
		U	M	B
Platinum Metal Content (wt%)	RuO_2	0.44	0.26	0.95
	Rh_2O_3	0.05	0.04	0.15
	PdO	0.25	0.17	0.45
	Total	0.74	0.47	1.55
Density ($\times 10^3$ kg/m^3)		2.754	2.756	2.763

Characterization of Glasses Sampled at U-A, M-A, B-A (TVF 2nd Campaign, 6th Batch)

	U−A	M−A	B−A
Density ($\times 10^3$ kg/m^3)	2.75	2.77	2.77
Thermal expansion ($\times 10^{-7}$/℃) Temp. range (30～300℃)	84	87	86
Tg (Transformation point, ℃)	499	505	503
Ts (Softening point, ℃)	613	612	615
Thermal conductivity (W/mK, at R.T.)	0.95	1.00	1.05
Leaching rate (Weight loss) ($\times 10^{-4}$ kg/m^2 d) JIS Type MCC−1 Method	 2.9 2.2	 2.6 2.3	 2.9 2.1



Electrical Resistivity of Glasses Sampled at U-A, M-A, B-A and Standard Glass(TVF 2nd Campaign, 6th Batch).



Viscosity of Glasses Sampled at U-A, M-A, B-A and Standard Glass (TVF 2nd Campaign, 6th Batch, Shear Rate $0.14 s^{-1}$).

SUMMARY

- Process qualification assures glass product quality.

- Homogeneity :
Most elements distribute uniformly in vitrified glass.
Platinum metal crystals [(Ru,Rh)O2, Pd-Rh-Te] distribute in the lower part of vitrified glass.

- Character :
Vitrified glass has uniform properties those are not remarkably affected by distribution of platinum metal crystals.

2.9 Characterization of HLLW

PNC TN8100 94－003

1

Characterization of HLLW

Prepared for
The 12th Annual KfK-PNC Meeting
on
Cooperation in High-Level Waste Management

by YAMASHITA, T.

December 7-9,1993

Power Reactor and Nuclear Fuel
Development Corporation

PNC

Heading

1. Chemical Analysis of HLLW

2. Volume and Composition of Precipitate

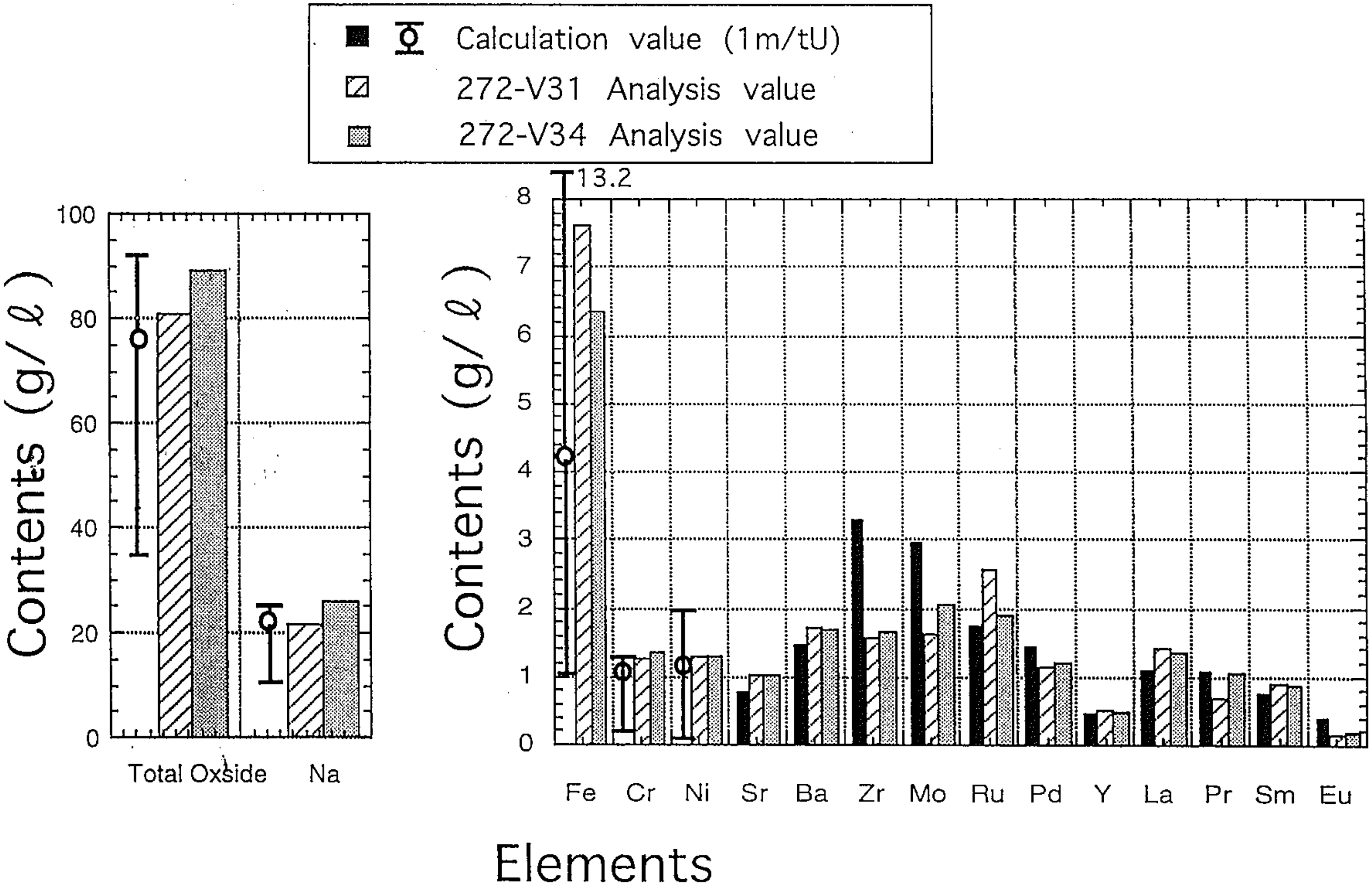
3. Formation of Precipitate in HLLW

3

Received HLLW at CPF

Times	HLLW Volume	Radio-activity	Remarks
1st	12 ℓ	110 TBq	
2nd	15 ℓ	190 TBq	
3rd	13 ℓ	110 TBq	
4th	13 ℓ	130 TBq	
5th	13 ℓ	58 TBq	
6th	12 ℓ	120 TBq	272-V31
7th	12 ℓ	70 TBq	272-V31
8th	12 ℓ	153 TBq	272-V34
9th	8 ℓ	77 TBq	272-V34
10th	9 ℓ	96 TBq	272-V31

4

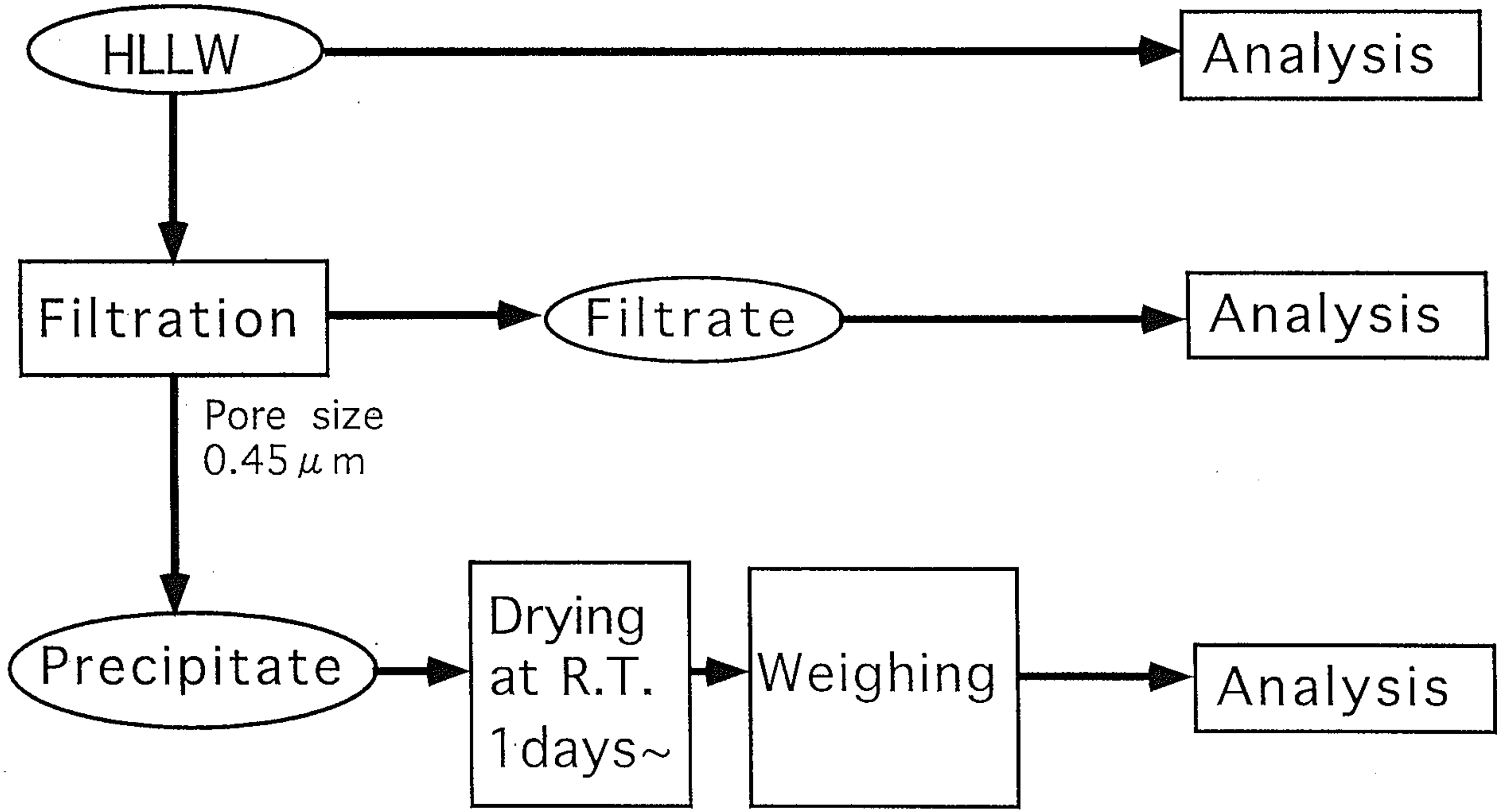


Calculation value and Analysis value of HLLW

5

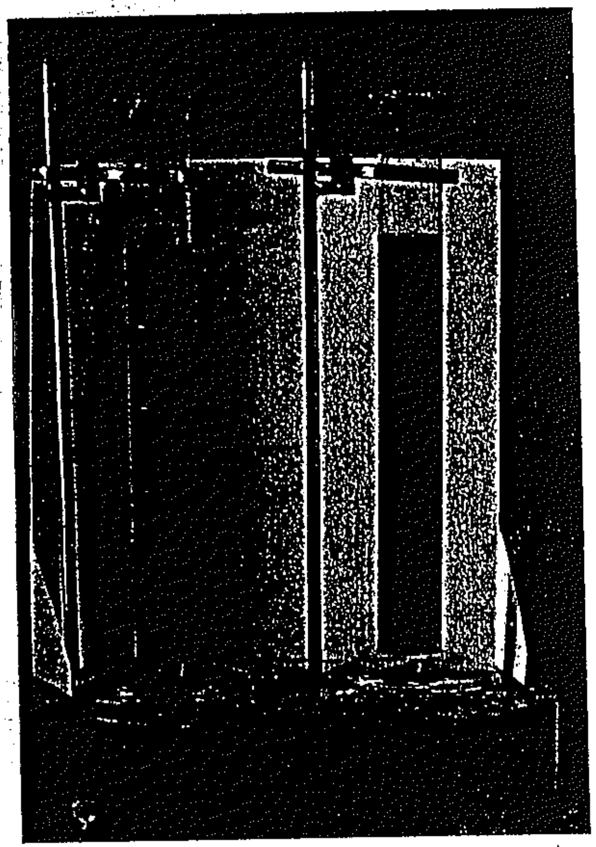
2. Volume and Composition of Precipitate

6

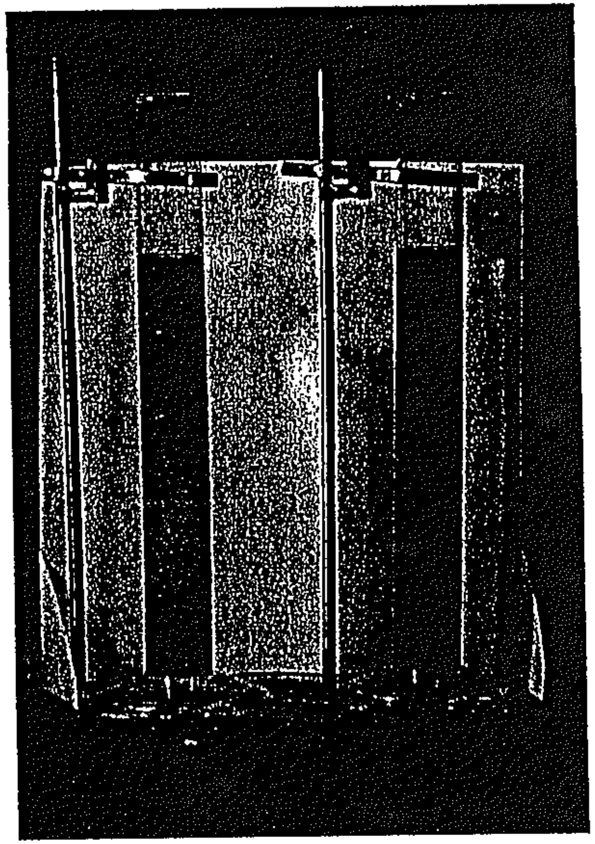


Filtration and measurements flow of 10th Received HLLW (CPF)

7



0h



After 24h

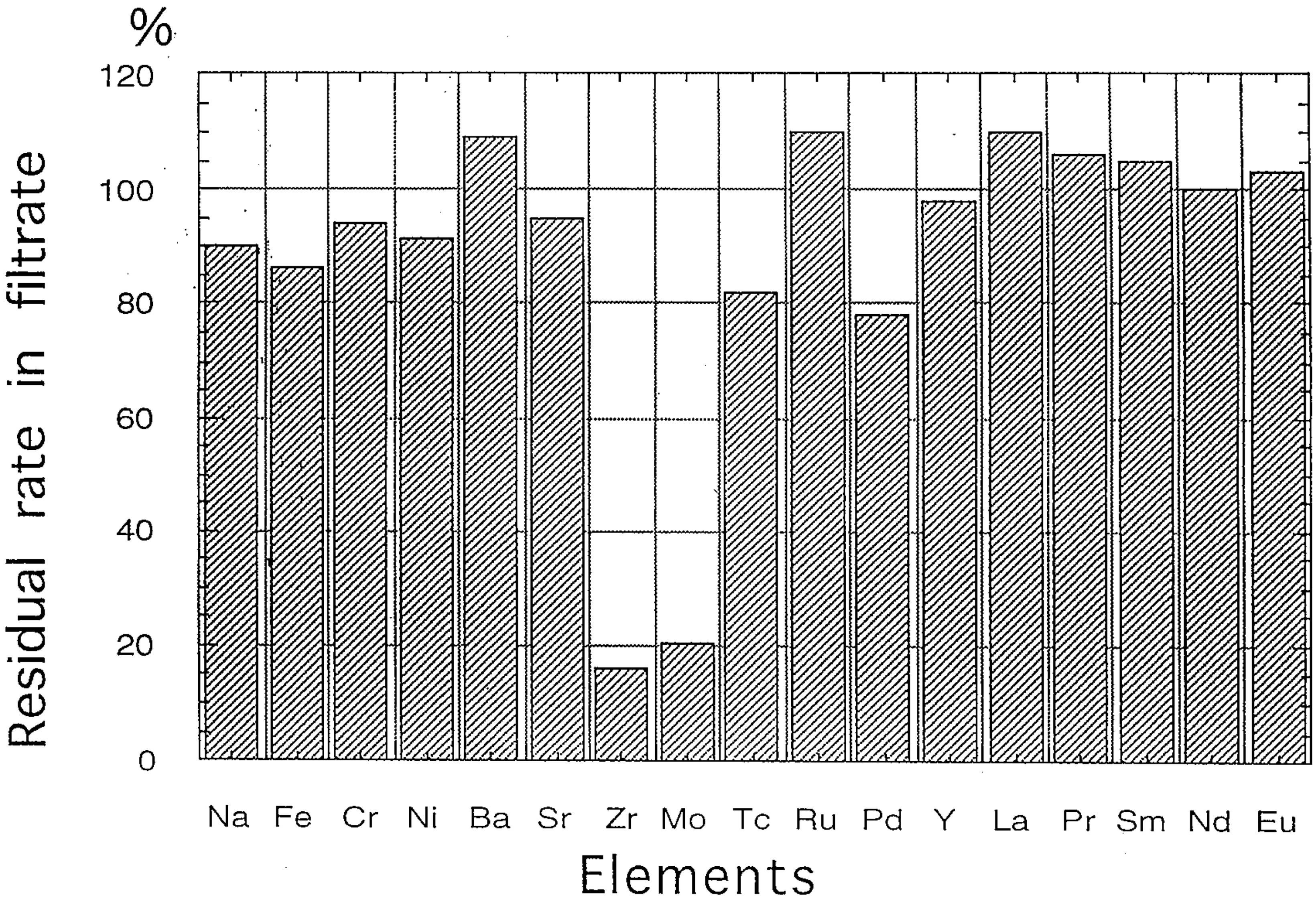
HLLW Sedimentation Test at CPF Hot Cell

8

Precipitate Volume of HLLW

HLLW	sedimentation Volume (after 24h)	Weight
CPF 10th	6.1mℓ／50mℓ	11.6g／ℓ

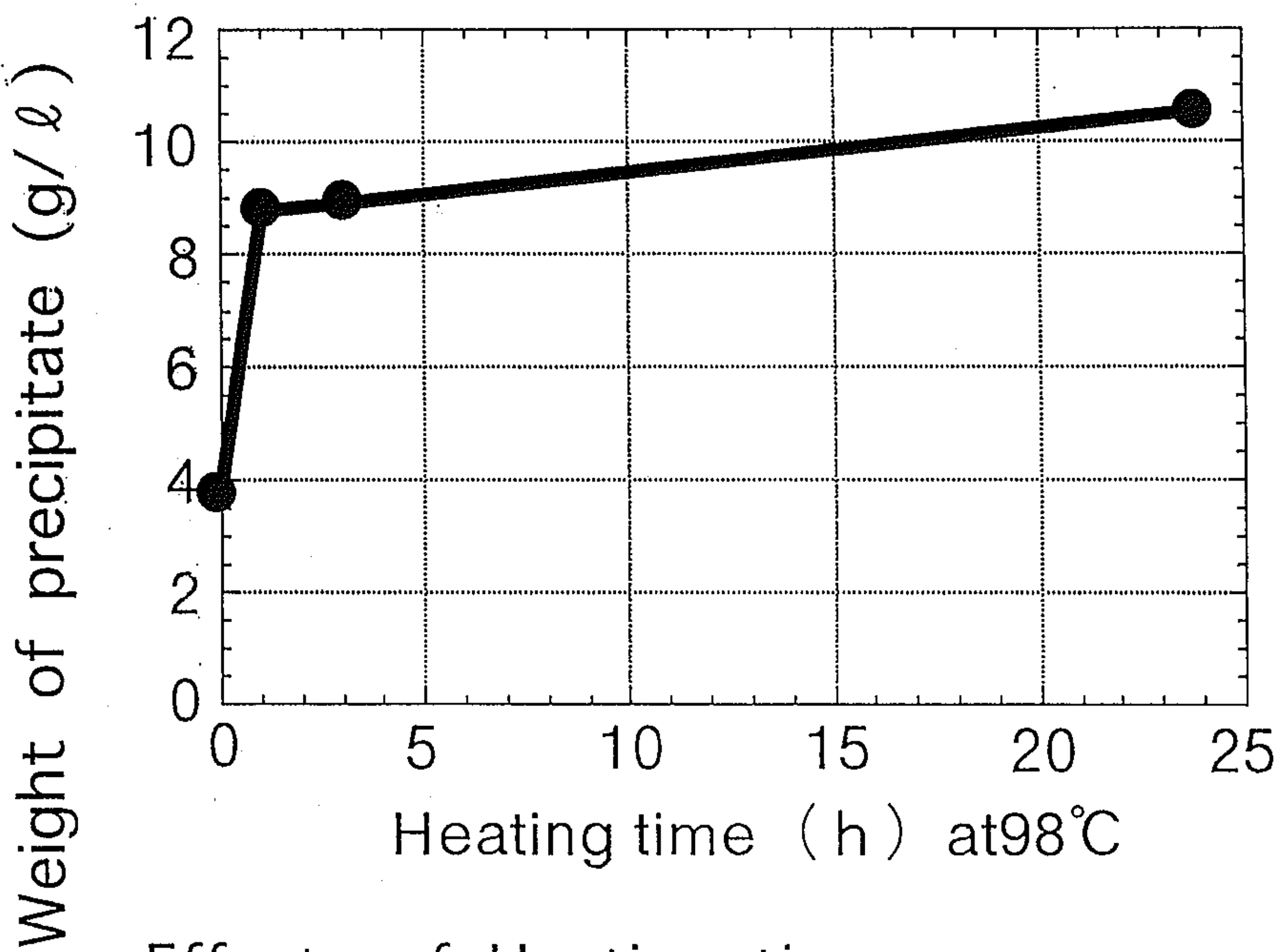
9



Residual rate of elements in filtrate

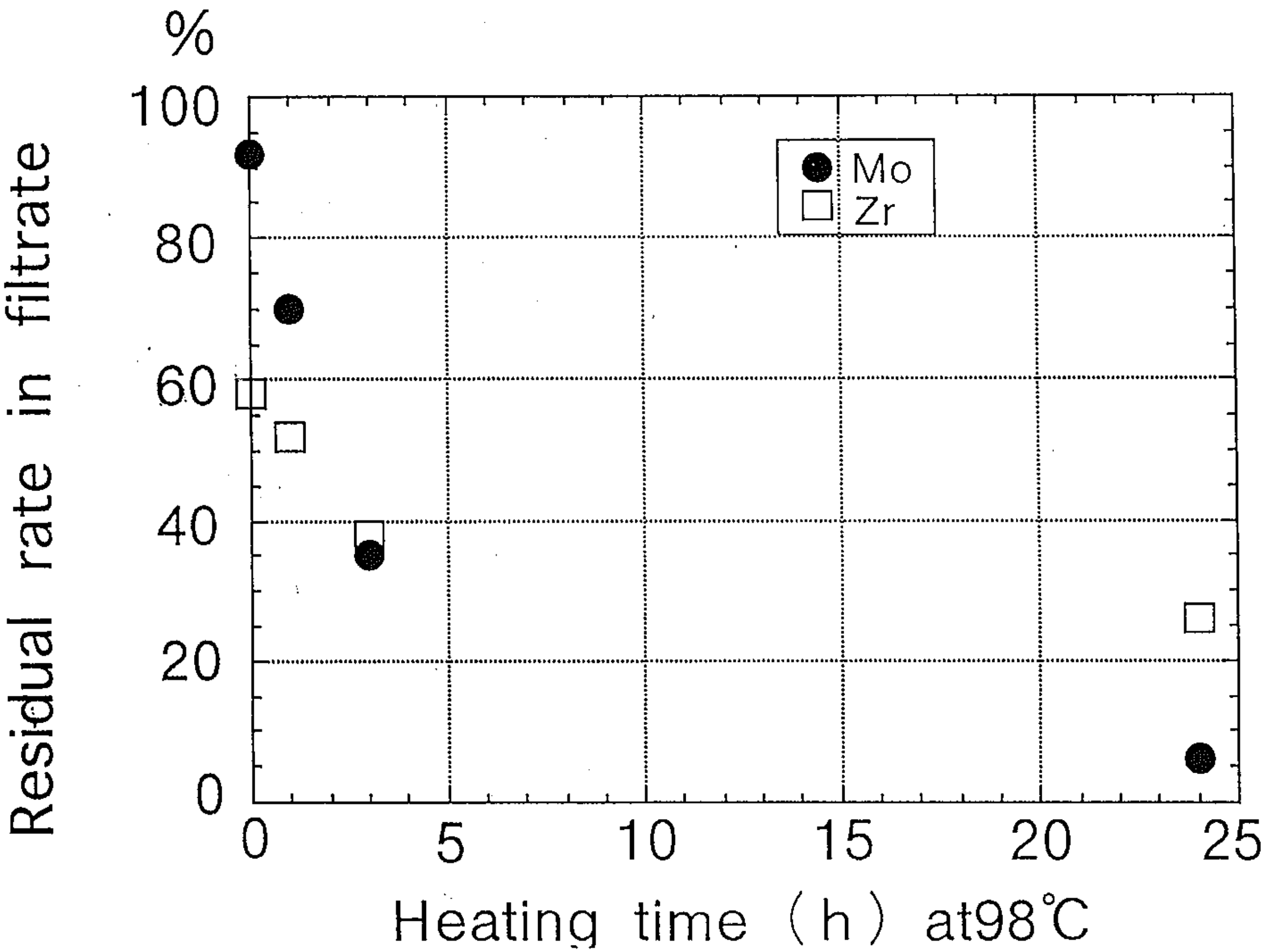
3. Formation of Precipitate in HLLW

11

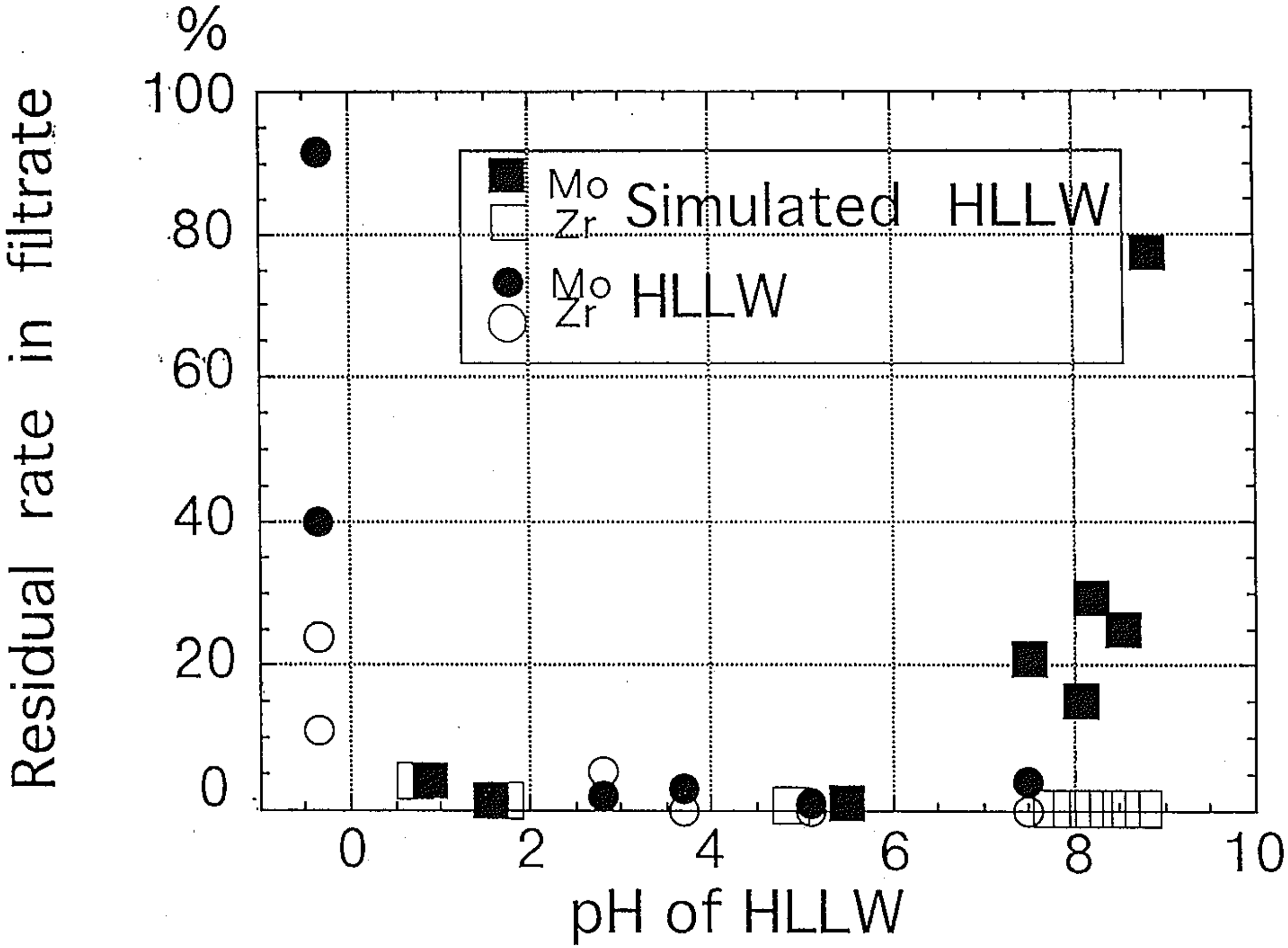


Effects of Heating time
on Precipitation in HLLW
(Simulated Waste)

12



Effects of Heating time
on Mo and Zr Residual Rate in Filtrate
(Simulated Waste)



Effects of pH on Mo and Zr Residual Rate in Filtrate

Conclusion

1. HLLW composition is equivalent to calculation value.

2. Most part of Mo and Zr is precipitate in HLLW

3. Formation of precipitate was affected by both heating time and pH.
   Separation of precipitate from HLLW reduce Mo concentration in HLLW.

3　KfK 側の発表資料

3.1 Current status of radioactive waste management in GERMANY

20 LWR on line

23 GWe installed capacity

30-35% Electricity supply

4,000 tons of spent fuel

4,000 ÷5,000 m^3 of conditioned wastes/year

until 2000:

150,000 m^3 wastes with negligible heat- production (≒95%)

3,000 m^3 wastes, heat-producing (≒15%)

The russian-type reactors (WWER) are presently being assessed with respect to safe operation by the GRS (Gesellschaft für Reaktorsicherheit mbH, Köln).

There is at present no direct participation by public utilities from the old federal states in public utilities in the new federal states.

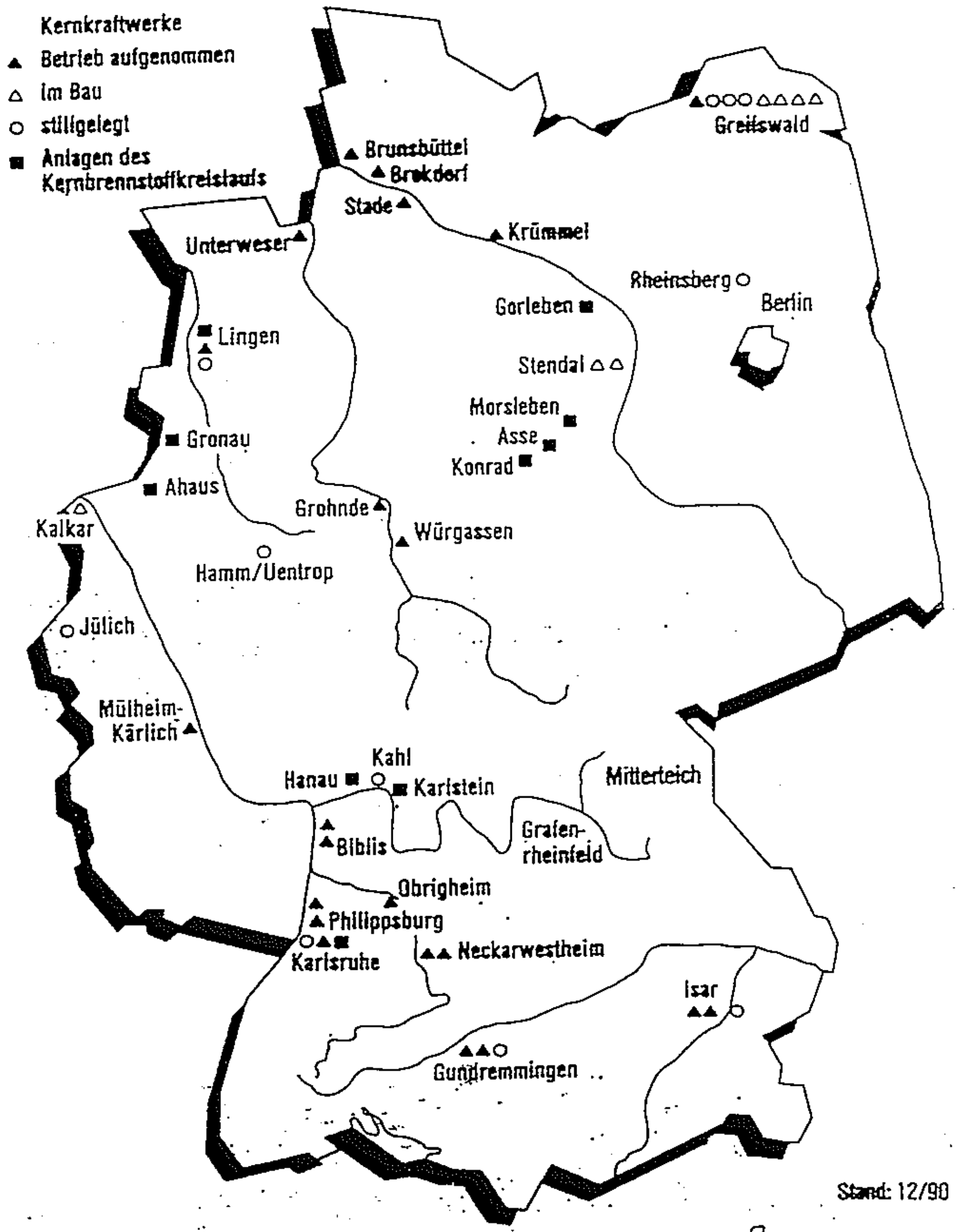


Fig. 1 Nuclear power plants and the facilities of the fuel cycle in the F R G

spent fuel with extremely high burnups or other spent fuel which does not meet the specifications of reprocessing.

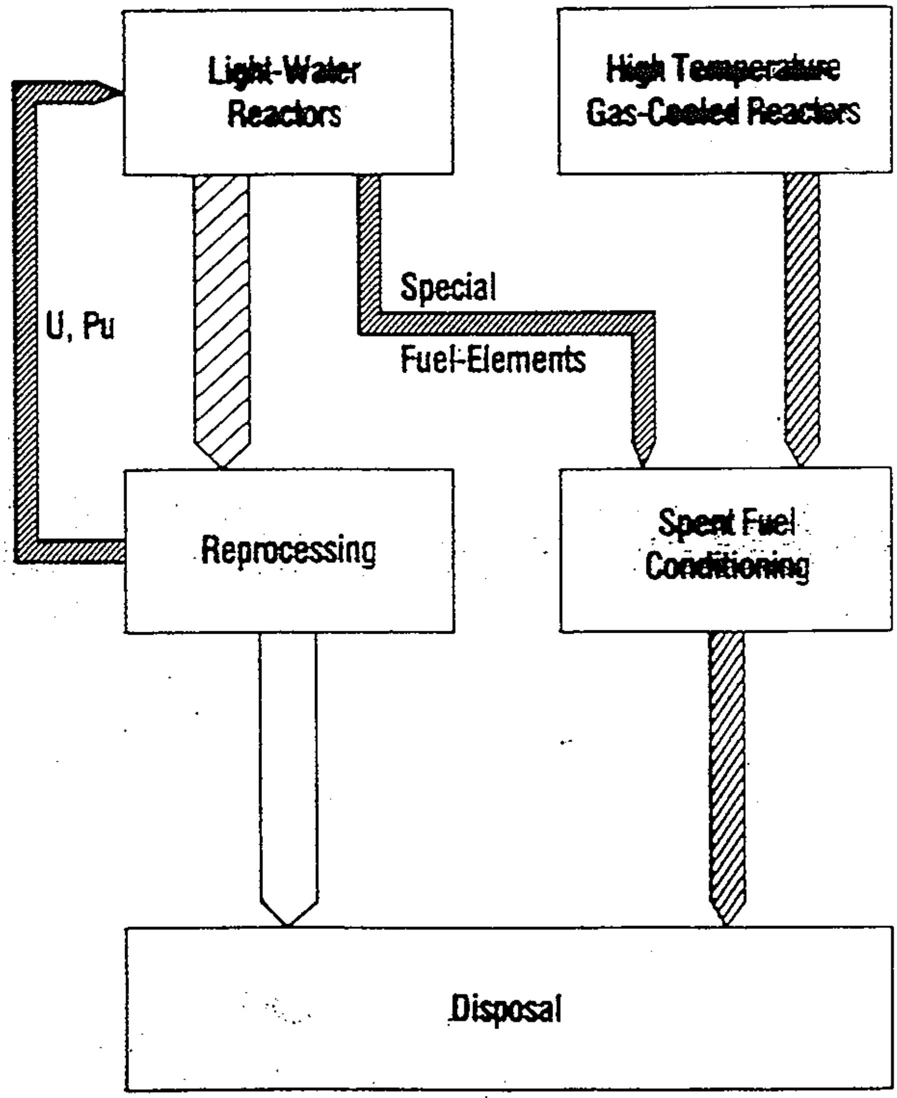
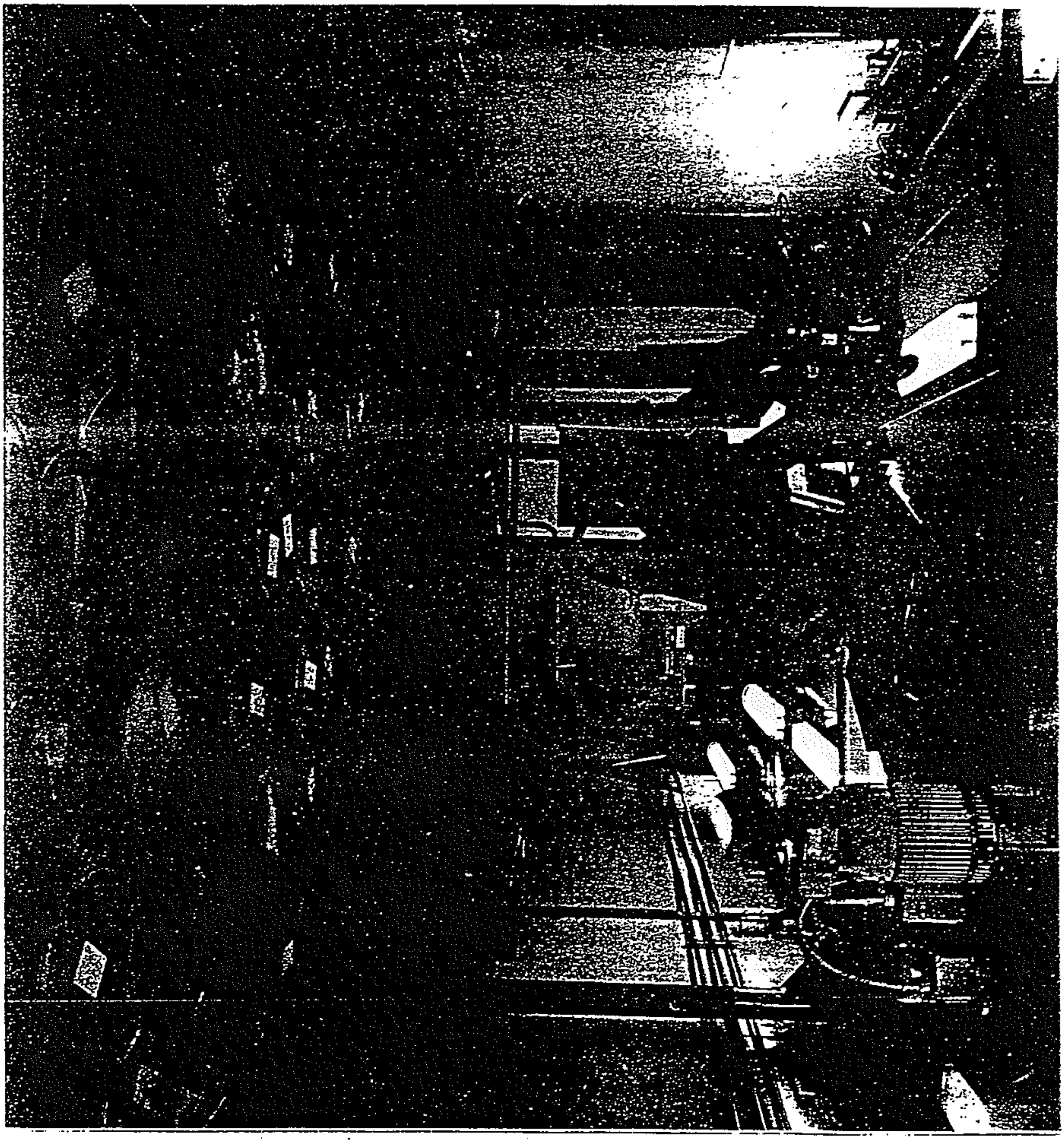


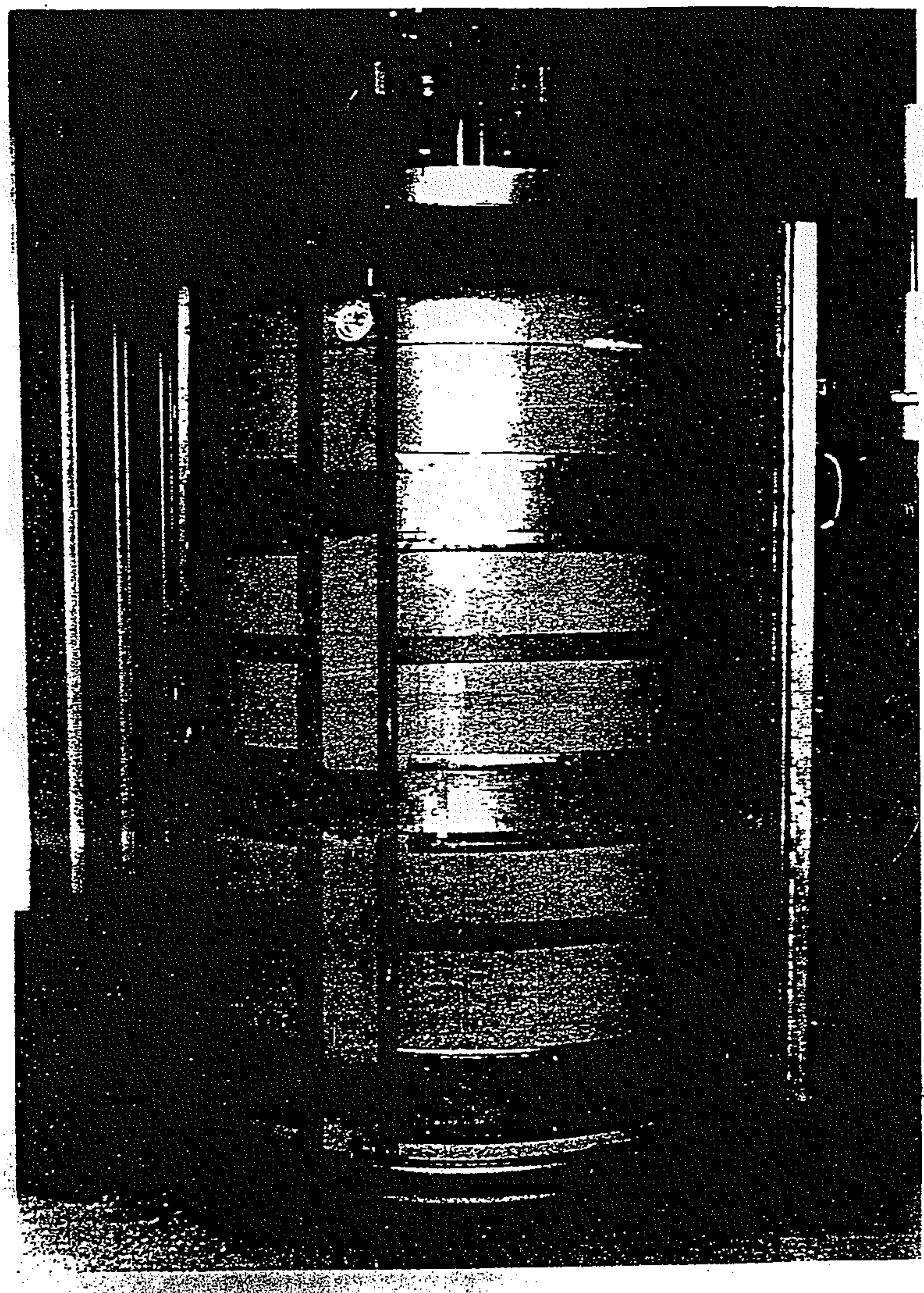
Fig. 2 **Future spent fuel strategy in the FRG**

Decommissioning of the WAK Plant

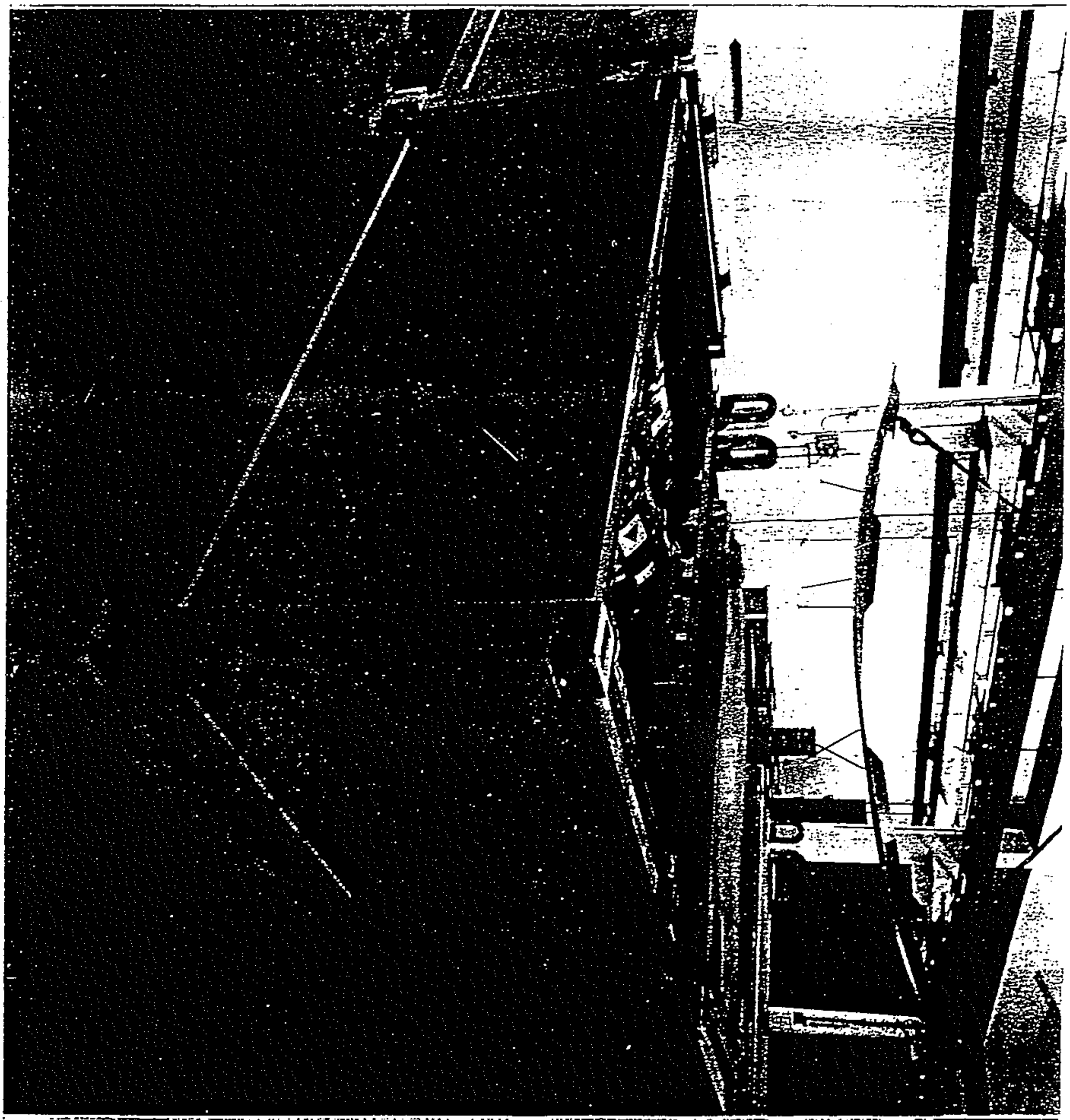
- Plant operation 1970-1991
- 88m³ HAWC(24Million Ci)generated
- waste to be vitrified in PAMELA plant of Mal/Belgium
- Transport licenscing applied, under progress
- Public hearing 1994
- Transportation by train, CASTOR casks
- 30 transportation events necessary
- Returned glass product to be stored in interim storage

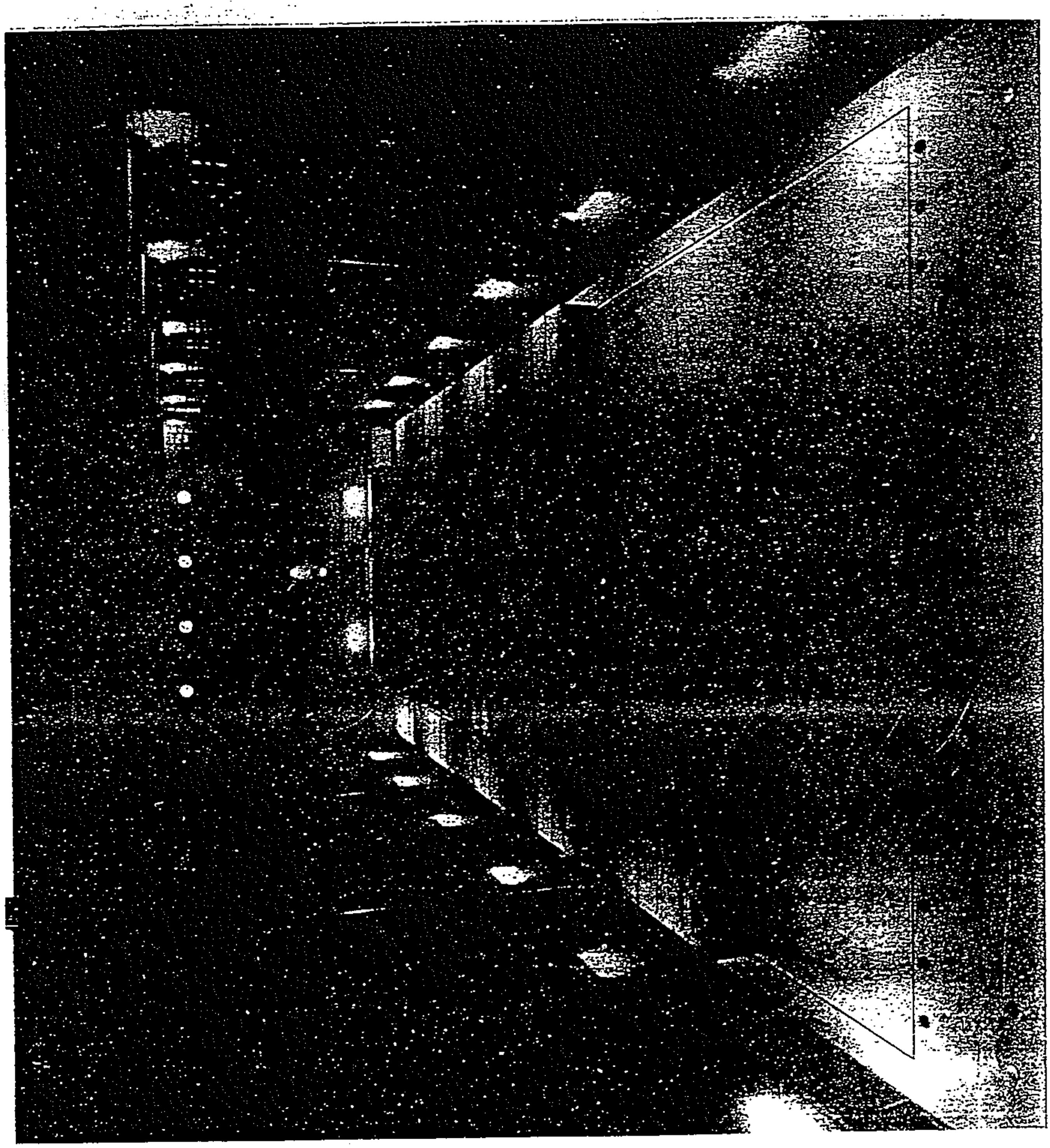
2005 Termination of decommissioning
1500 tons of metallic waste
3000 m³ of construction materials waste
2.55 Billions DM estimated cost



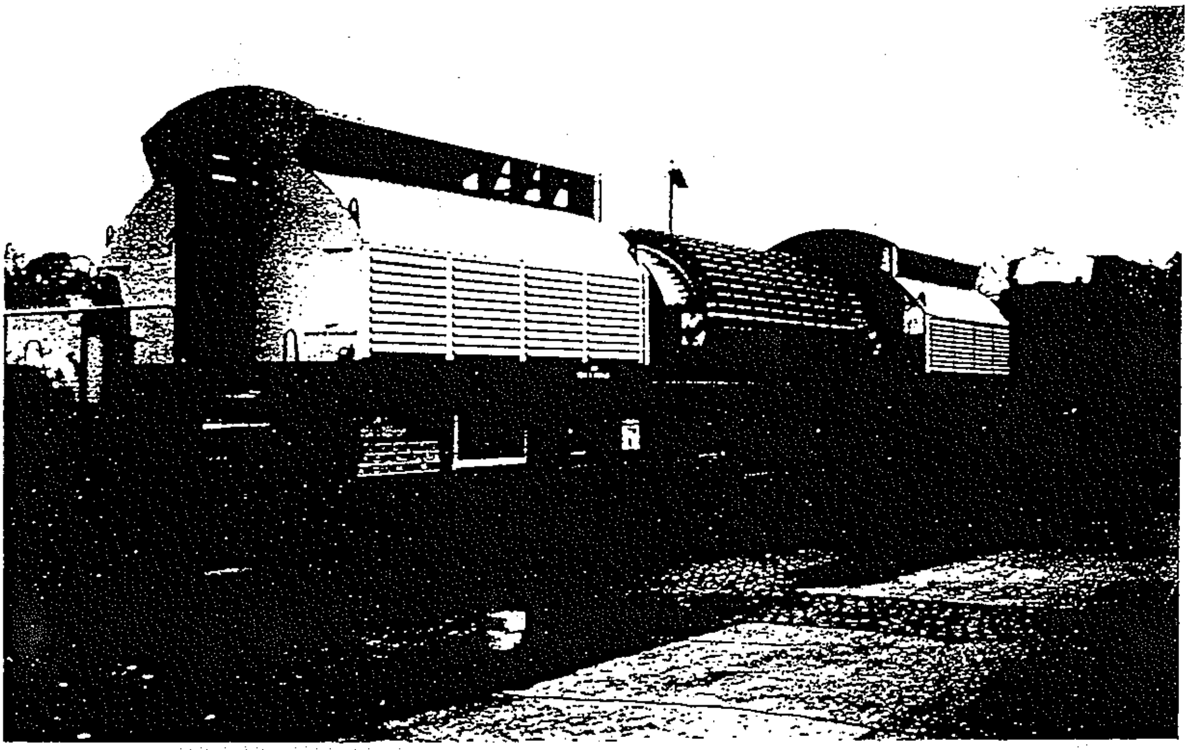


GNS	FAVORIT	Behälterheizung cask heating

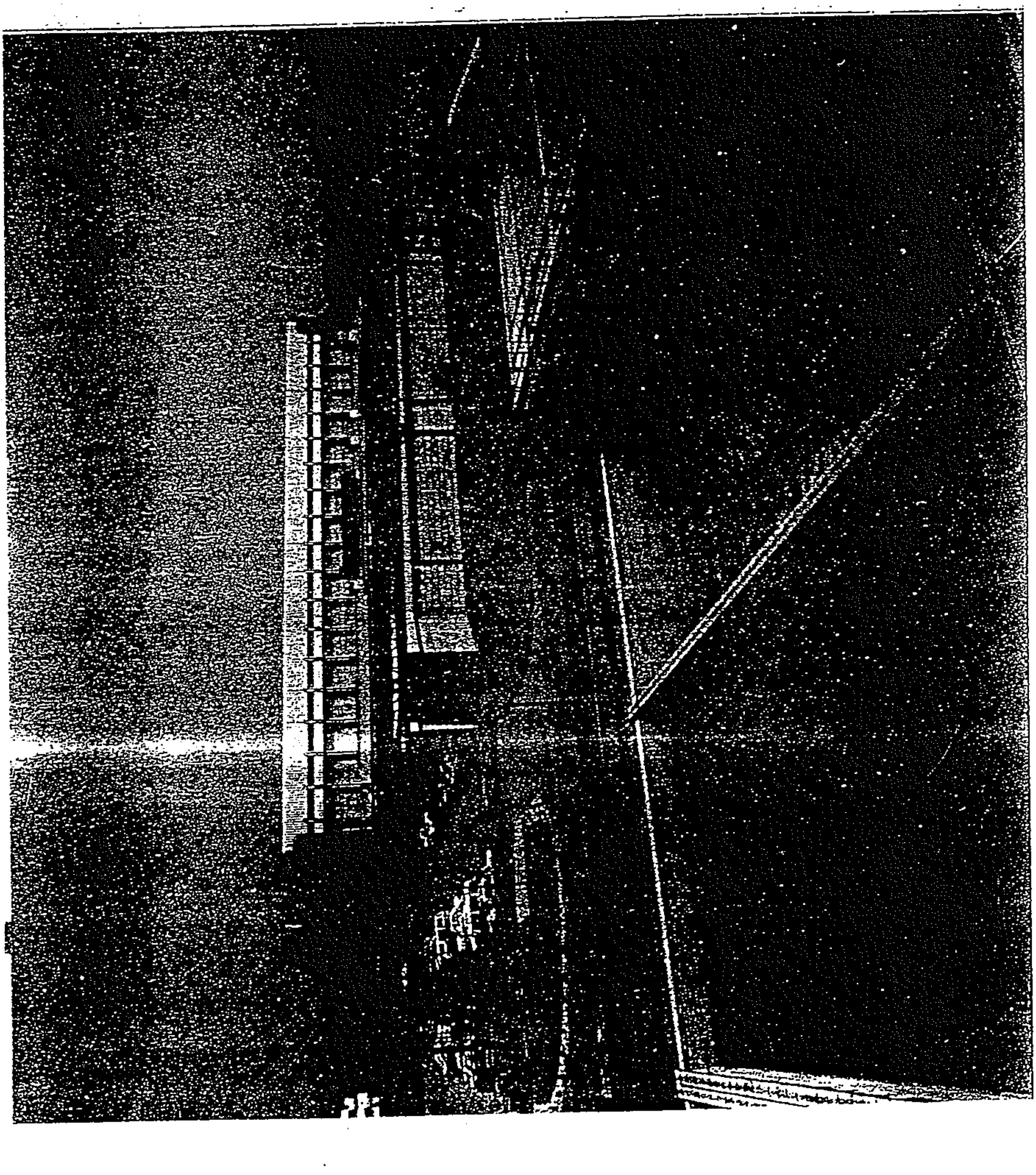




TN 1300



Transportbehälter für bestr. Brennelemente
Transport container for spent fuel elements



Direct disposal of spent fuel

・additional management strategy for unreprocessable spent fuel elements

・amendment to the Atomic Energy Act to eliminate the priority of reprocessing

スケジュール

1979 Development of direct disposal tectniques started

1986 License application for a pilot plant for spent fuel conditioning and encapsulation at Gorbeben

1996 Intended start-up of hot operation

・plant capacity : 35 tons/year spent fuel from LWR

・Two package options :

Pollux-casks for disposal in drifts(reference)

for disposal in boreholes(back-up)

・Cask-dimensions :5.5m×1.5mφ, 65tons(loaded)

Reprocessing of spent fuel

1985 Atomic Energy Act : Reprocessing as reference strategy
1989 German plants for industrial reprocessing(wackersdorf) abandoned
1990 Decision to reprocess spent fuel abroad

Contract with BNFL/COGEMA covering 500t/year reprocessing capacity

1994 start of return of waste glass from France

Year 2000 : 887tons of spent fuel reprocessed by BNFL/COGEMA
4200 canisters(150ℓ)of glass product
After 2000: 3200 canisters, optional

Waste disposal

Interim storage:Gorbeben, Aarhus(waste glass)
Mitterteich(NPP wastes)

Gorbeben repository

- salt dome, investigated since 1979
- suitable for all types of waste, especially heat-generating ones
- Above-ground exploration almost complete
- underground exploration still in progress
- Expected to be available in 2005-2010
- cost estimate for characterization, design and construction 2.6 billion DM

Konrad repository

- Former iron mine, to be used for non-heat generating waste
- 10^6 m³ disposal volume(40 years utilization)
- Licensing procedure not yet terminated
- Start-up expected for mid-nineties
- costs for design, 380 million DM

Moersleben disposal facility

- used for disposal since 1979
- About 12000 m³ liquid waste conditioned by in-situ solidification
- 4600m³ solid waste packages
- presently safety evaluation underway
- Will be used only to accommodate former GDR waste

Vitrification of the HAWC-WAK

Main operation data

88m³ of HAWC(incl. dilution by transfer etc.)

9.6×10^{17}Bq total activity, main radionuclides
Cs-137 and Sr-90 with daughters, 95%

About 400kg noble metal(commercial-like HAWC)

28ℓ/hr Melter feed rate (incl. 10%recycle)

5 months operation time(100% availavility)

50 tons of glass product

125 glass canisters(400kg、150ℓ)

16wt% waste oxides loading

Melter technology

- Melter type K-6', noble metals-compatible
- designed and constructed by KfK-INE
- Tested in the VA-WAK facility 1990-93

Vitrification schedule

- Transportation of the HAWC-WAK to Mol 1997/98
- 1998 Start of vitrification campaign

3. 2 Conceptual study for the conditioning of the HAWC-WAK waste and on-site vitrification

Basic data (theoret. blend of tanks)

Total quantities and main data

Total feed volume	86 m^3
Total activity	9.6*10^{17} Bq
Specific activity	1.1*10^{13} Bq/l
Specific decay heat	0.9 W/l
Glass production	49.5 to
Total spec. activity product	1.9*10^{13} Bq/kg
Specific heat in product	1.6 W/kg

Material data

Oxide yield	92 g/l
Waste loading	16 wt-%
Quantity of product per liter HAWC	0.575 kg

Main material streams

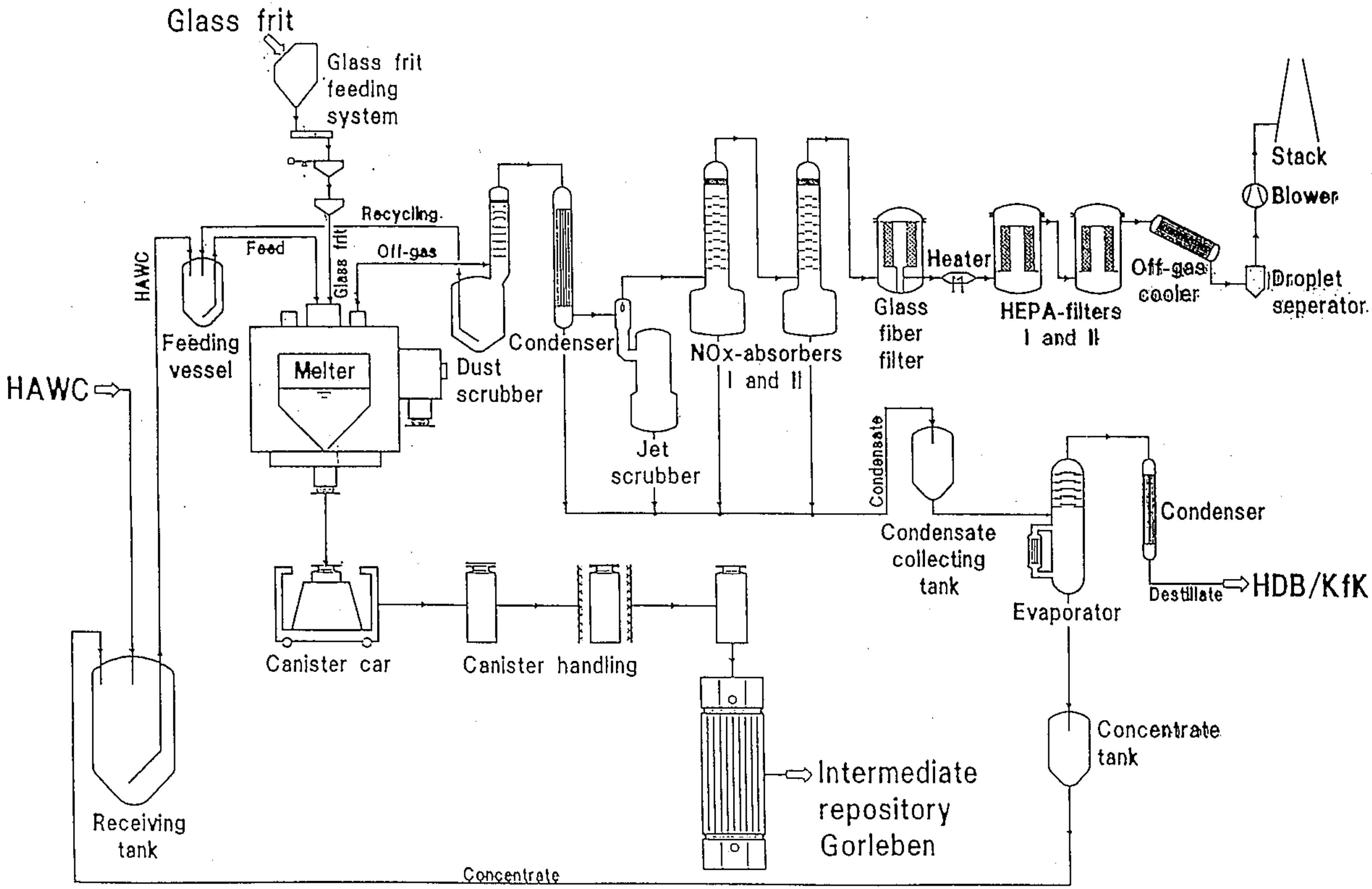
Throughput of HAWC	25 l/h
Throughput of Feed	28 l/h
Glass production rate	14.4 kg/h
Canister production rate	1 canister in 28 h

Canister data

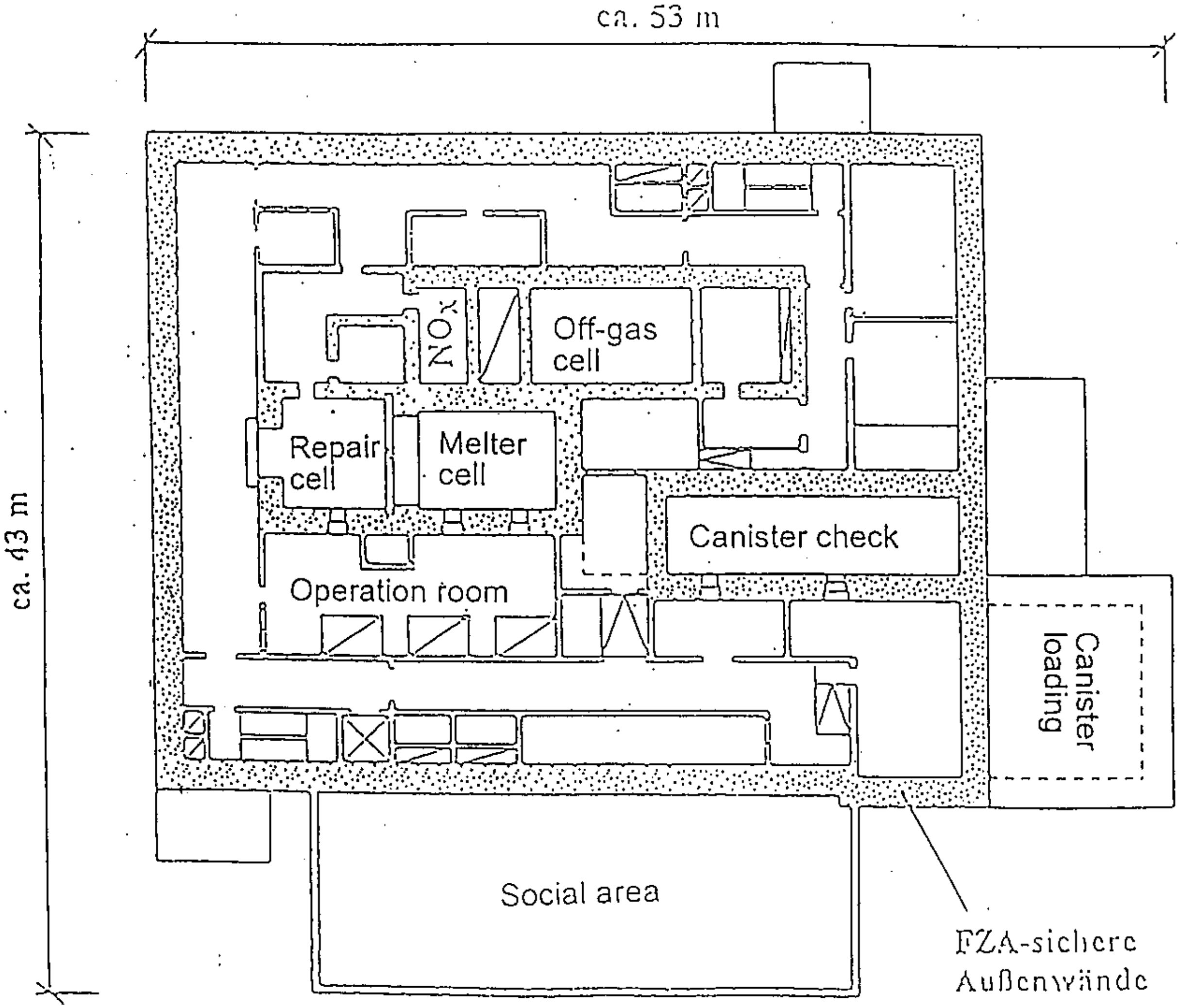
Canister size	dia. 430*130 mm height
Capacity	400 kg
Total activity	$7.8*10^{15}$ Bq
Main radioisotype	Cs-137/Ba-137 m, 55 %
Number of canisters	124
Volume of HAWC pressed for one canister	≈ 700 l

Operational data

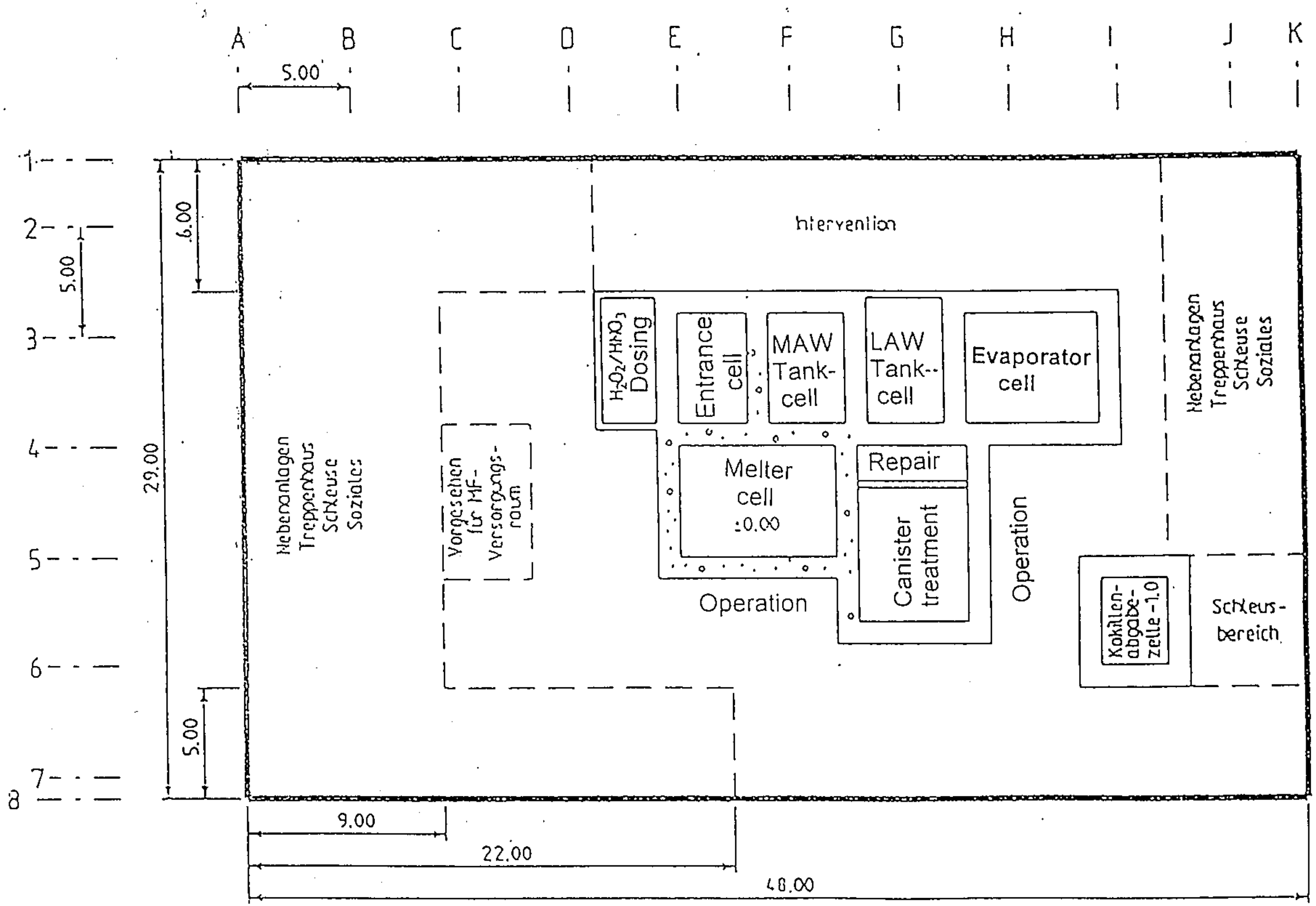
Total operation time (25 l/h, 100% availability)	143 days (≈ 5 months)
Operation mode	continous
Secondary liquid waste, total	≈ 70 m^3 condensate ≈ 25 m^3 scrub solution
Quantity of evaporator concentrate	≈ 3 m^3 (concentration factor of 30)



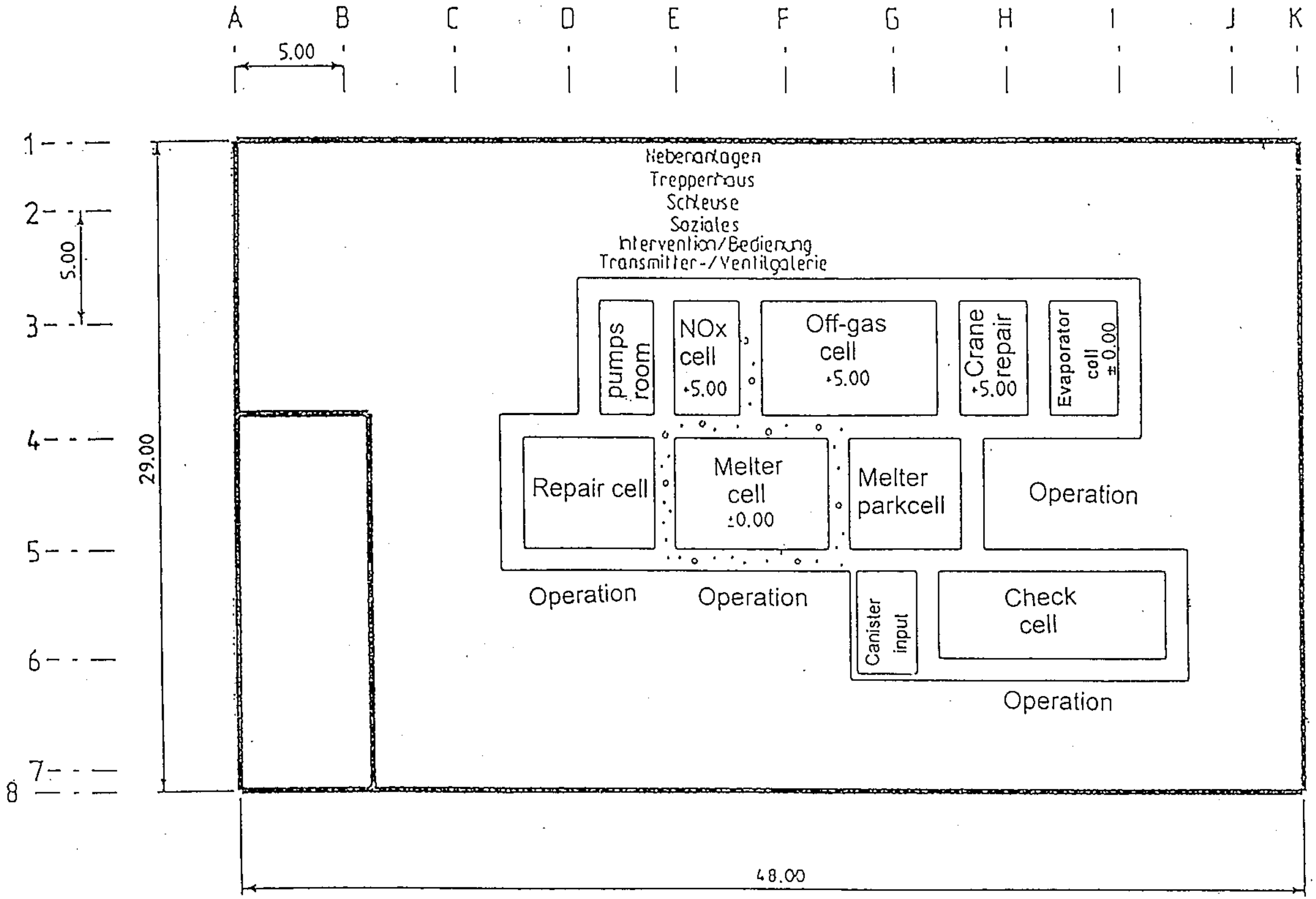
Basic flowsheet of the HAWC-WAK vitrification plant on site



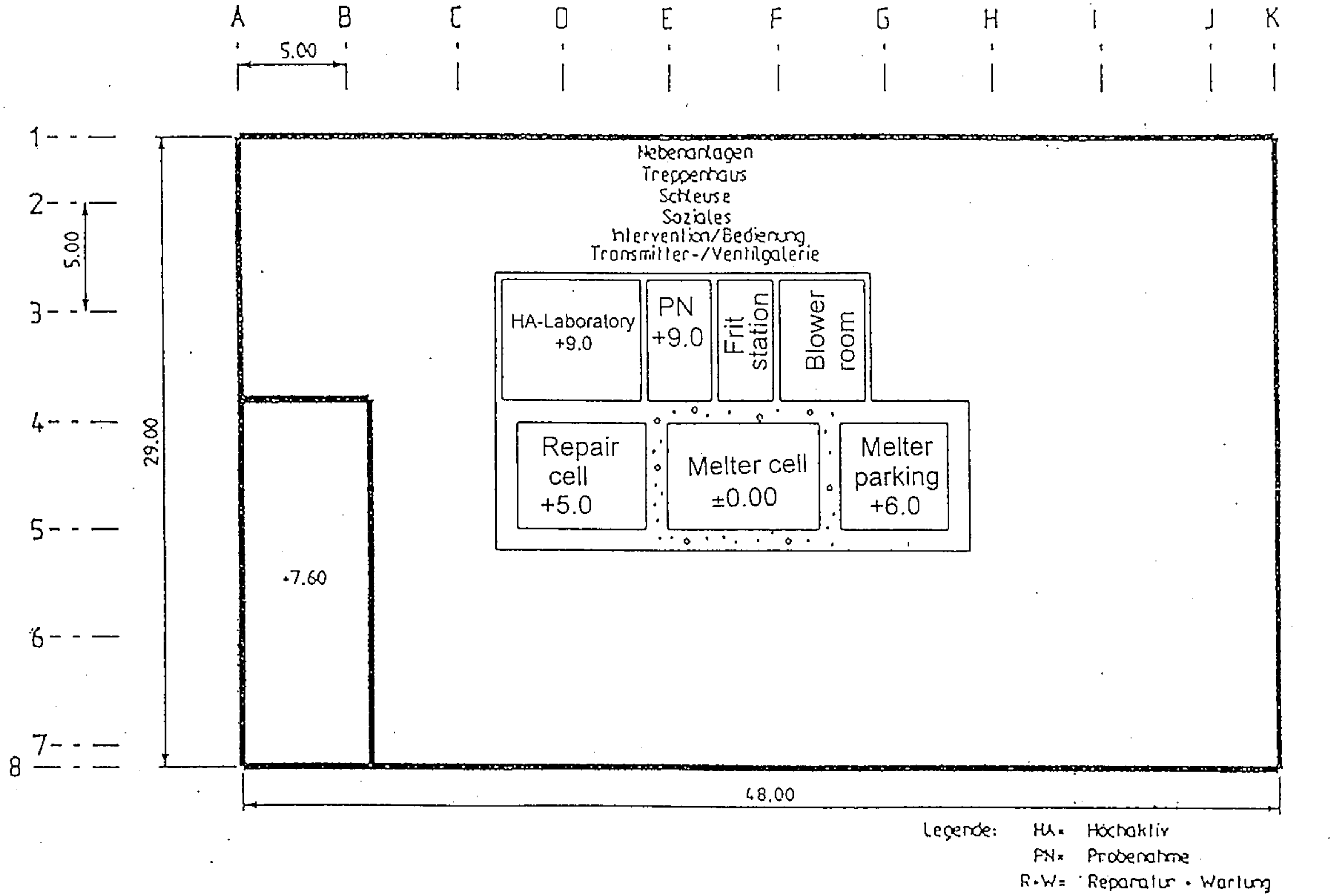
Possible structure of the on-site vitrification plant



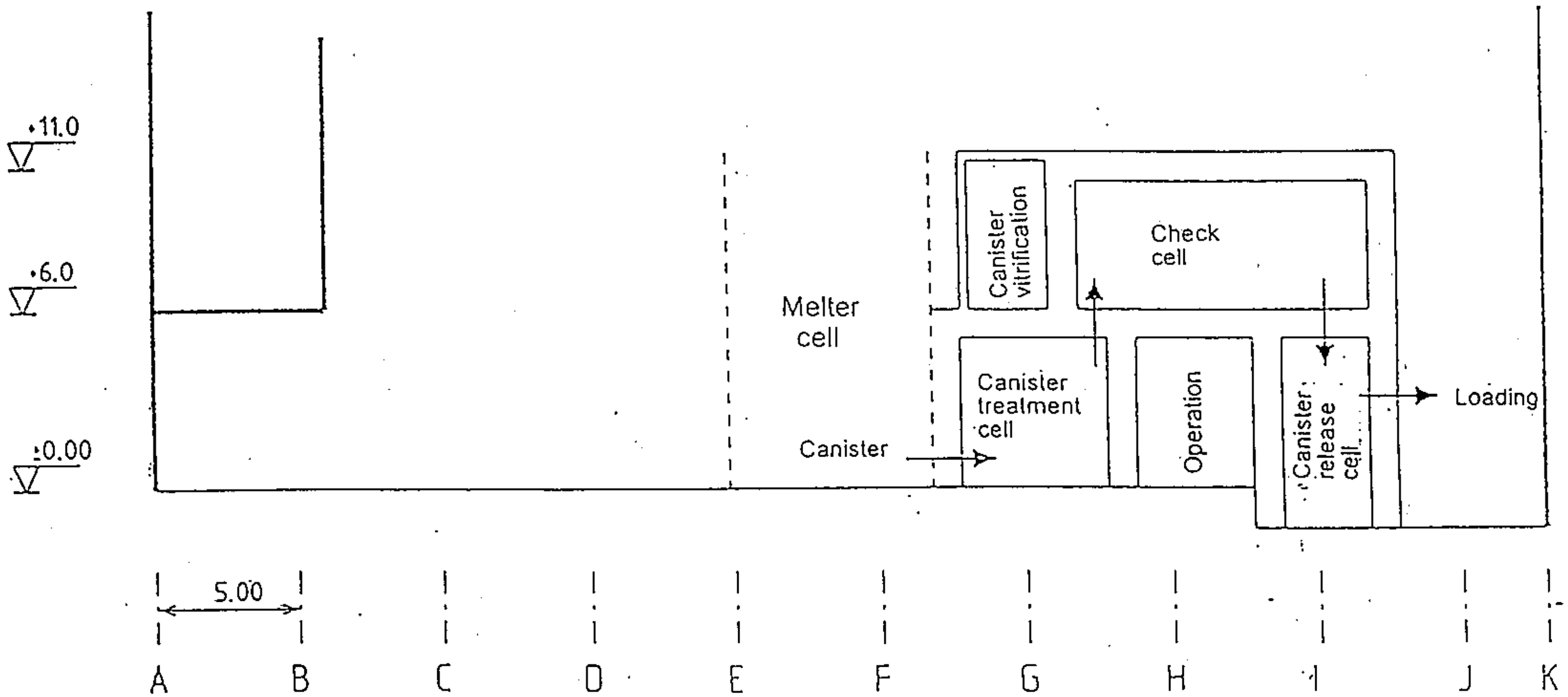
Cell arrangement, plan view, level +0m



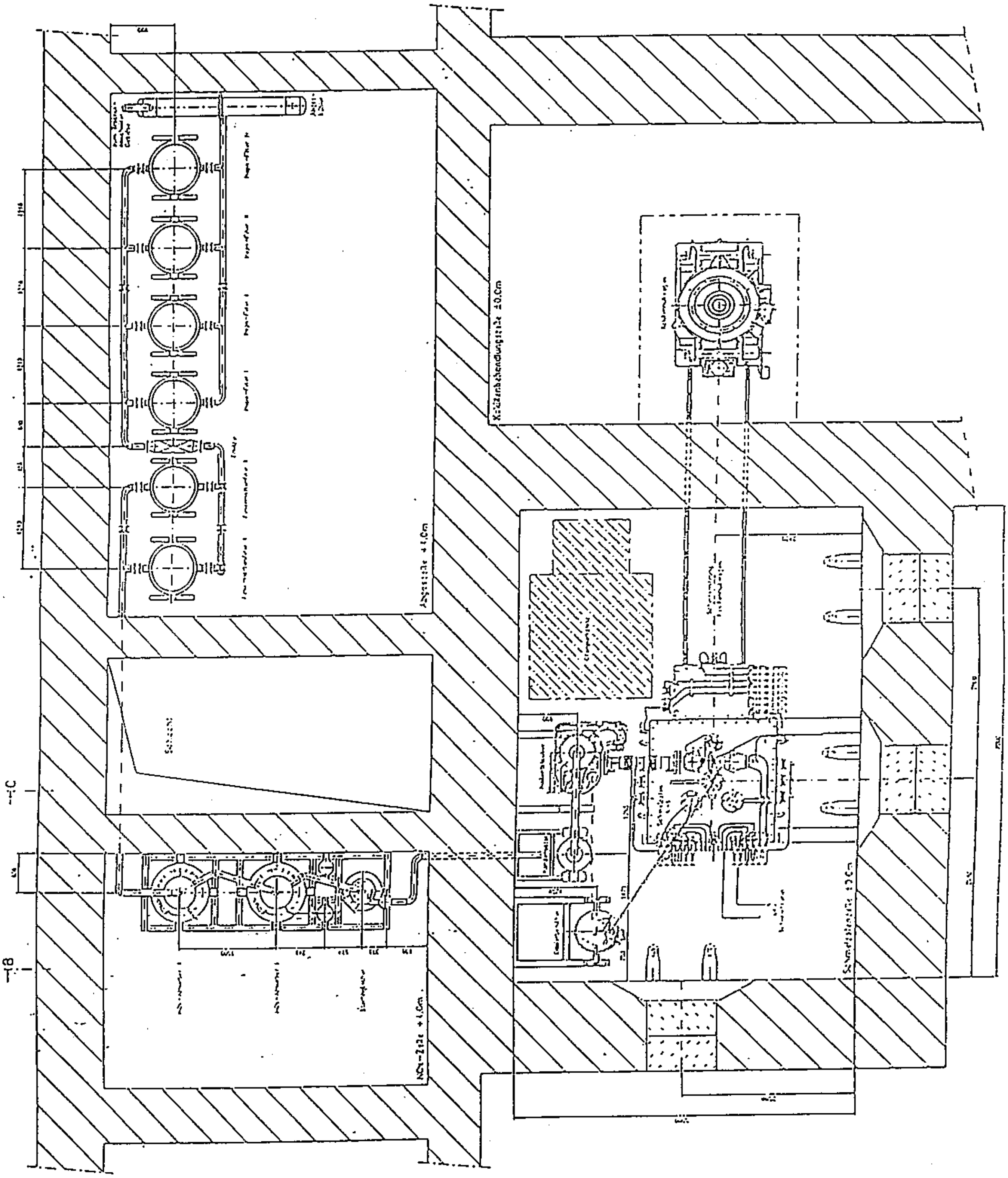
Cell arrangement, plan view, level +6m

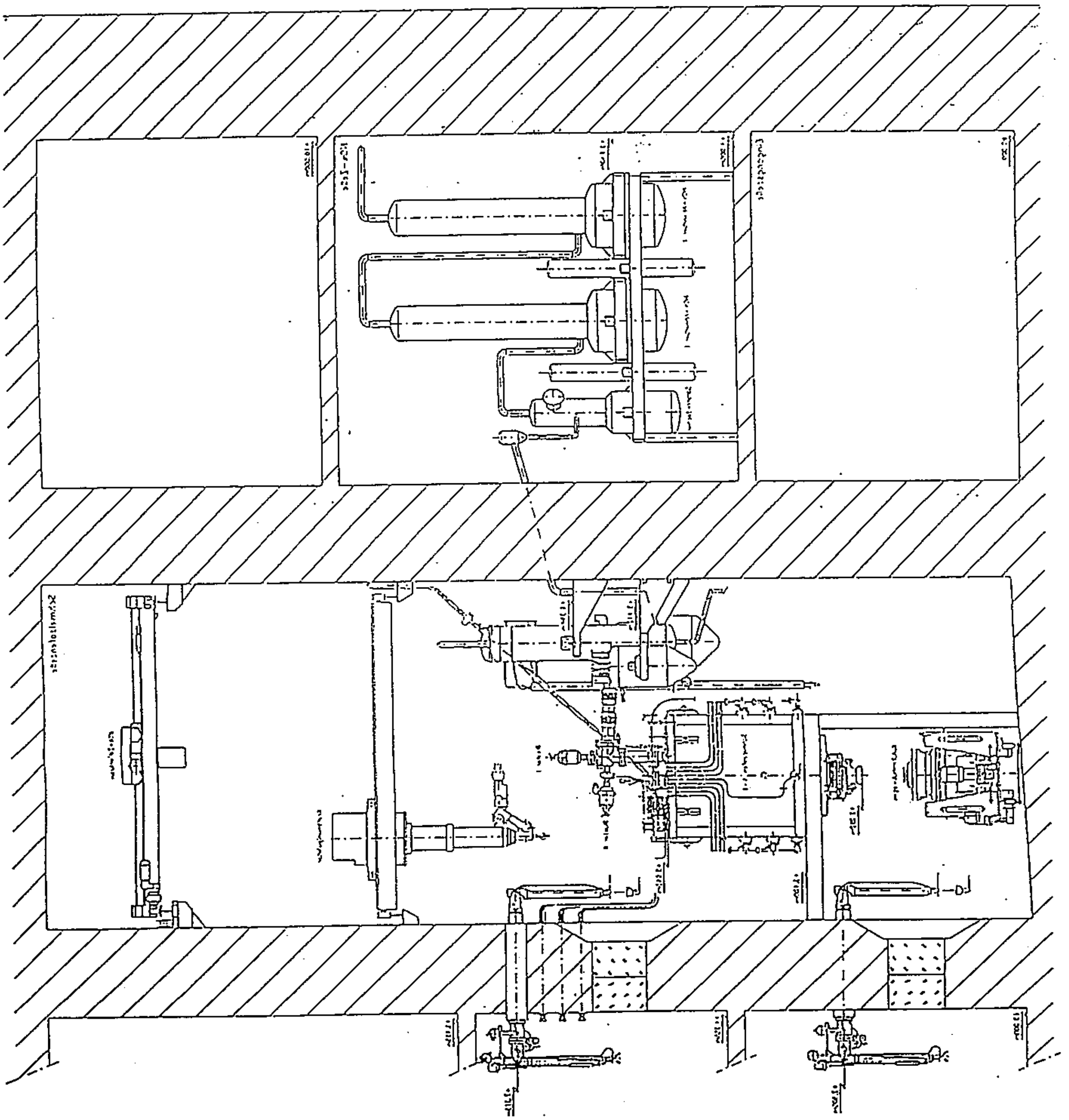


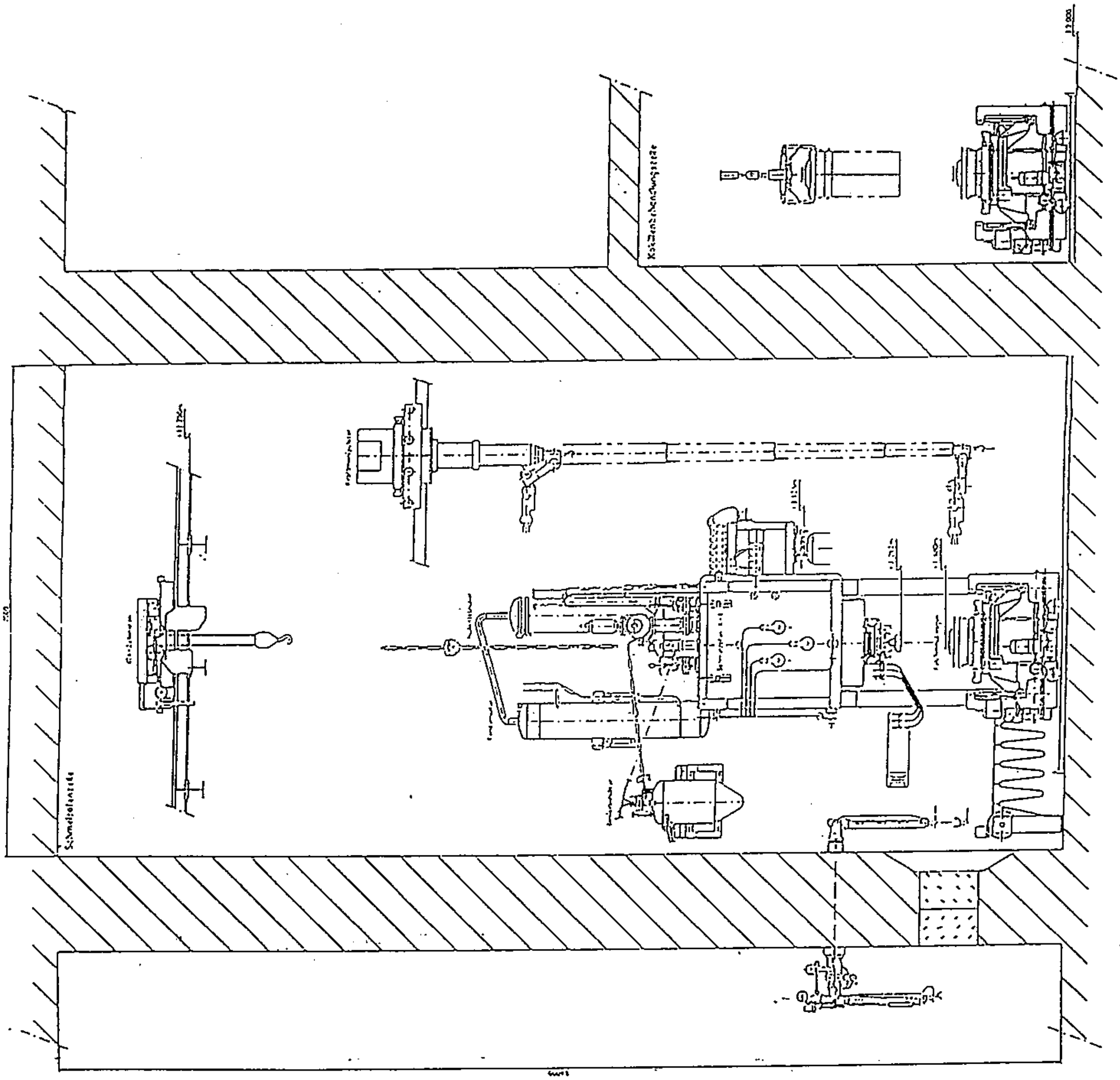
Cell arangement, plan view, level +11 m



Cell arrangement, longitudinal cut canister handling / loading







HAWC-Transfer

- Transport cask (CASTOR)
- Tube channel (underground / above ground)
- Direct transfer

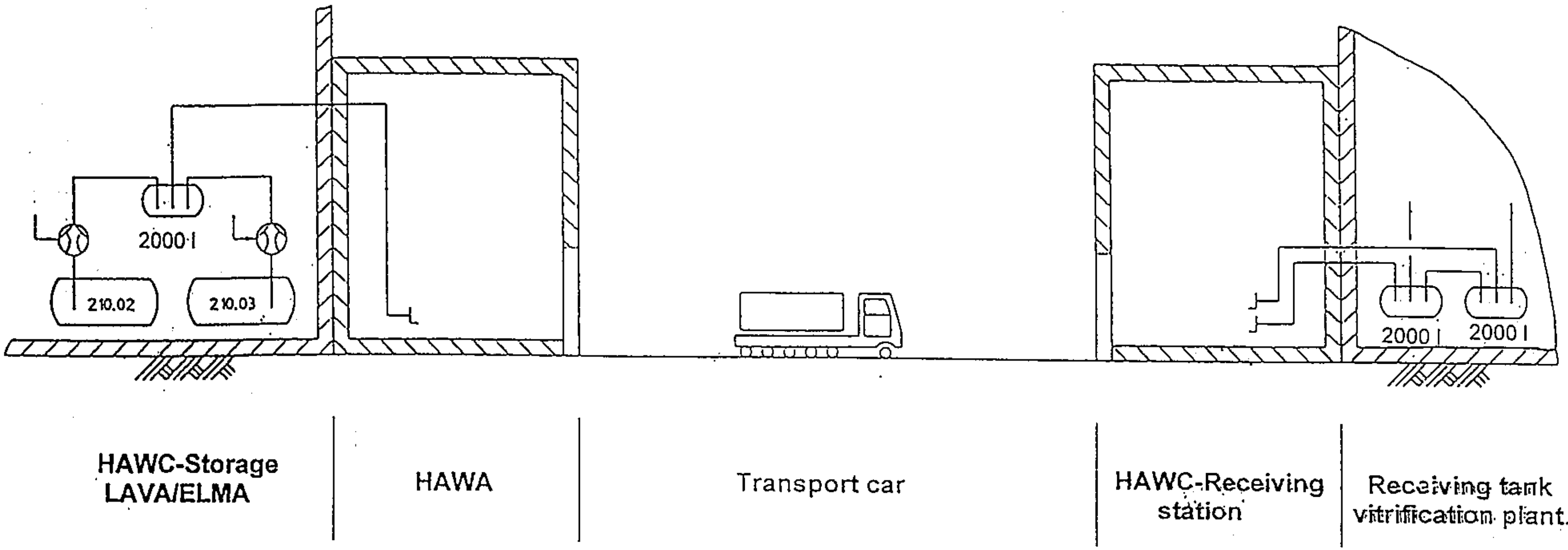
Location

- Installation inside existing WAK / KfK buildings
- New building on WAK site / KfK site

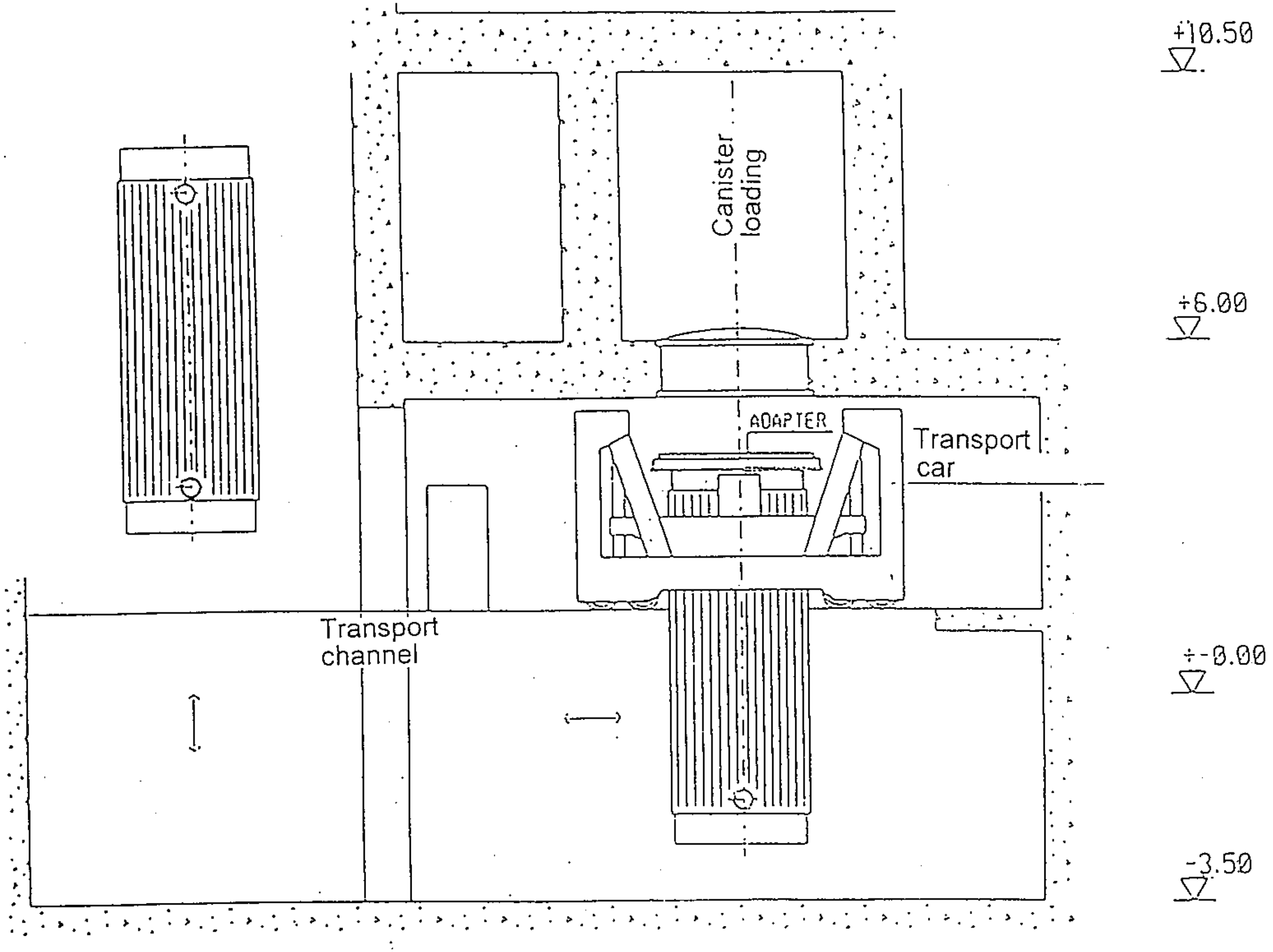
Canister storage

- Direct storage inside existing WAK / KfK buildings
- Direct storage inside new WAK / KfK buildings
- Temporary storage in CASTOR on site
- CASTOR transport to Gorleben

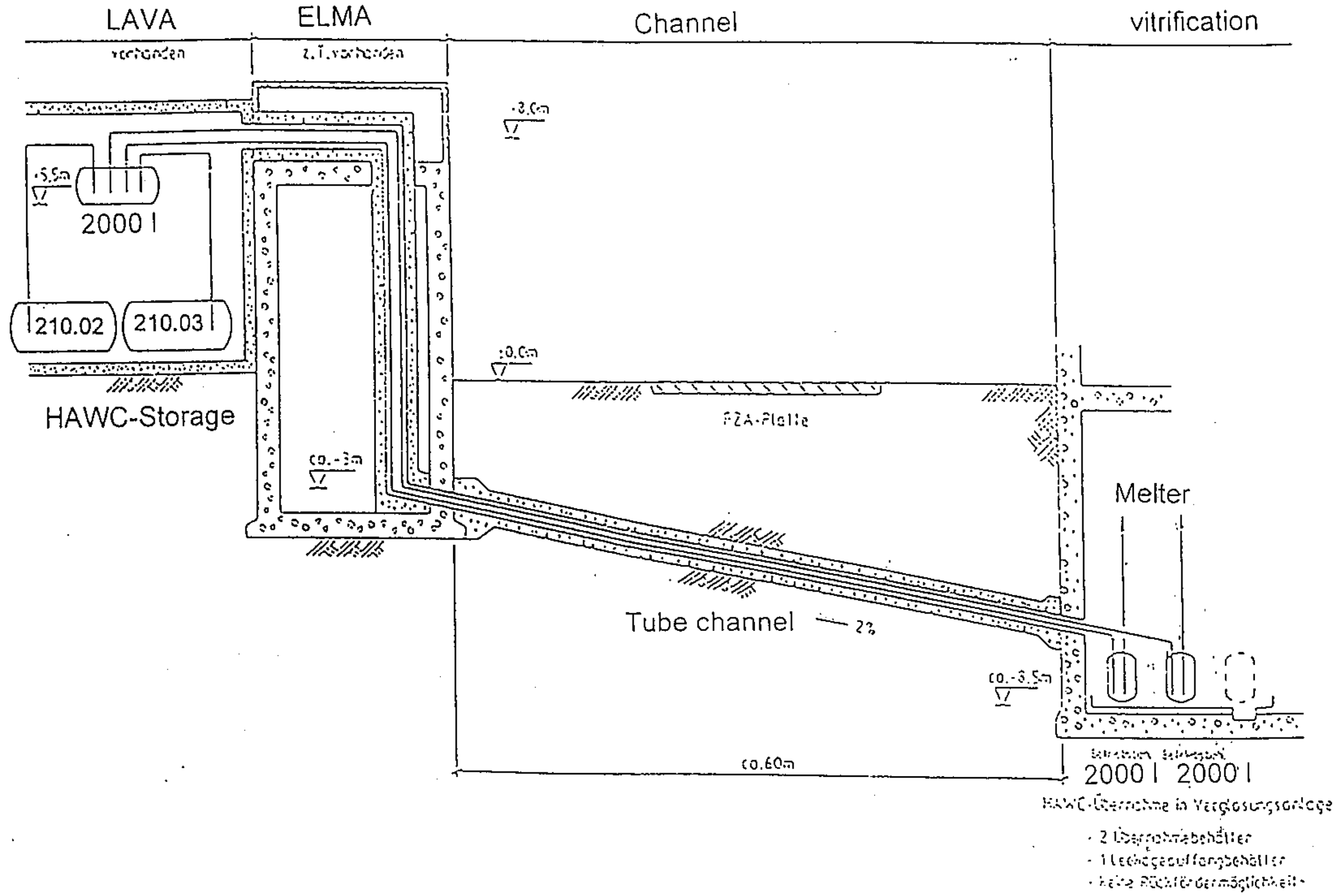
Variants considered for the vitrification plant



HAWC transfer by transport car



Canister loading device for CASTOR



Underground HAWC transfer channel

Time schedule for vitrification plant for on-site

Steps (6/93)	Months
1. Planing of construction, safety report, application	30
2. Examination of application	16
3. Participation of public	12
4. Permission of construction	14
5. Construction of building	18
6. Construction of facility	30
7. Cold test	6
8. Permit of operation	6
9. Vitrification operation	16
Total time in months	148
Total time in years	12

ccfovp.xls

	state of cost' 93	extrapolated
1. Work of building owner	65 Mio DM	74 Mio DM
2. Planning costs	120 Mio DM	136 Mio DM
3. Cost of construction	242 Mio DM	340 Mio DM
4. Operation	36 Mio DM	60 Mio DM
5. Decomissioning, Removal	220 Mio DM	420 Mio DM
6. Glass canister, secondary waste	40 Mio DM	70 Mio DM
7. Operation HAWC storage tanks	340 Mio DM	450 Mio DM
Total costs	1.063 Mio DM	1.550 Mio DM

Costs calculation for the vitrification plant

3.3 Evaluation of the noble metals behavior, ESM feed preparetion system

Vitrification process performance

- Noble metals behavior in the K-6' melter
- ESM - project

12th annual PNC/KfK meeting, Dec. 1993

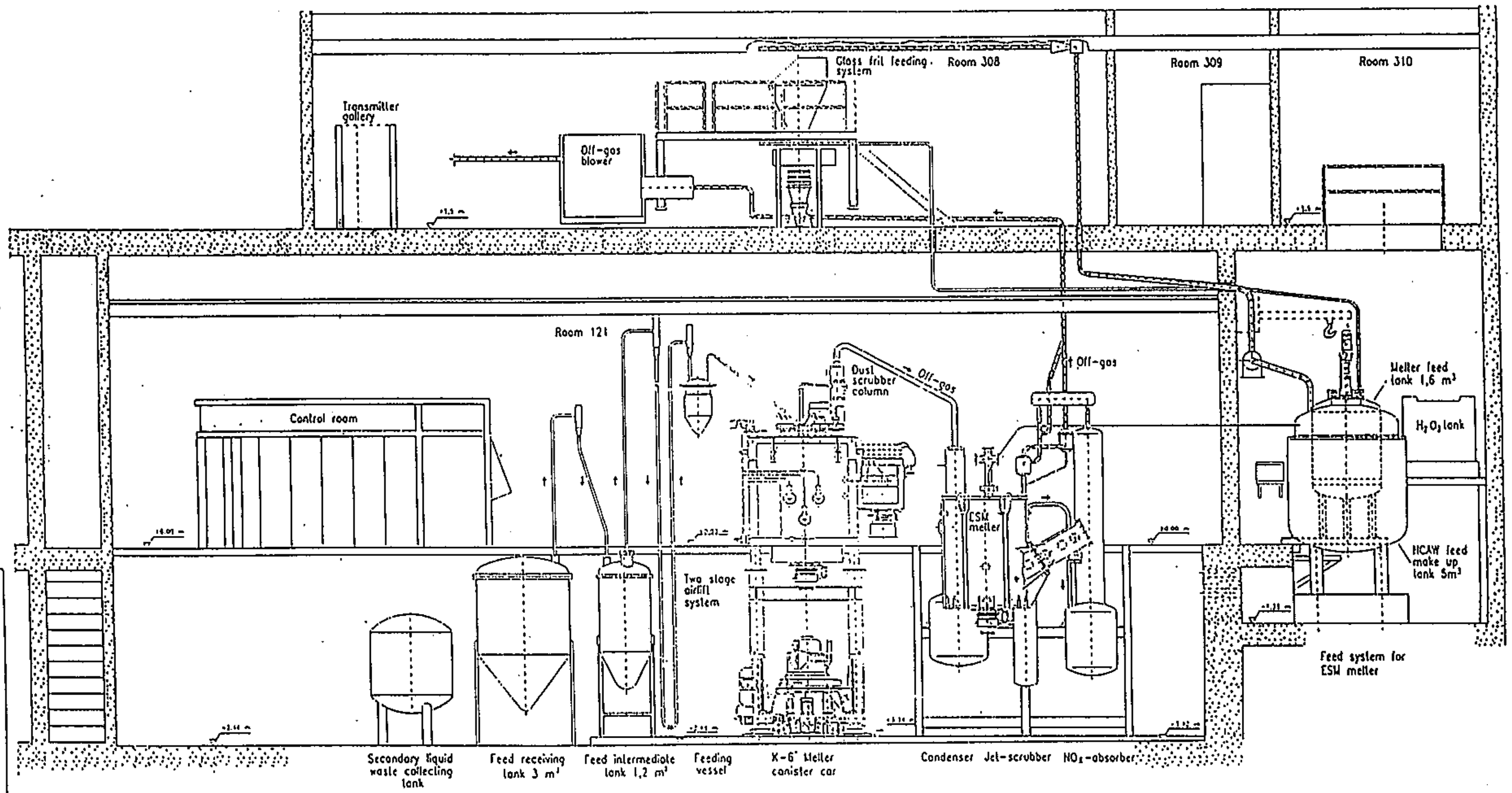


Fig. 4-1: Simplified sketch of the longitudinal cross section of the inactive test facility VA-WAK with the melter K-6'
(integrated in this facility is the ESM melter on the right side of K-6' and its feeding system)

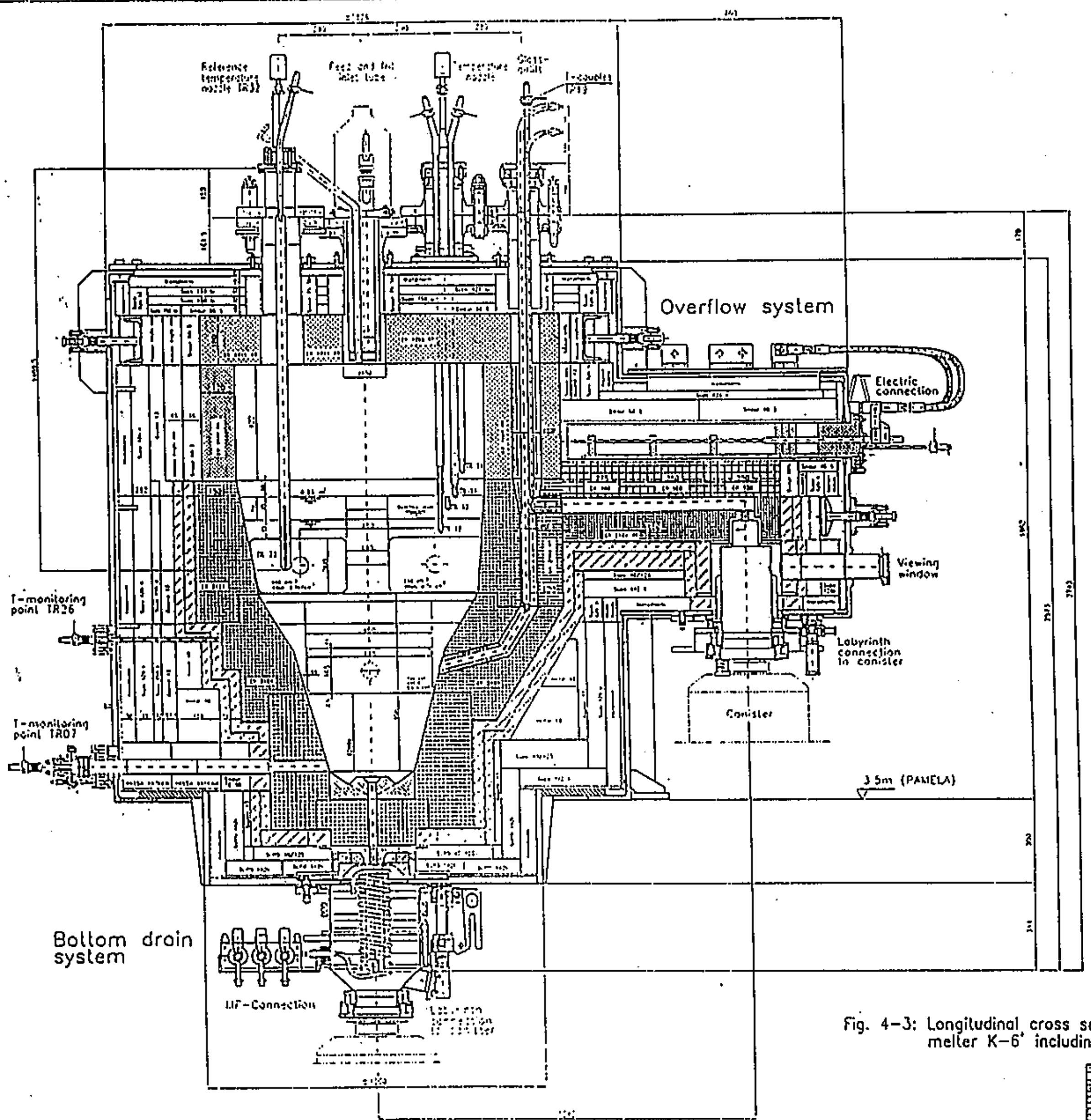


Fig. 4-3: Longitudinal cross section through the prototype melter K-6' including the overflow system

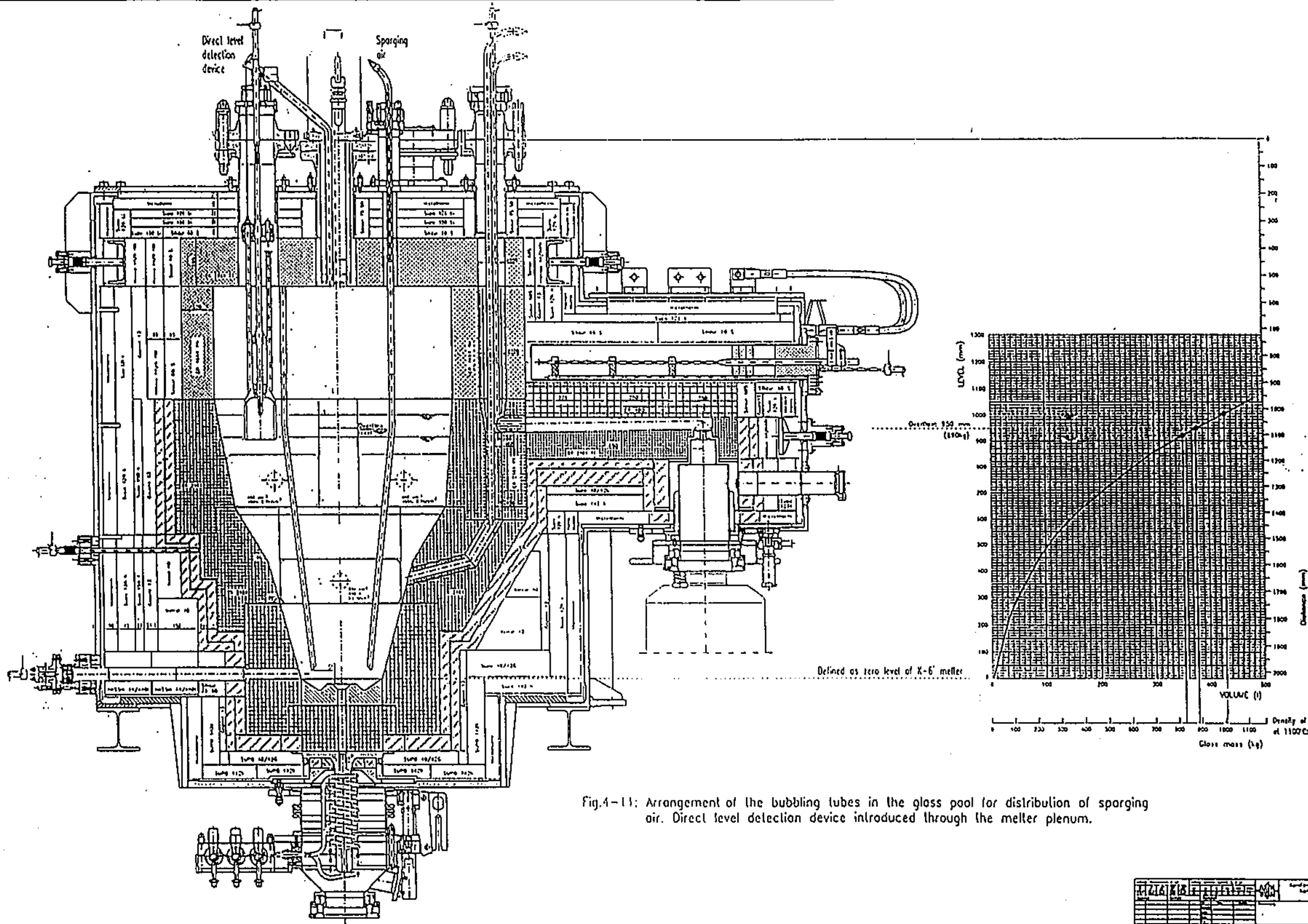


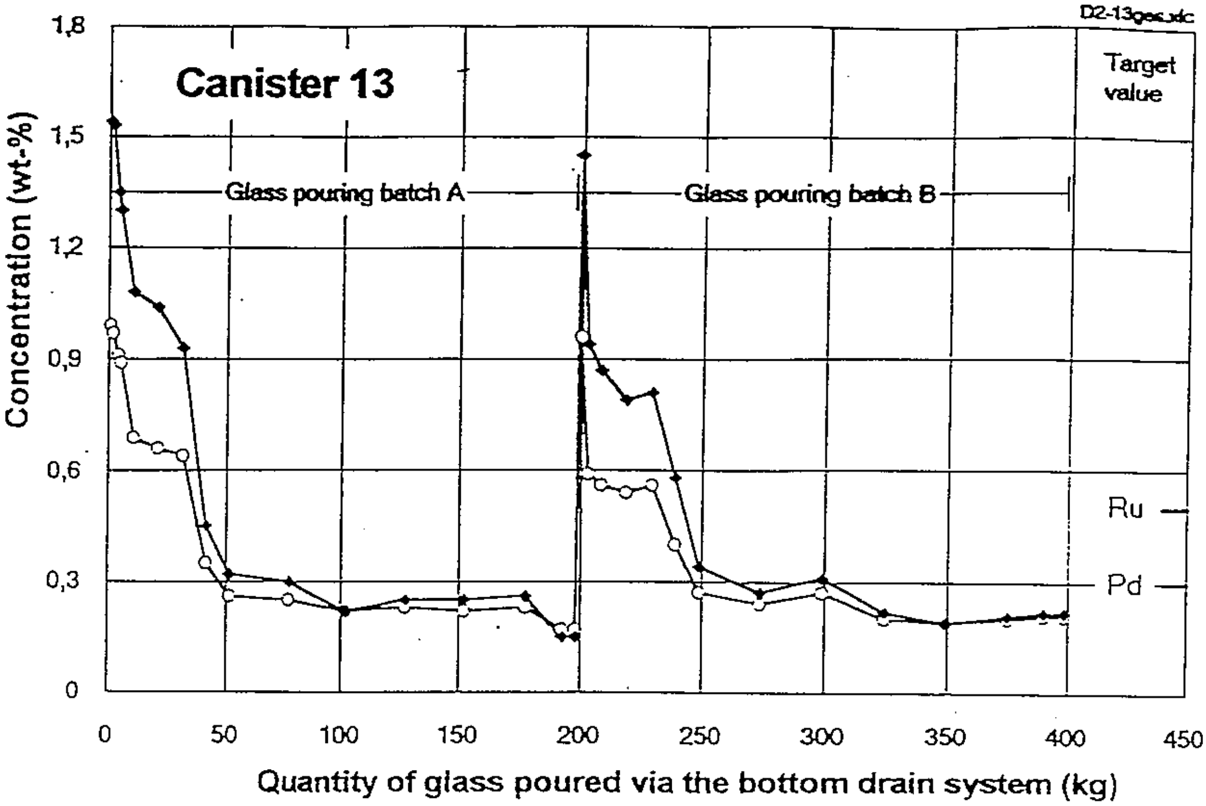
Fig.4－11: Arrangement of the bubbling tubes in the glass pool for distribution of sparging air. Direct level detection device introduced through the melter plenum.

Vitrification runs with the K-6' melter

	D 1	D 2	D 3	D 4	D 5	D 6
Time of operation:	May 25 - June 4, 1990	June 4 - 24, 1990	April 13 - 18, 1991	June 5 - 26, 1991 (42 h idling)	Feb. 17 - March 28, 1992 (336 h idling)	March 25 - July 1, 1993 (286 h idling)
Feed type	HAWC-WAK <u>no</u> noble metals	HAWC-WAK Tank 210.02 2,91 g/l Ru 1,75 g/l Pd	– glass product feeding	HAWC-WAK Tank 210.02 2,91 g/l Ru 1,75 g/l Pd	HAWC-WAK Blend of Tank 210.02 + 210.03 2,28 g/l Ru 1,32 g/l Pd	HAW-WAK Blend of Tank 210.02 + 210.03 + undissolved Zr 2,28 g/l Ru 1,32 g/l Pd
Total volume, m^3	5	10,3 (30 kg Ru 18 kg Pd)		9,6 (28 kg Ru 17 kg Pd)	15,4 (35 kg Ru 20 kg Pd)	15,9 (36 kg Ru 21 kg Pd)
glass frit	SWA 752	SWA 752		SWA 752	GG-WAK 1	GG-WAK 1
glass loading, wt.%	13	14 (0,5 wt-% Ru 0,3 wt-% Pd)		13,9 (0,5 wt-% Ru 0,3 wt-% Pd)	14,3 (0,4 wt-% Ru 0,23 wt-% Pd)	13,8 (0,38 wt-% Ru 0,22 wt-% Pd)
glass product, to	2,5	5,9	0,8	5,6	8,7	9,3
number of pourings	15	30	8	28	42	47
glass pouring via	bottom drain	bottom drain	overflow drain	overflow drain	bottom drain	overflow drain

Vitrification runs with the K-6' melter, continued

	D1	D2	D3	D4	D5	D6
Feed throughput, l/h	26-28	25	-	30 (max 35)	36	34
glass production rate, kg/h	15,4	13	14	15,7 (max 18,3)	18	17,9
pouring batch, kg	195	195	100	195	195	195
glass production yield, g/l	585	580	-	580	594	594
total melter power, kW (average)	80	82		85	85	80
power skew (upper to lower electr.)	2:1	2:1		3:1	4:1	7:1
glass pouring rate, kg/h	100-120	100-120		100-120	100-120	100-130
time availability, %	100	100		98	100	100
bubbling air	no	no	yes (600 l/h each tube)	yes (600, 400, 200 l/h each tube)	no	yes
Draining of the melter		^ 2,2 kg Ru, 1,5 kg Pd			^ 3,4 kg Ru, 2 kg Pd	



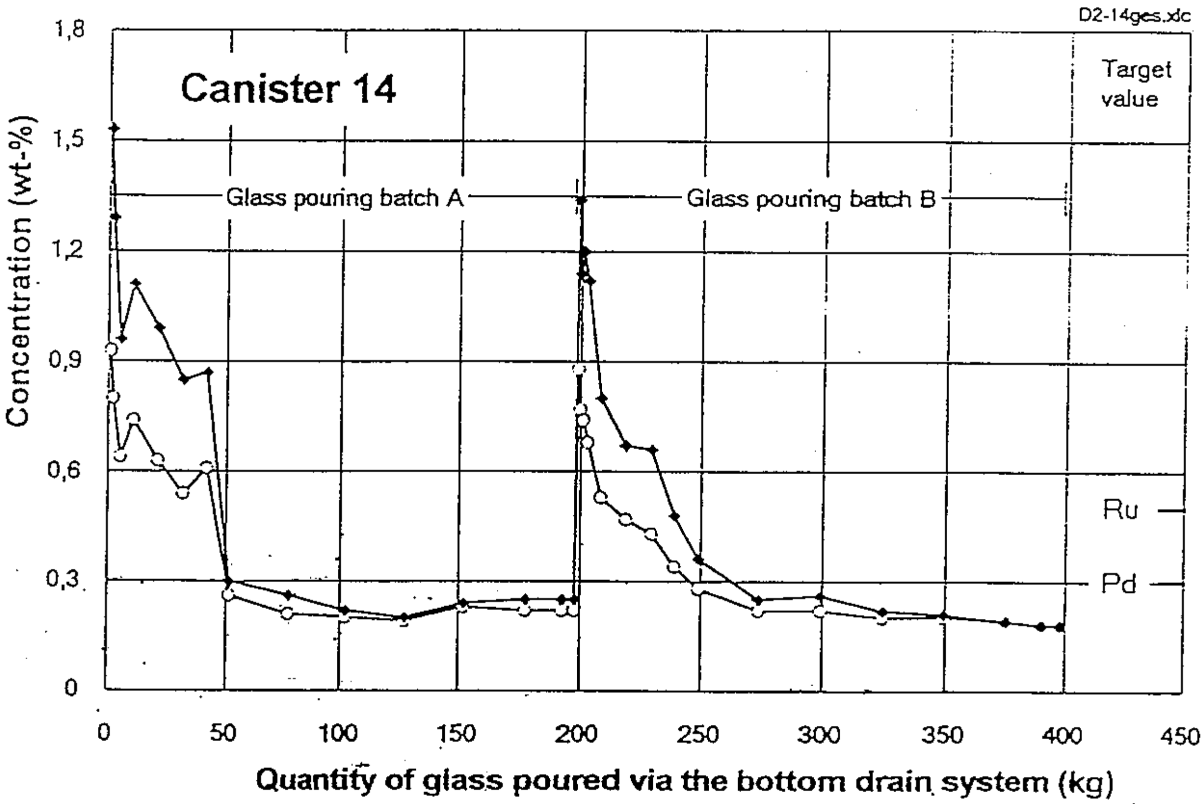
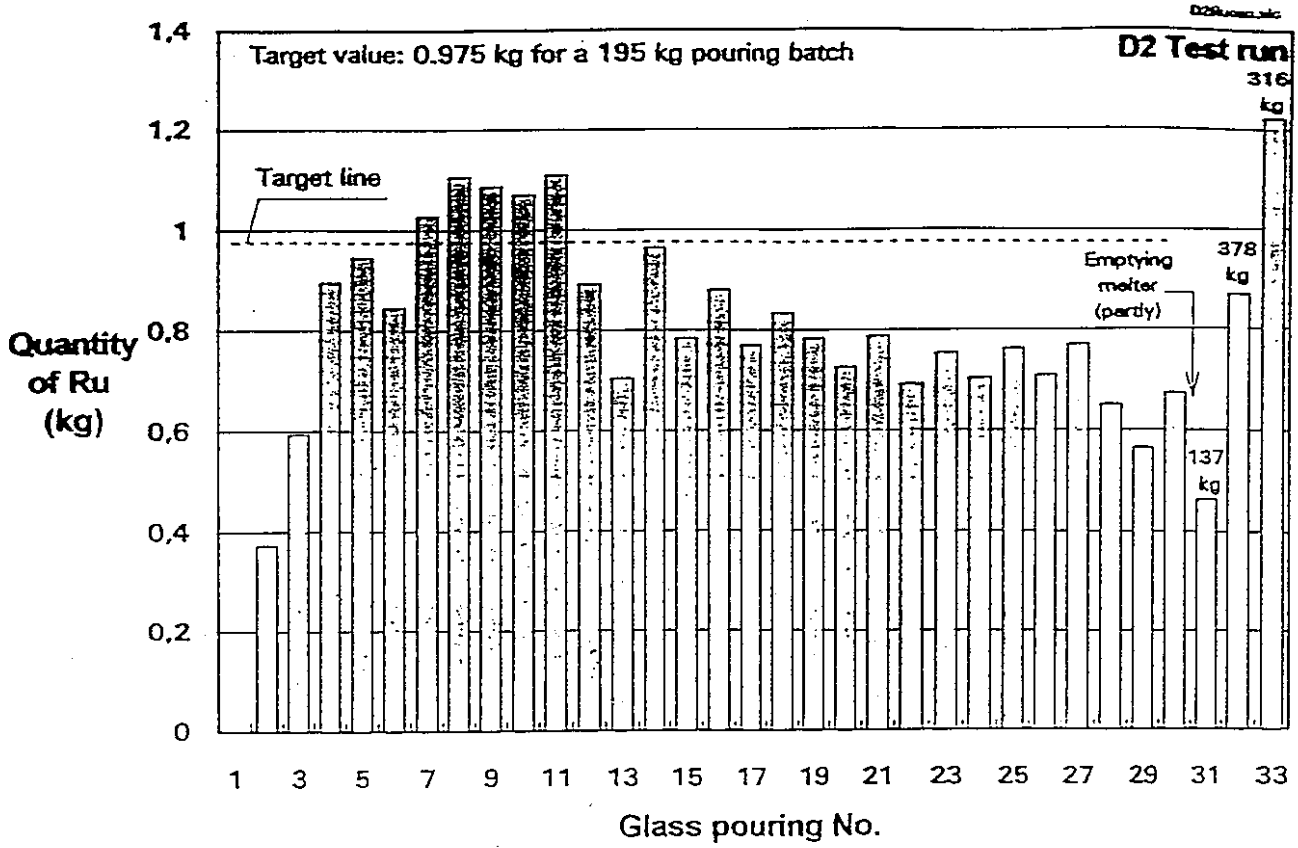


図3.2-10

Fig. 6-7g : Noble metal concentrations in glass samples taken from pouring stream while filling canister 13 and 14 of the D2 test run



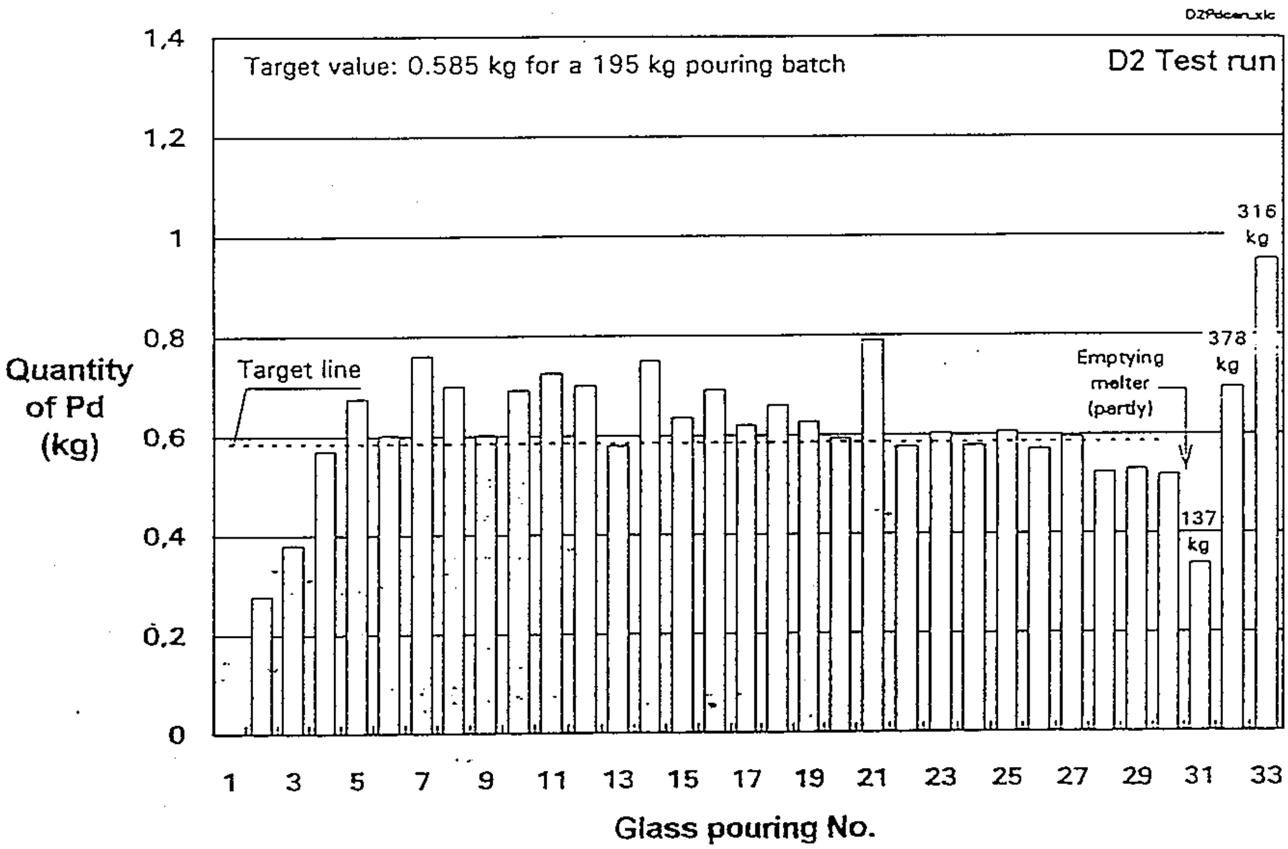


Fig. 6-8: Quantity of Ruthenium and Palladium, respectively, removed from melter by glass pouring via the bottom drain system. Test run D2; June 1990

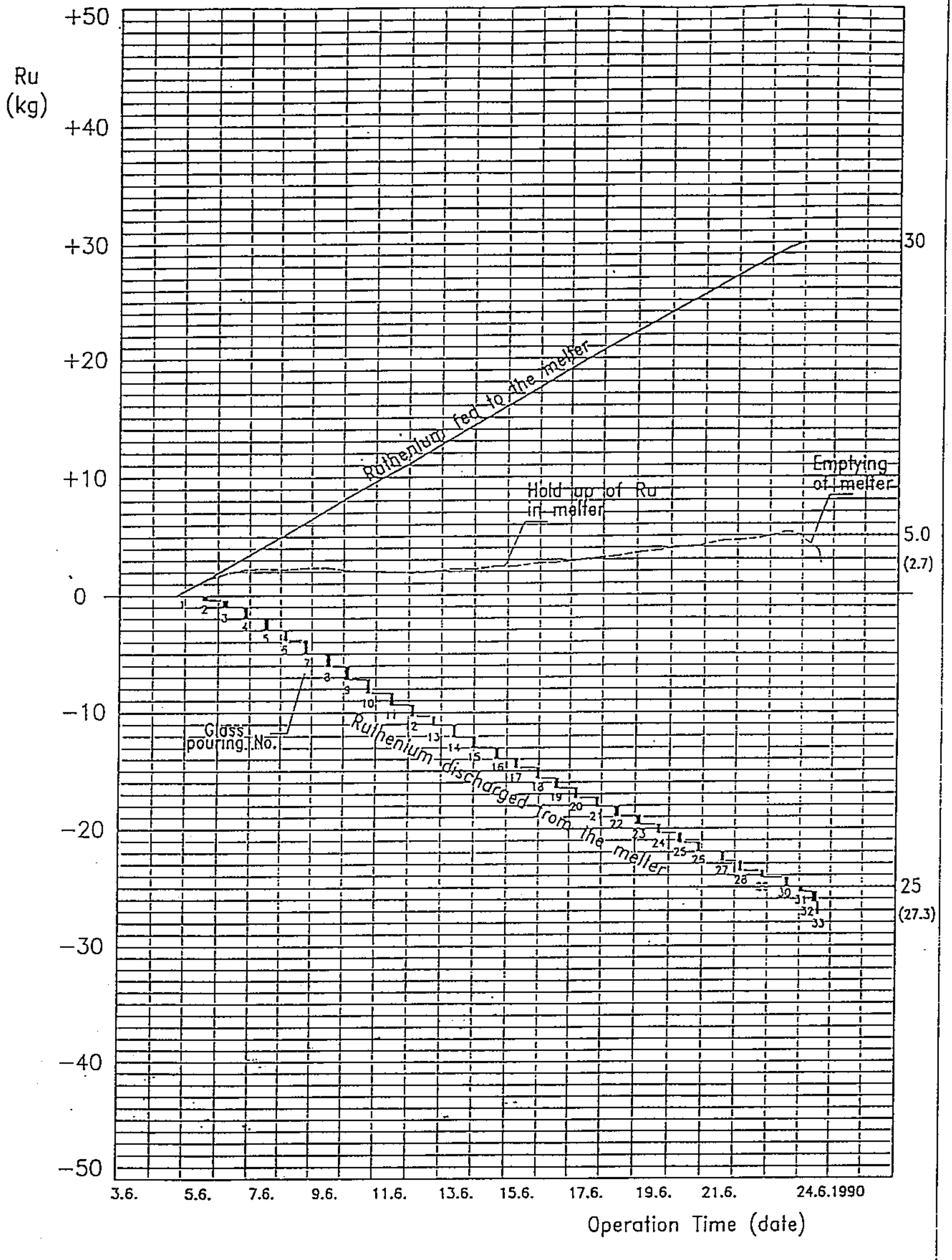


Fig.6−9a: Input and removal of Ruthenium from the K−6' melter during the long−term noble metals test run D2

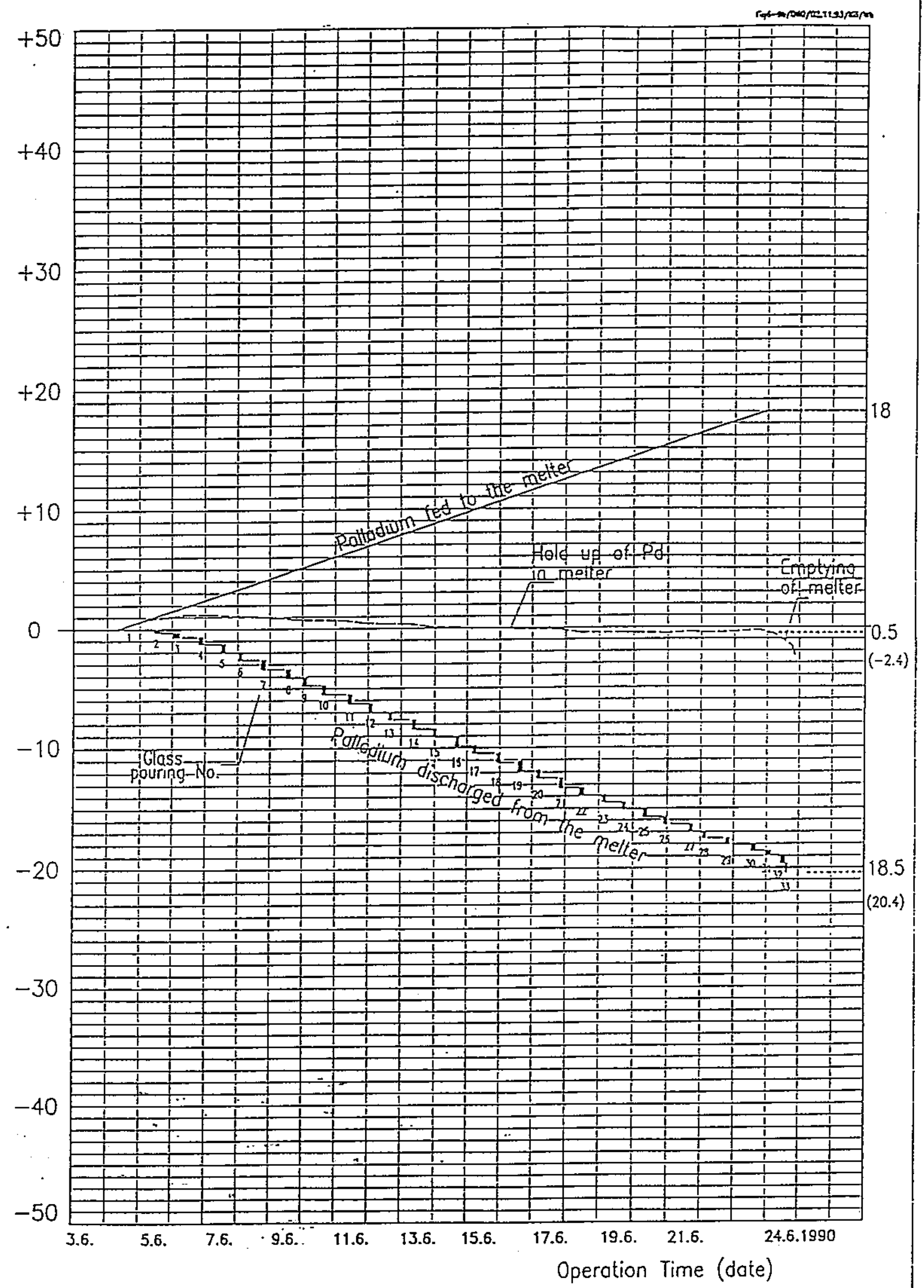
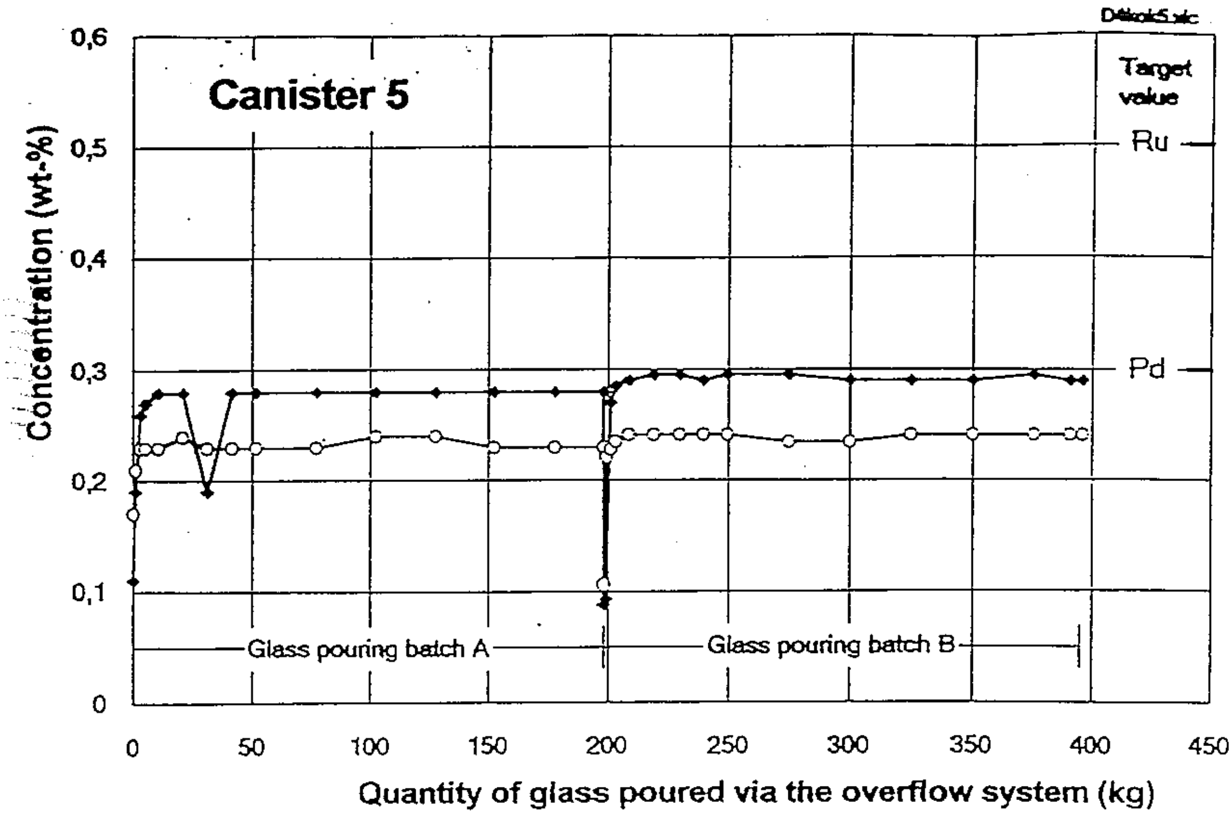


Fig.6-9b: Input and removal of Palladium from the K-6' melter during the long-term noble metals test run D2



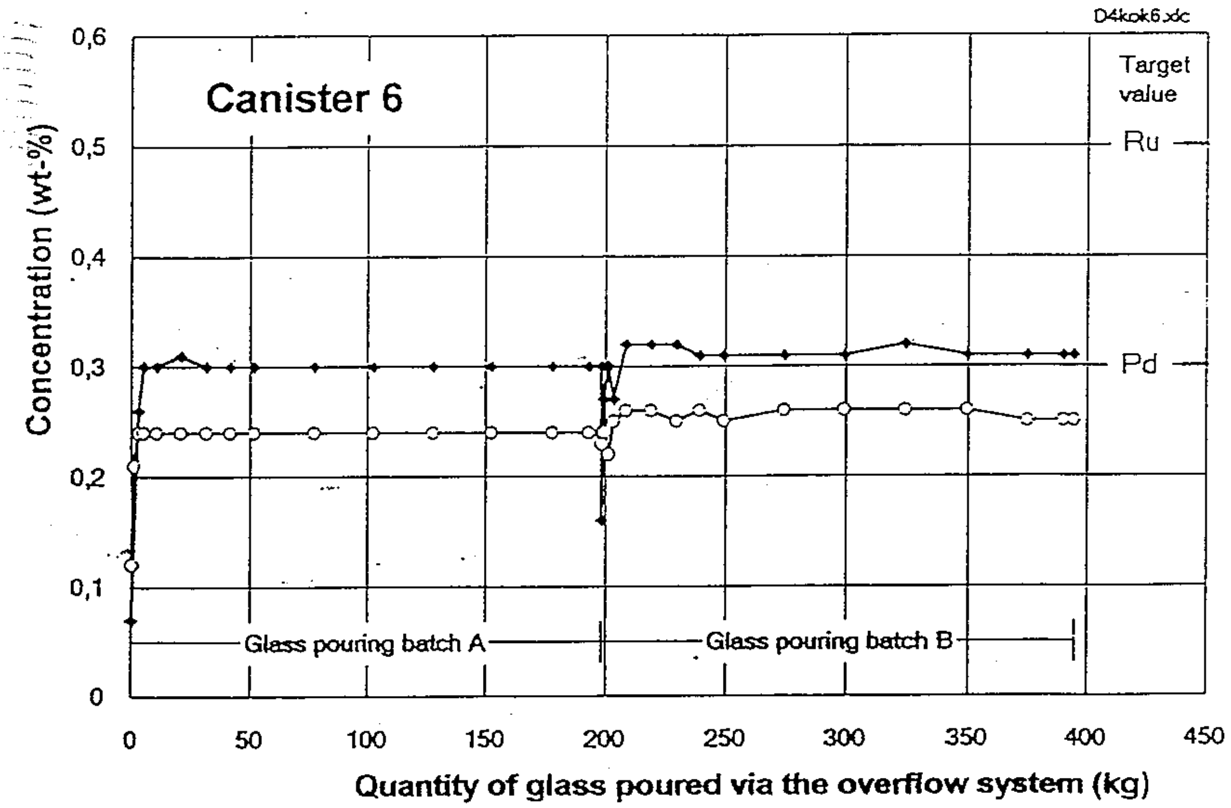
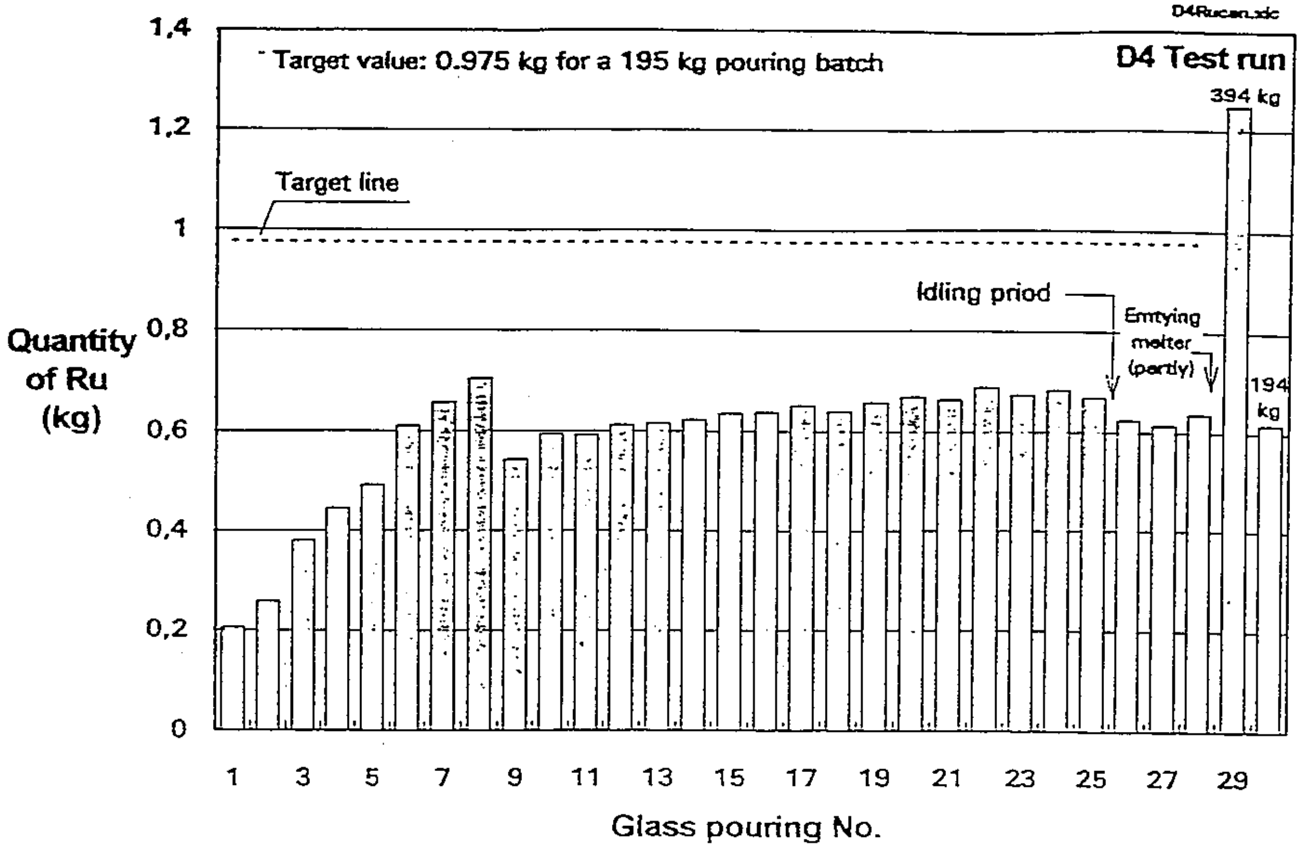


Fig. 6-17c : Noble metal concentrations in glass samples taken from pouring stream while filling canister 5 and 6 of the D4 test run



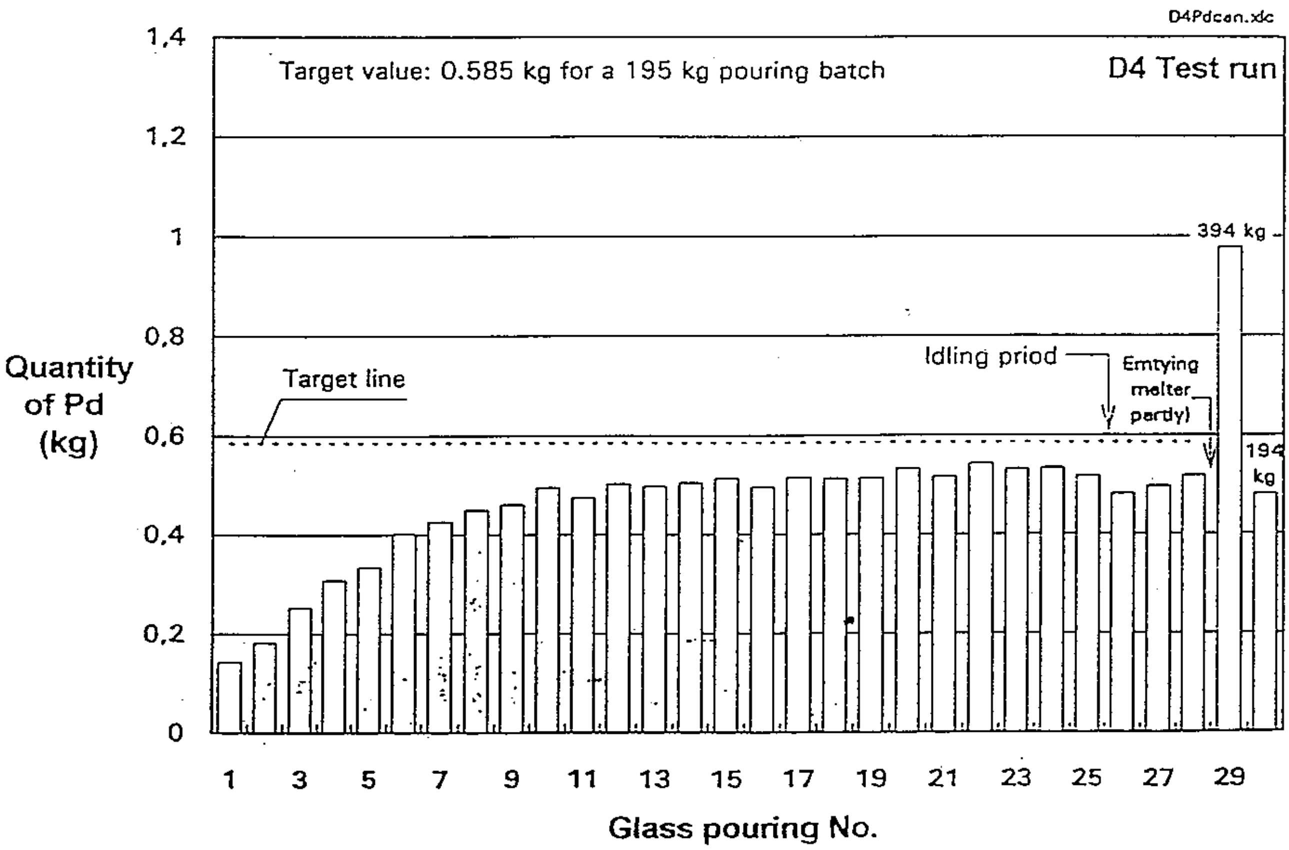


Fig. 6-18: Quantity of Ruthenium and Palladium, respectively, removed from melter by glass pouring via the overflow system. Test run D4, June 1991

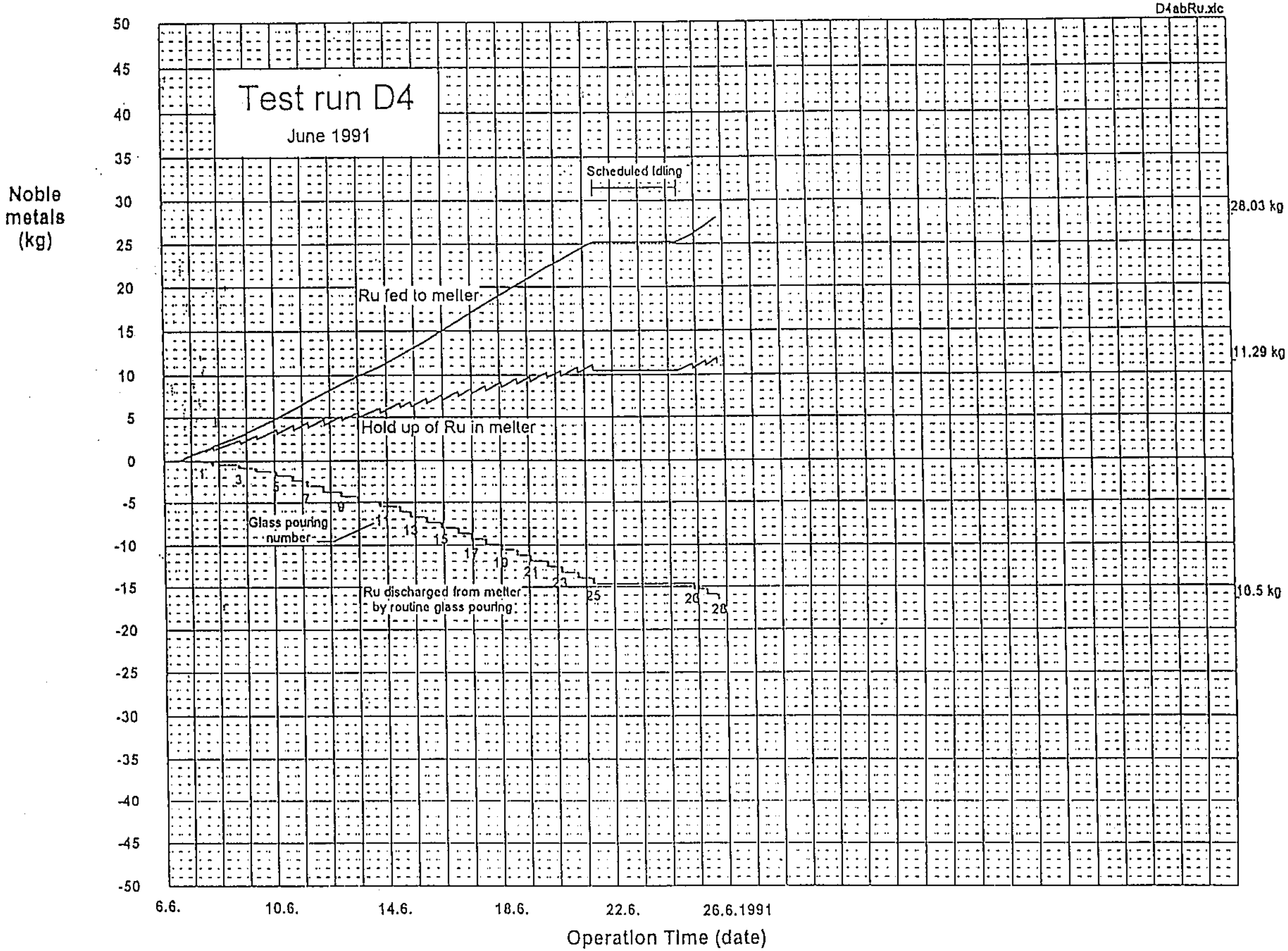


Fig. 6-19 : Input and removal of Ruthenium from the K-6' melter during the long-term noble metals test run D4

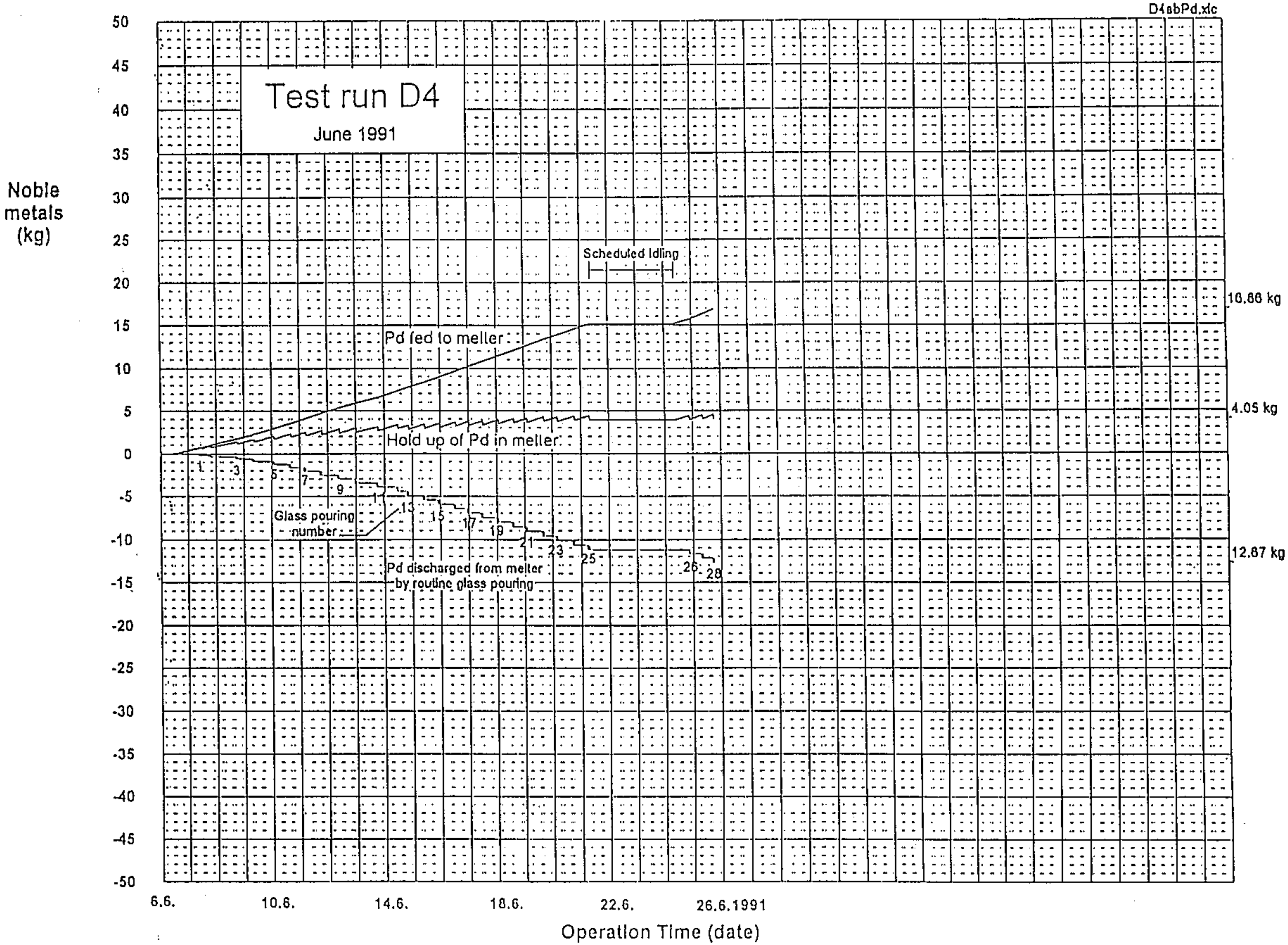
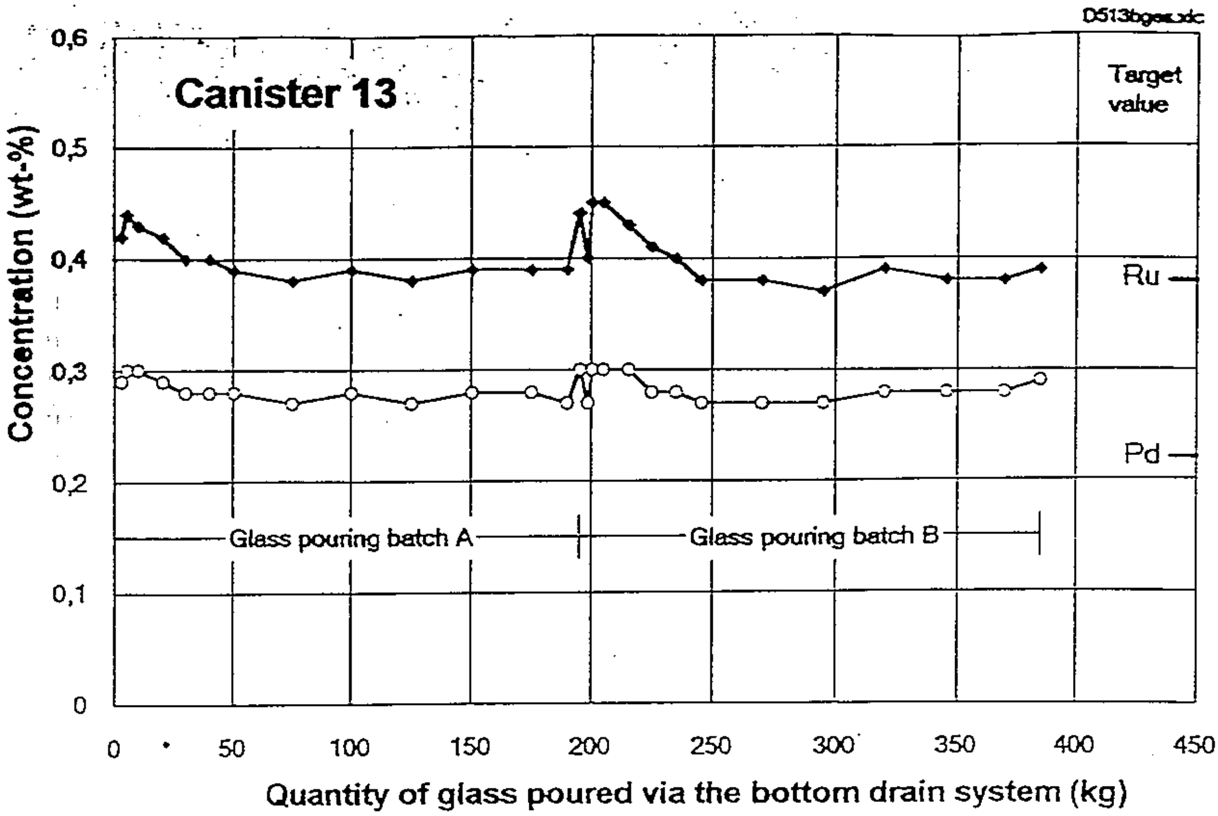


Fig. 6-20 : Input and removal of Palladium from the K-6' melter during the long-term noble metals test run D4



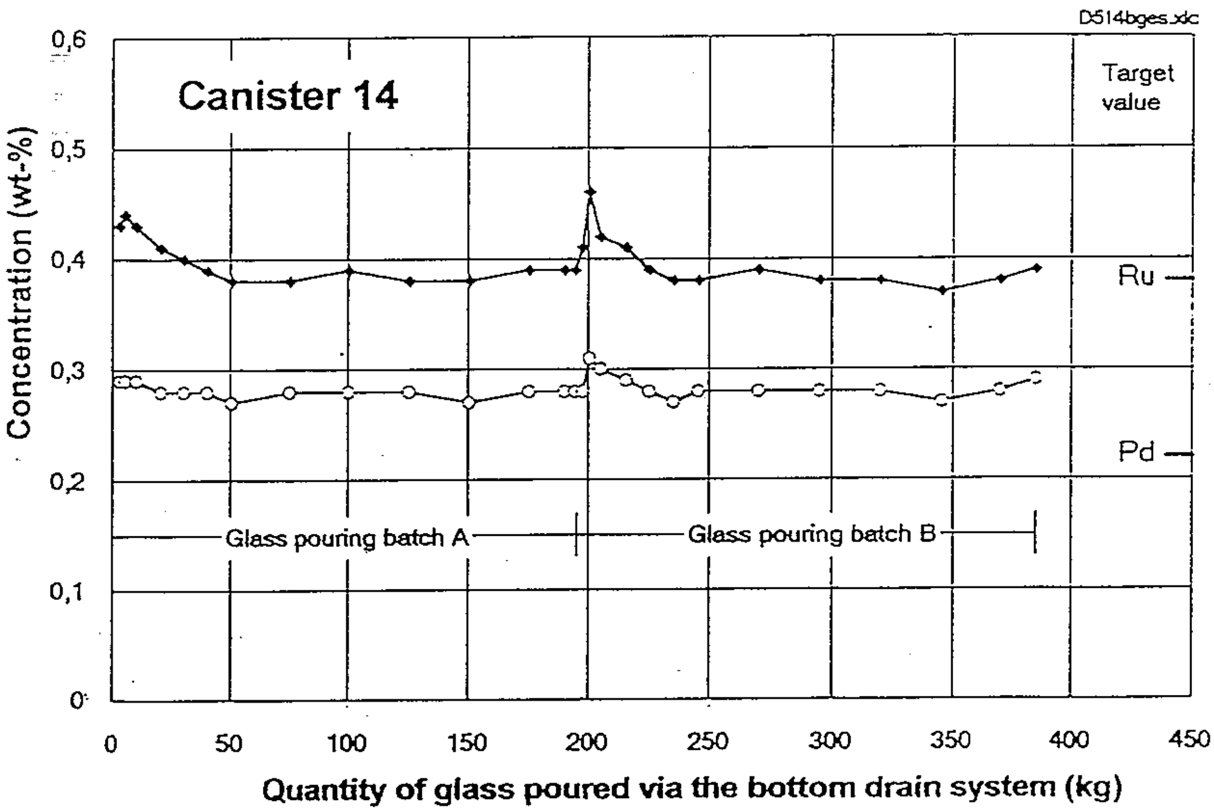


Fig. 7-7g : Noble metal concentrations in glass samples taken from pouring stream while filling canister 13 and 14 of the D5 test run

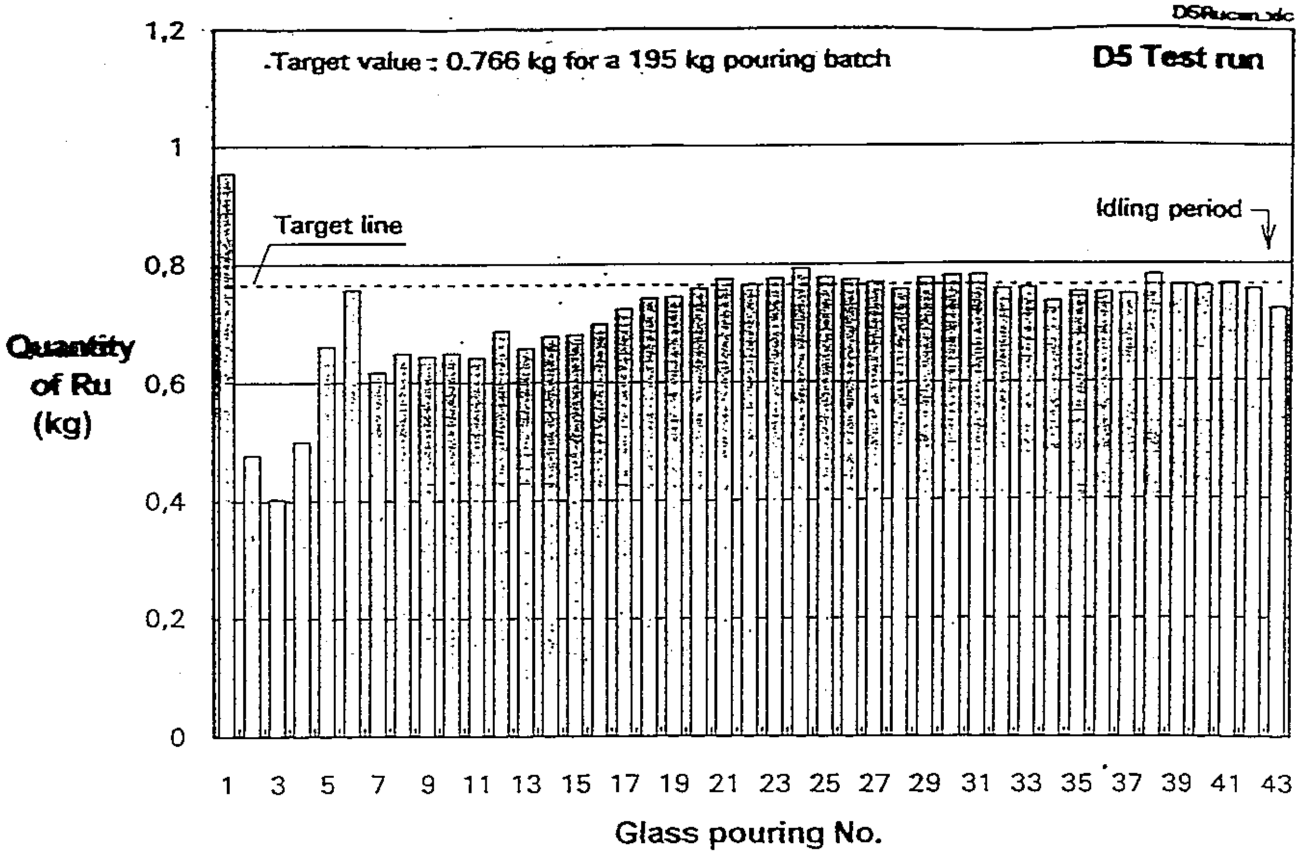


Fig. 7-8: Quantity of Ruthenium removed from melter by glass pouring via the bottom drain system. Test run D5, February/March 1992.

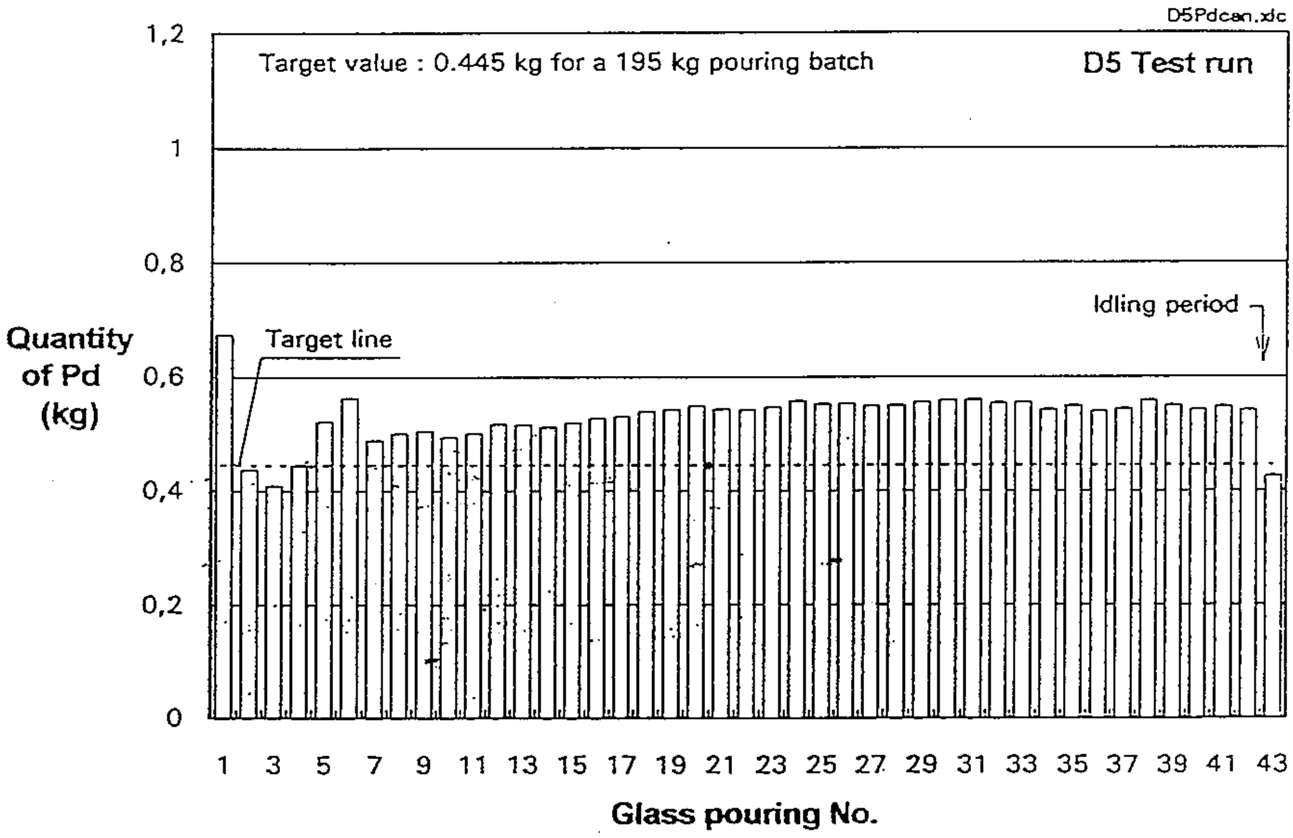


Fig. 7-9: Quantity of Palladium removed from melter by glass pouring via the bottom drain system. Test run D5, February/March 1992.

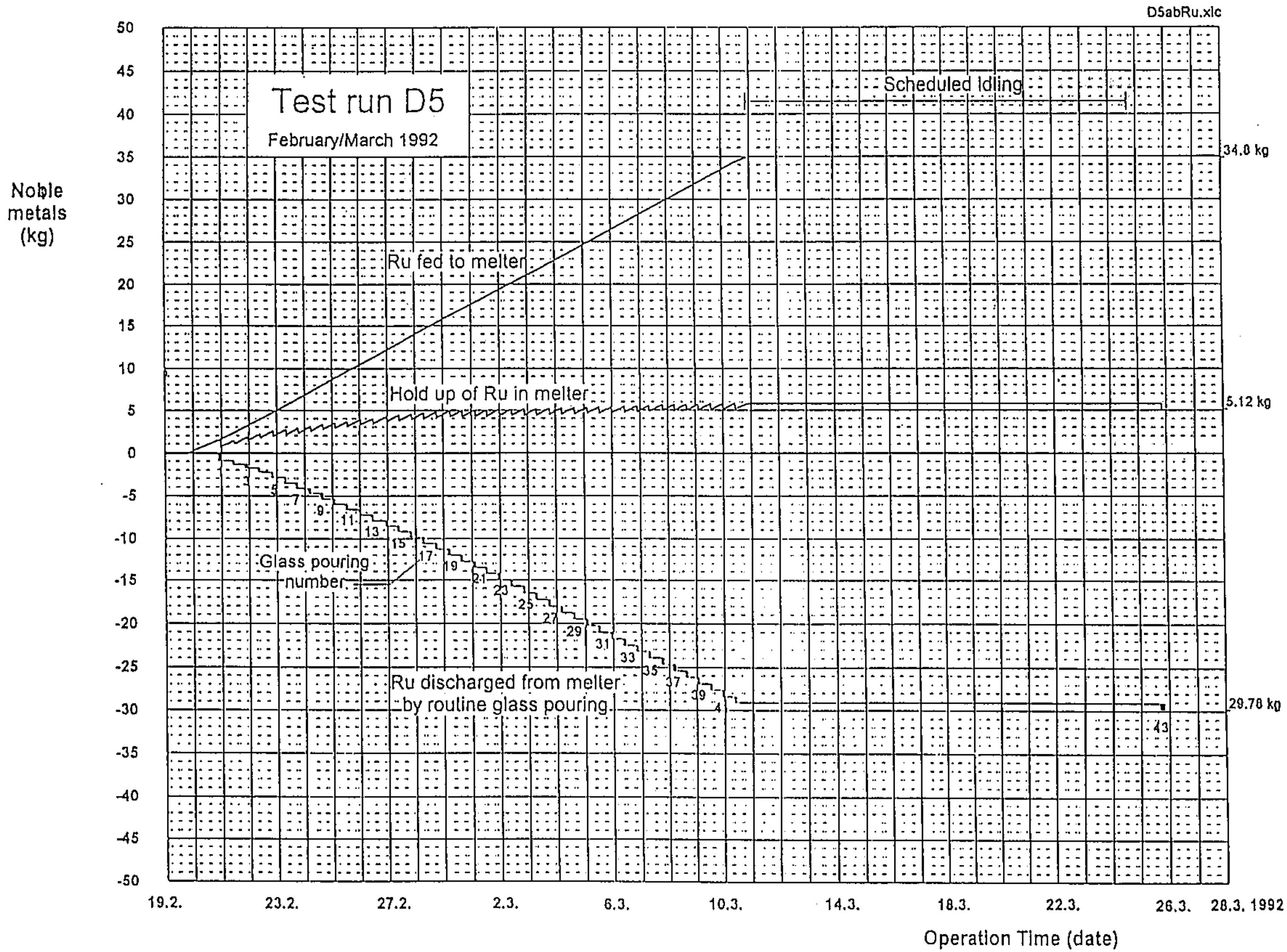


Fig. 7-10a : Input and removal of Ruthenium from the K-6' melter during the long-term noble metals test run D5

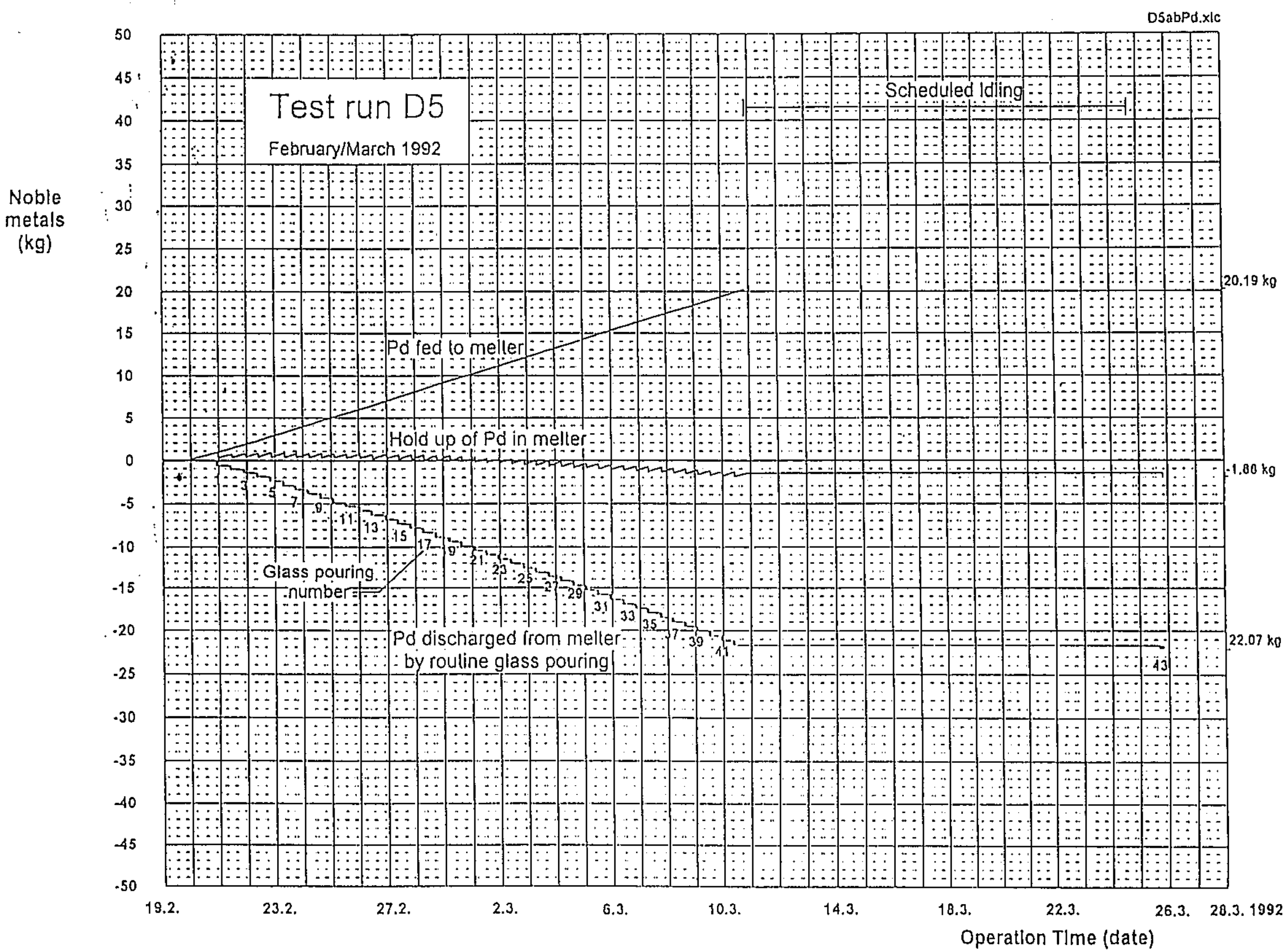
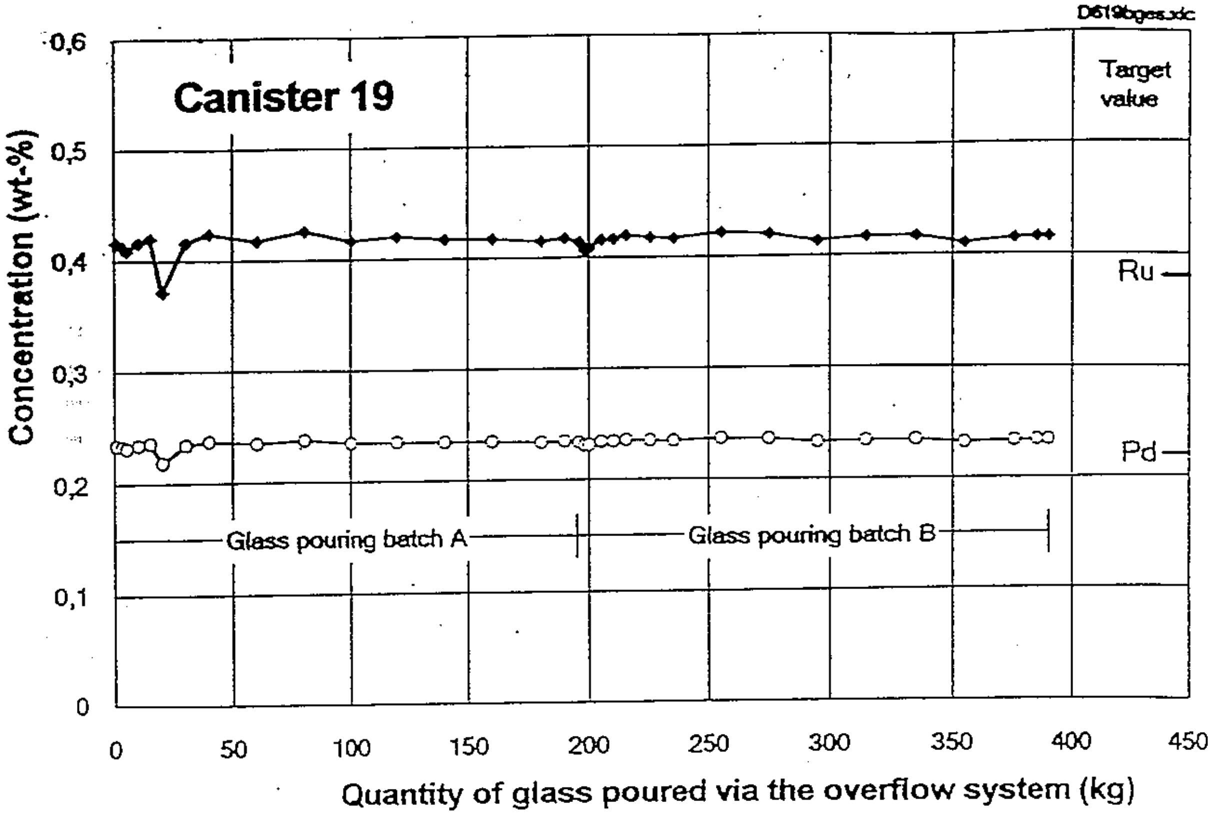


Fig. 7-10b : Input and removal of Palladium from the K-6' melter during the long-term noble metals test run D5



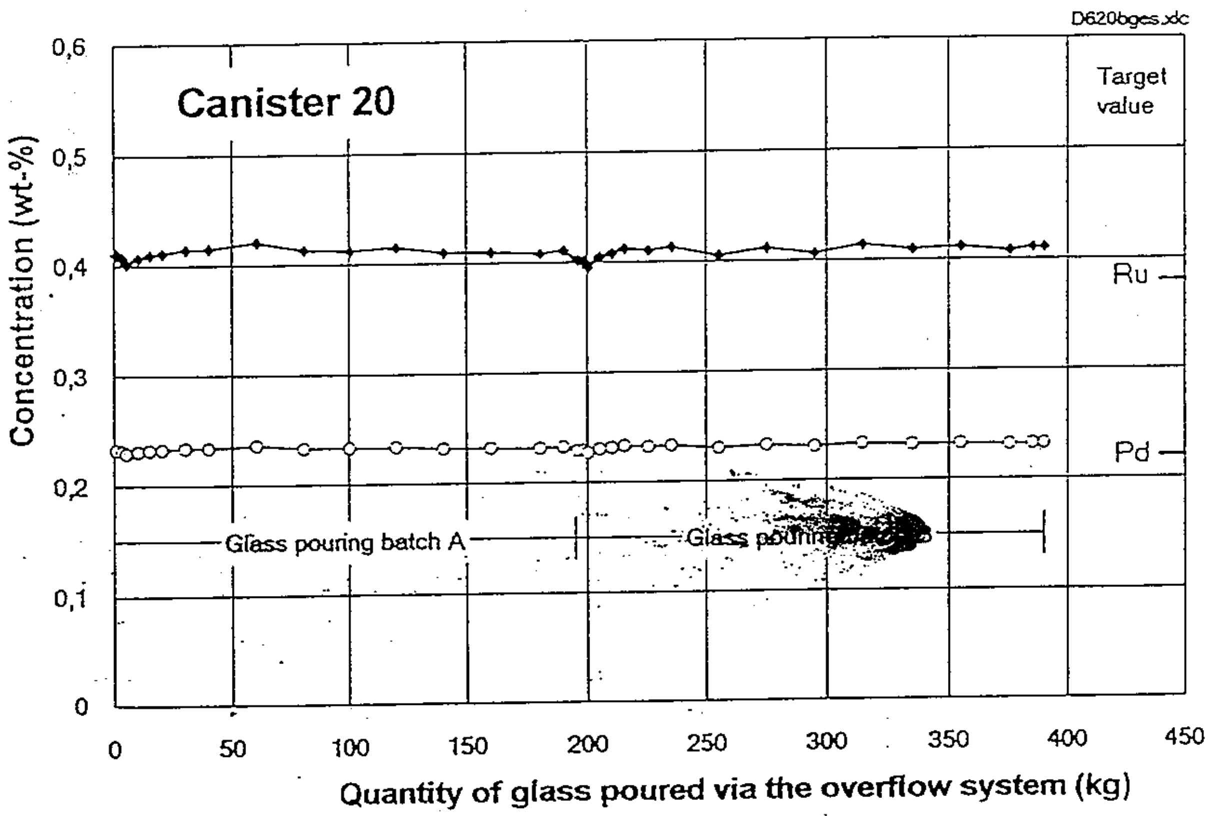
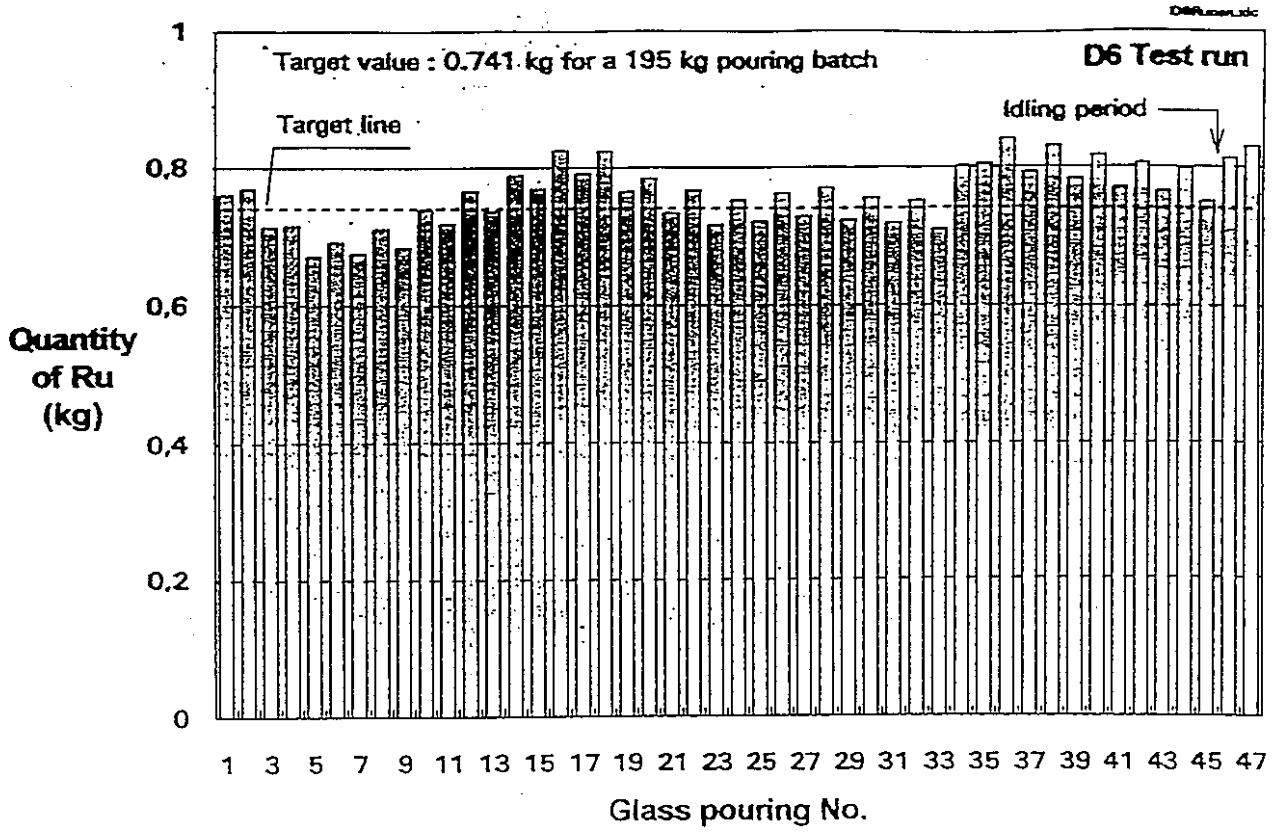


Fig. 7-22j : Noble metal concentrations in glass samples taken from pouring stream while filling canister 19 and 20 of the D6 test run



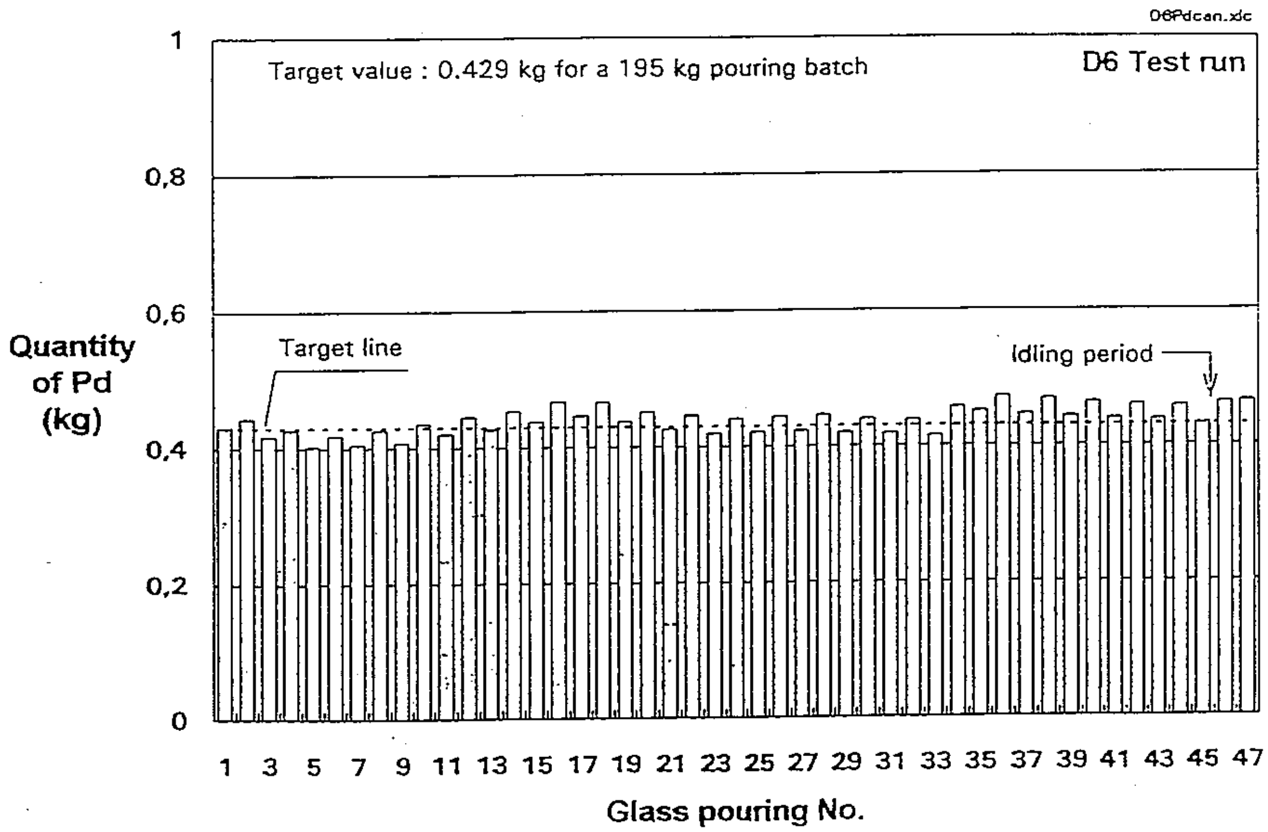


Fig. 7-23: Quantity of Ruthenium and Palladium, respectively, removed from melter by glass pouring via the overflow system. Test run D6 May/June 1993

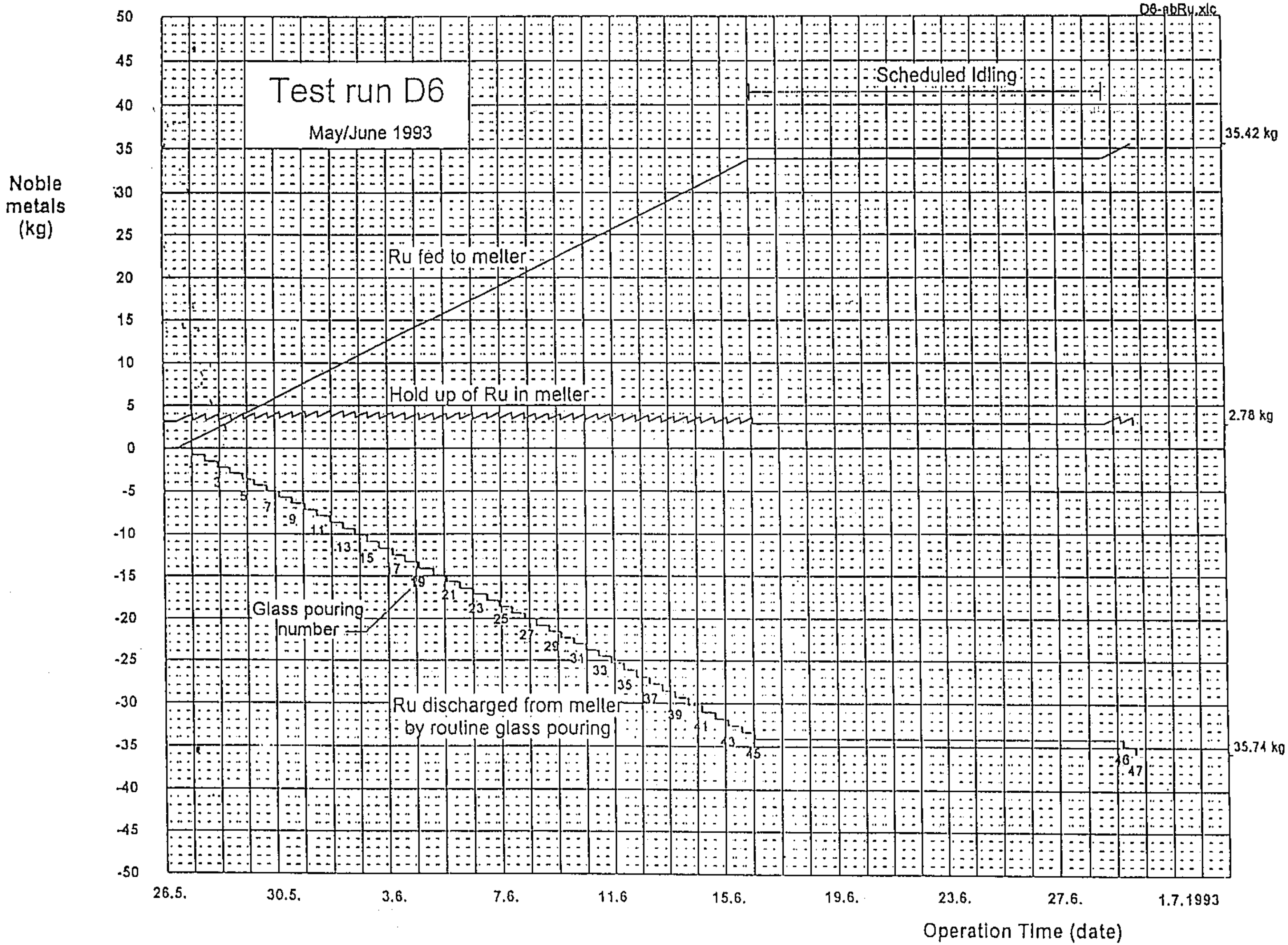


Fig. 7- 24: Input and removal of Ruthenium from the K-6' melter during the long-term noble metals test run D6

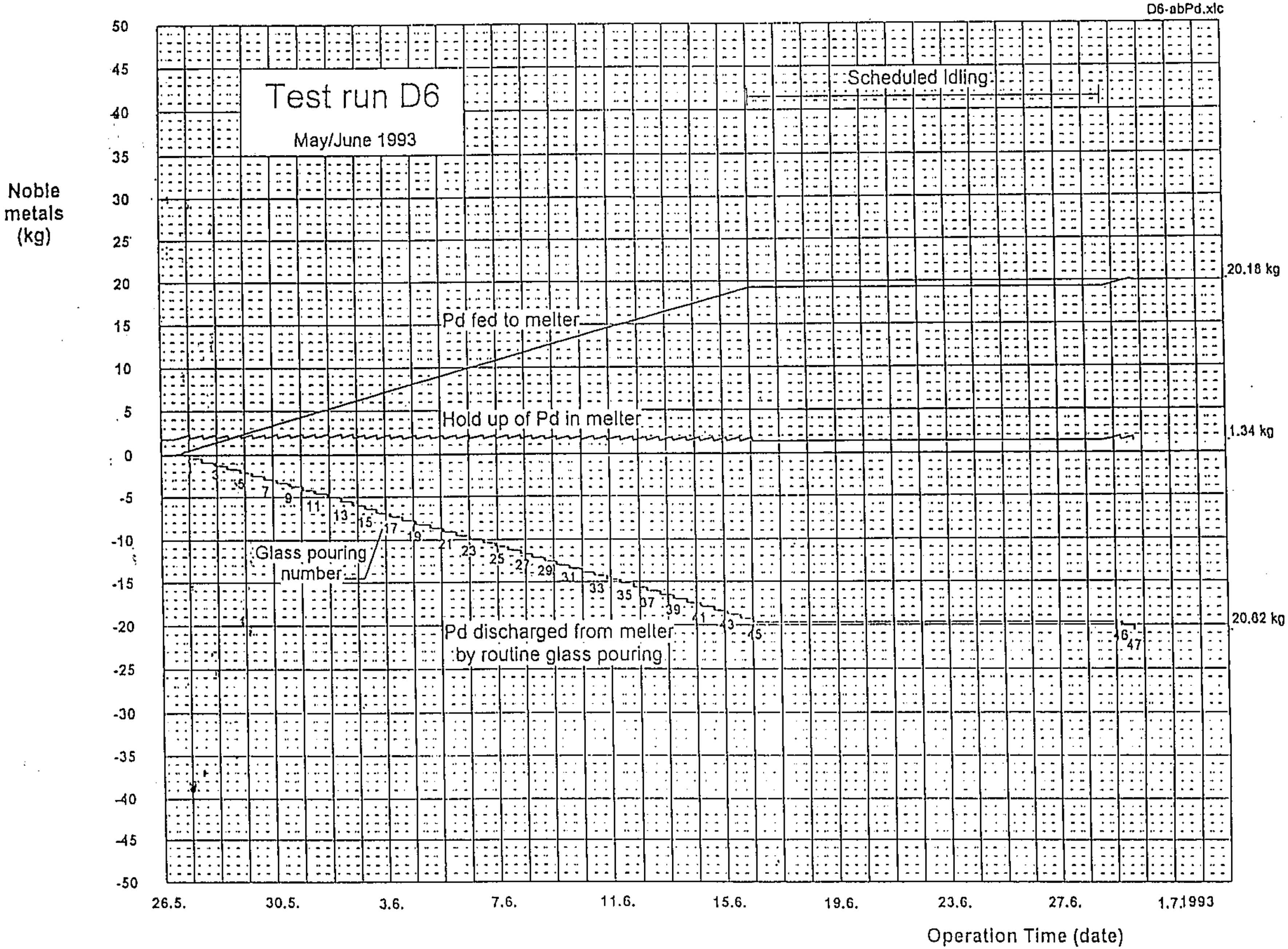


Fig. 7- 25 : Input and removal of Palladium from the K-6' melter during the long-term noble metals test run D6

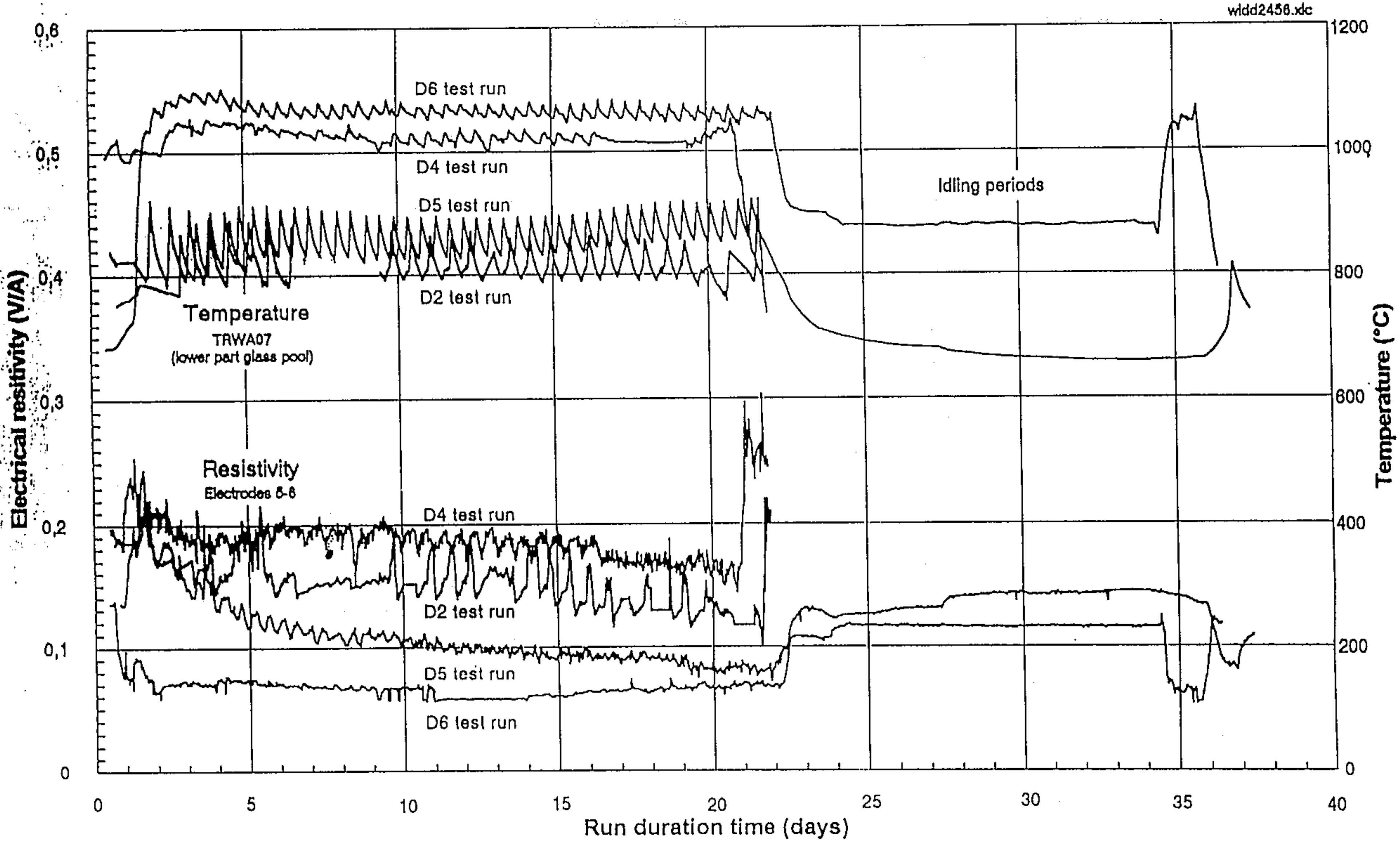
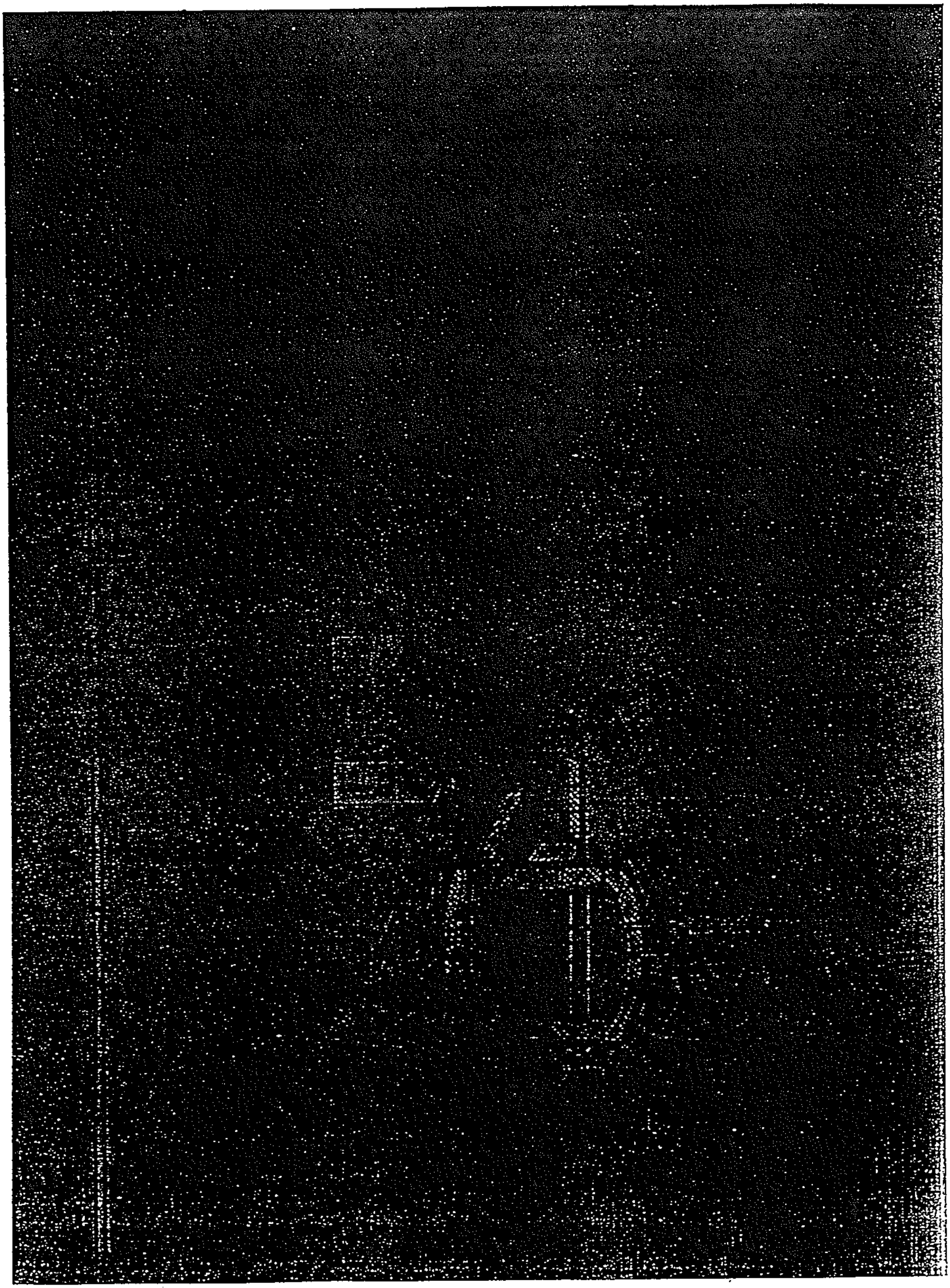
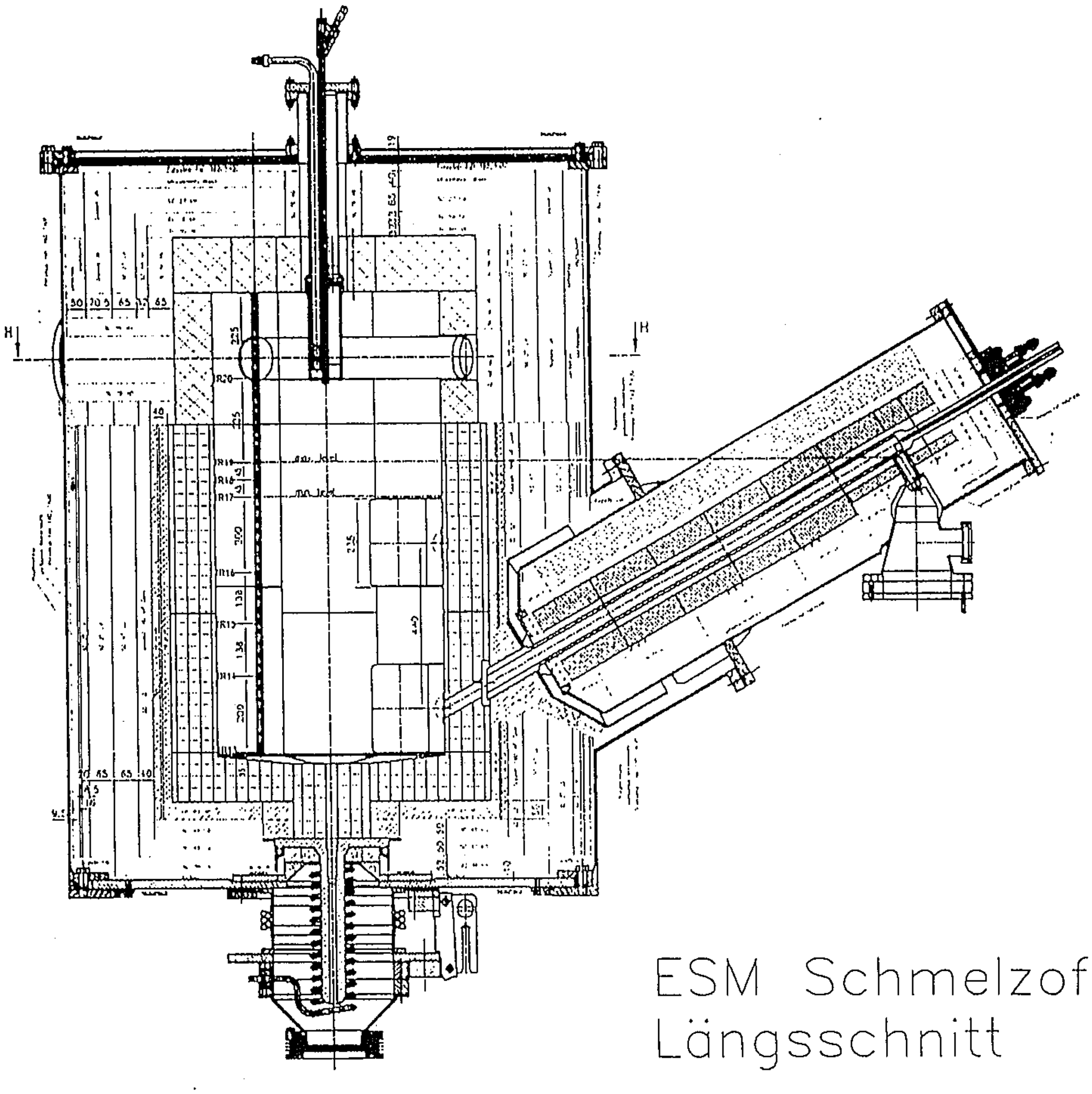


Fig. 7-28: Electrical resistivity curves of the test runs D2, D4, D5 and D6 obtained for the electrode pair 5-6. Included are key temperature curves for the lower part of the glass pool.

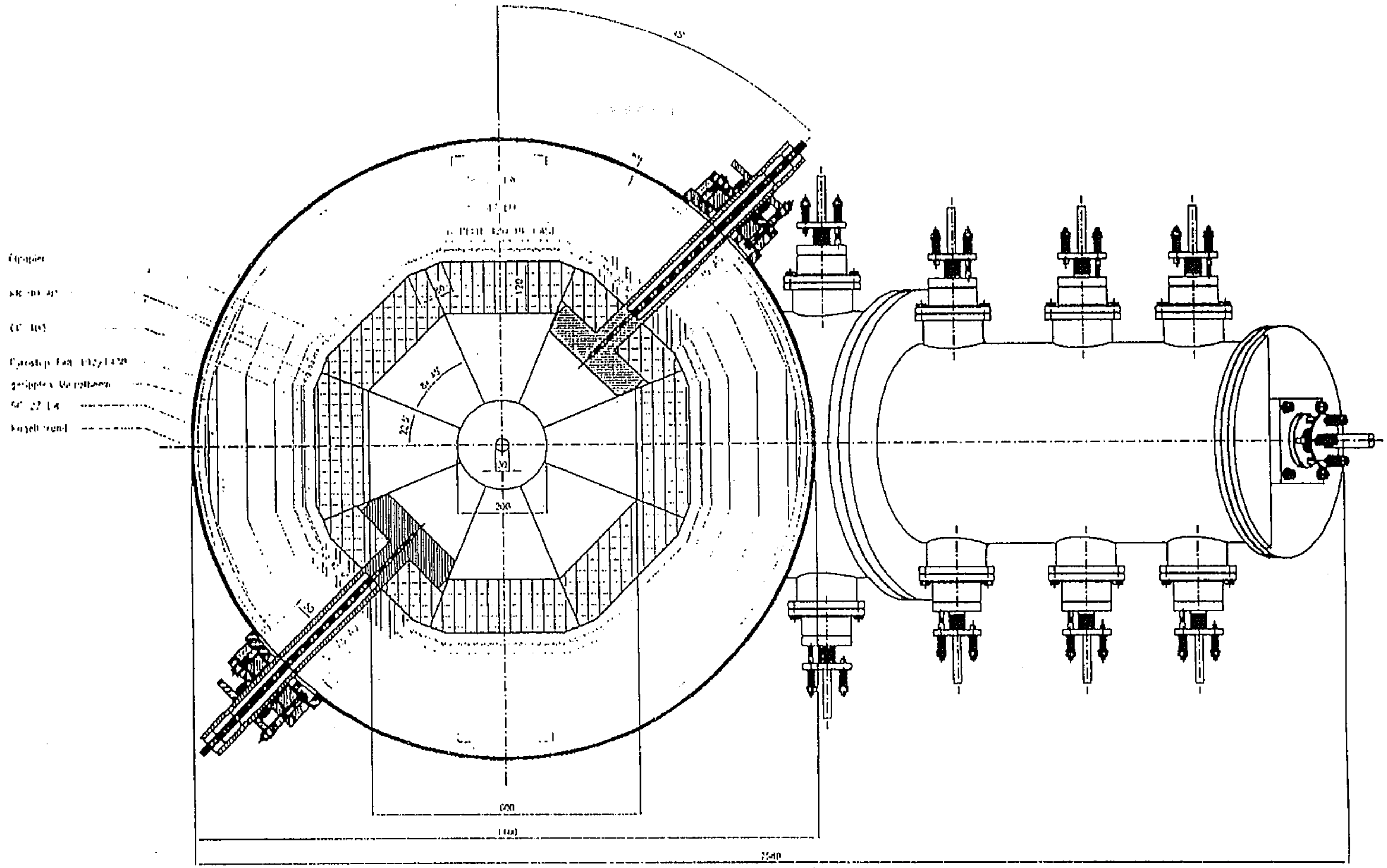


Layout data ESM - Melter

	Full-scale melter	1/10-melter (ESM)
glass pool volume	2383 l	234 l
surface area	2.63 m^2	0.298 m^2
glass pool depth	0.86 m	0.78 m
feed rate	222 l/h (100 kg/h)	20 l/h (10 kg/h)
residence time	58.5 h	58.5 h



ESM Schmelzofen
Längsschnitt



ESM Schmelzofen, Horizontalschnitt

Compilation of the main test run data

	Pretest	Noble metal test
Design feed rate	20 l/h	20 l/h
Corresponding glass production rate	10 kg/h	10 kg/h
Melting temperature	1150 °C	1150 °C
Temperature of heater pipes	900 °C	900 °C
Amount of feed	3 m^3	14 m^3
Oxide yield	139 g/l	140 g/l
Recycle	17 g/l	17 g/l
Glass frit	343 g/l	343 g/l
Total oxides	494 g/l	500 g/l
Waste glass loading	30.7 wt %	31 wt %
Amount of glass frit to be used	0.92 to	4.31 to
Glass production	1.3 to	6.3 to
Noble metals amount for this run		
Ruthenium	-	5.996 kg
Palladium	-	2.069 kg
Rhodium	-	1.646 kg
Number of glass canisters	4	17
Canister type	φ 430 x 1350 mm (400 kg maximum capacity)	
Number of pouring operations (per canister)	5 (75 kg each pouring)	
Glass sampling	25 samples are taken filling one canister	
Total Glass samples	90	420

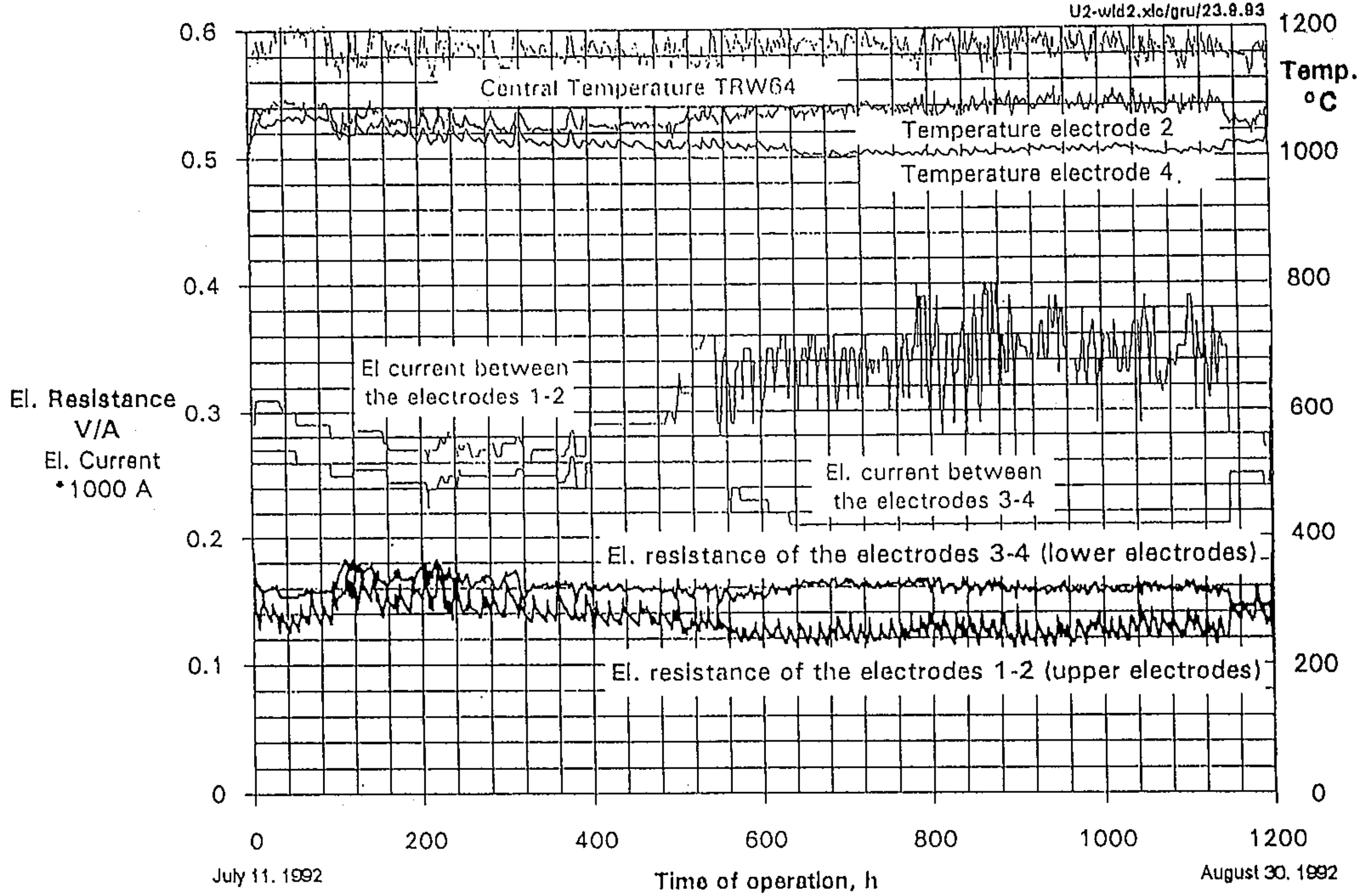


Fig. 5-17 Electric data of the ESM monitored by the PISA system during the U2 test run

3.4 Gravis process control and data acquisition system

GRAVIS

Graphical Visualization and Information System

Applied in the V-W1 vitrification mock-up test facility

Developed by KfK-INE

Features
- Acquisition of process data
- Process visualization
- Determination of process-relevant parameters
- Calculation of mass balances
- Long-term storage of data
- Documentation

Experience available from two long-term test runs

C:\winword\allgemei\Intouch.doc

INTOUCH Process control software

Based on Windows/Windows NT

Modern man/machine interface

Easy to configure

Exceptional visualization tools

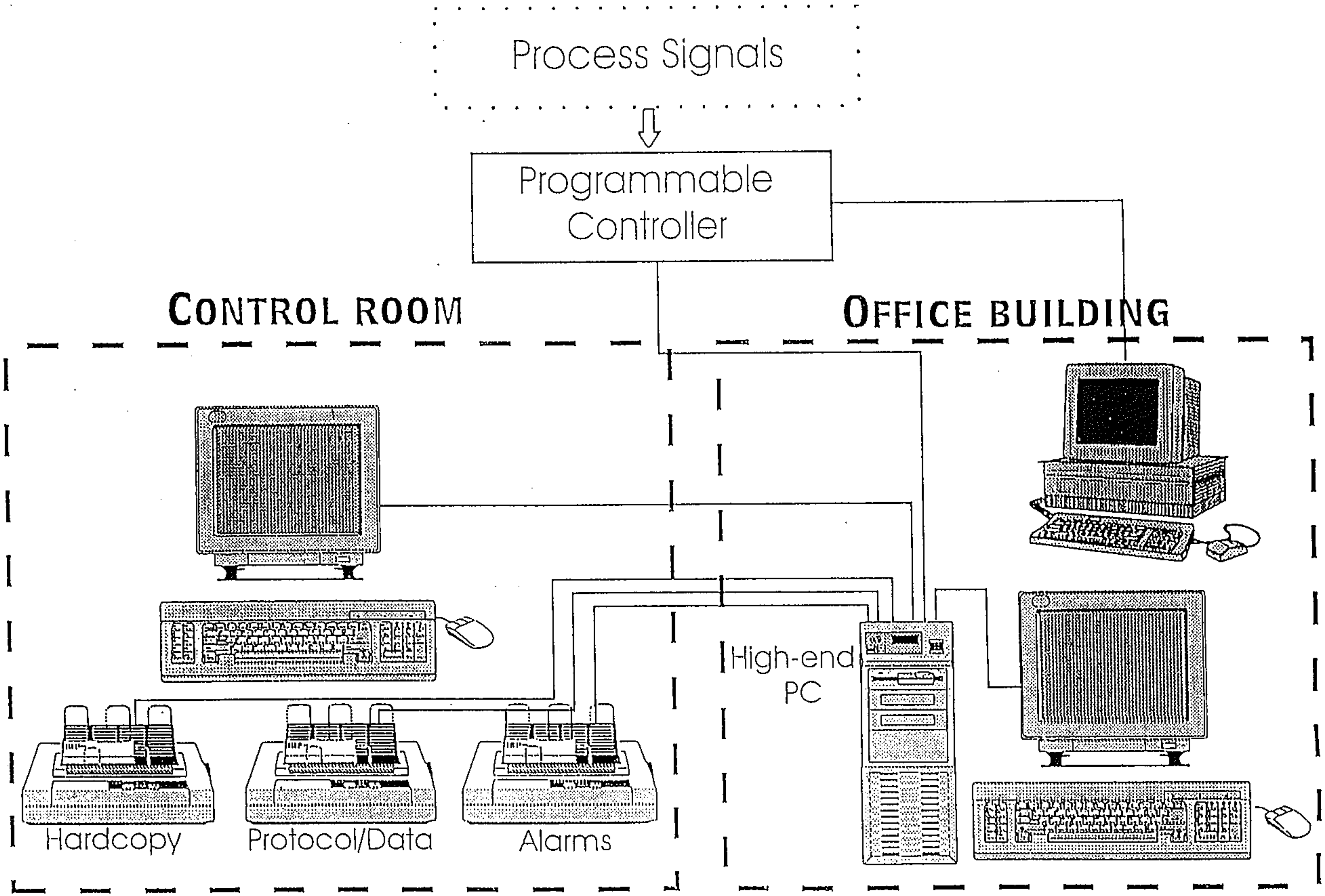
Historical data management

Real time/historical trending

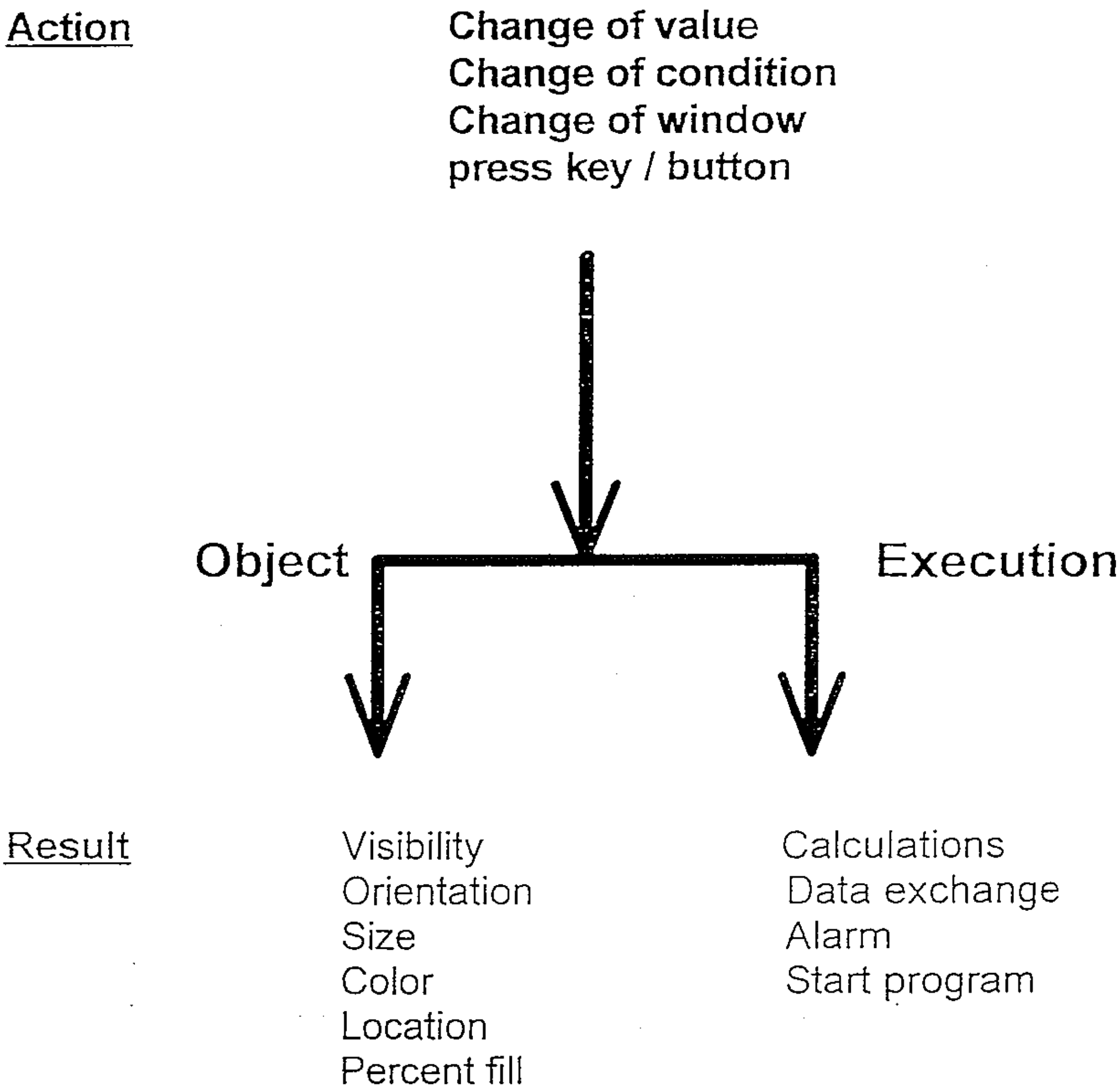
Event-based background actions (calculations etc.)

Parallel development/runtime execution

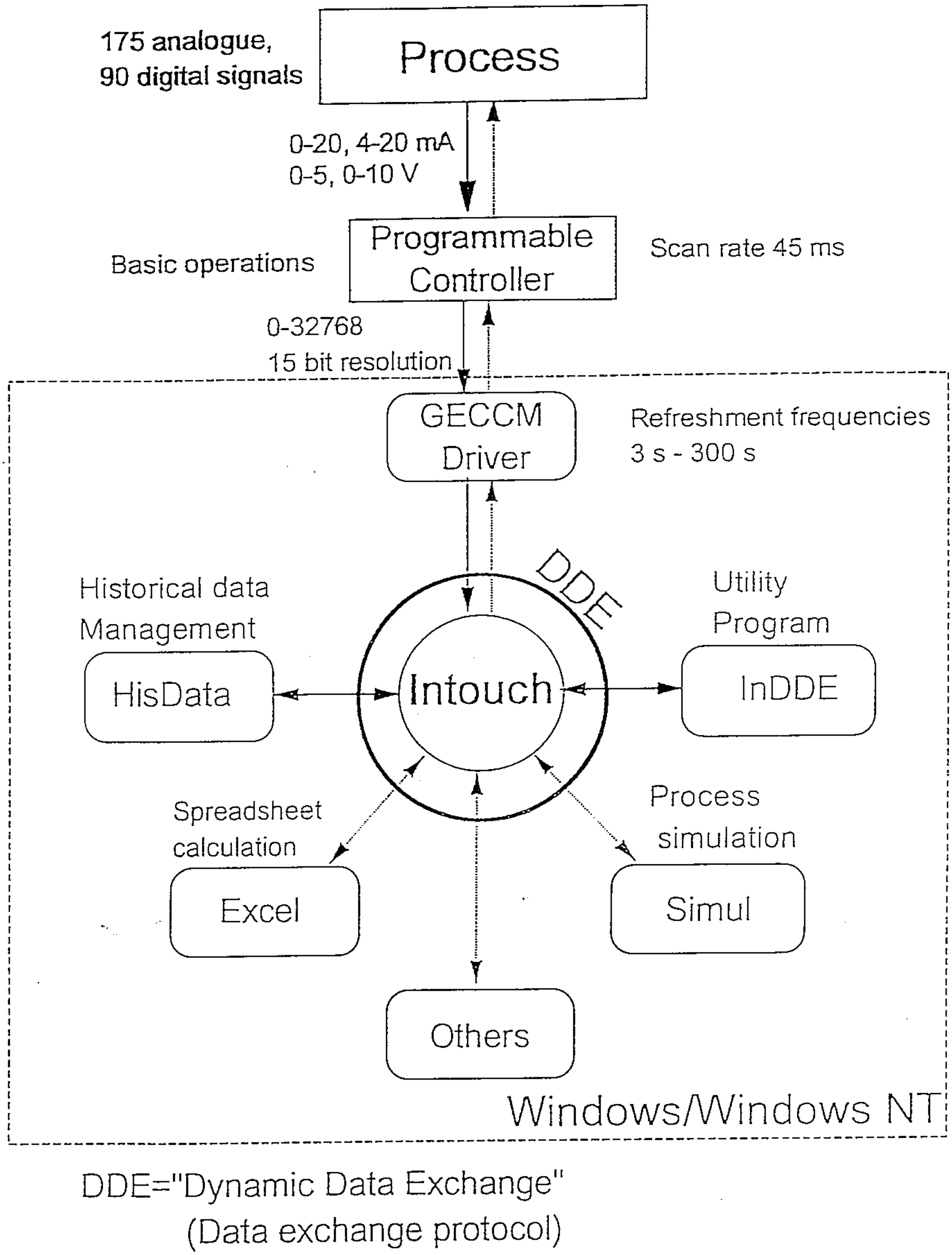
Easy data exchange with other programs/computers



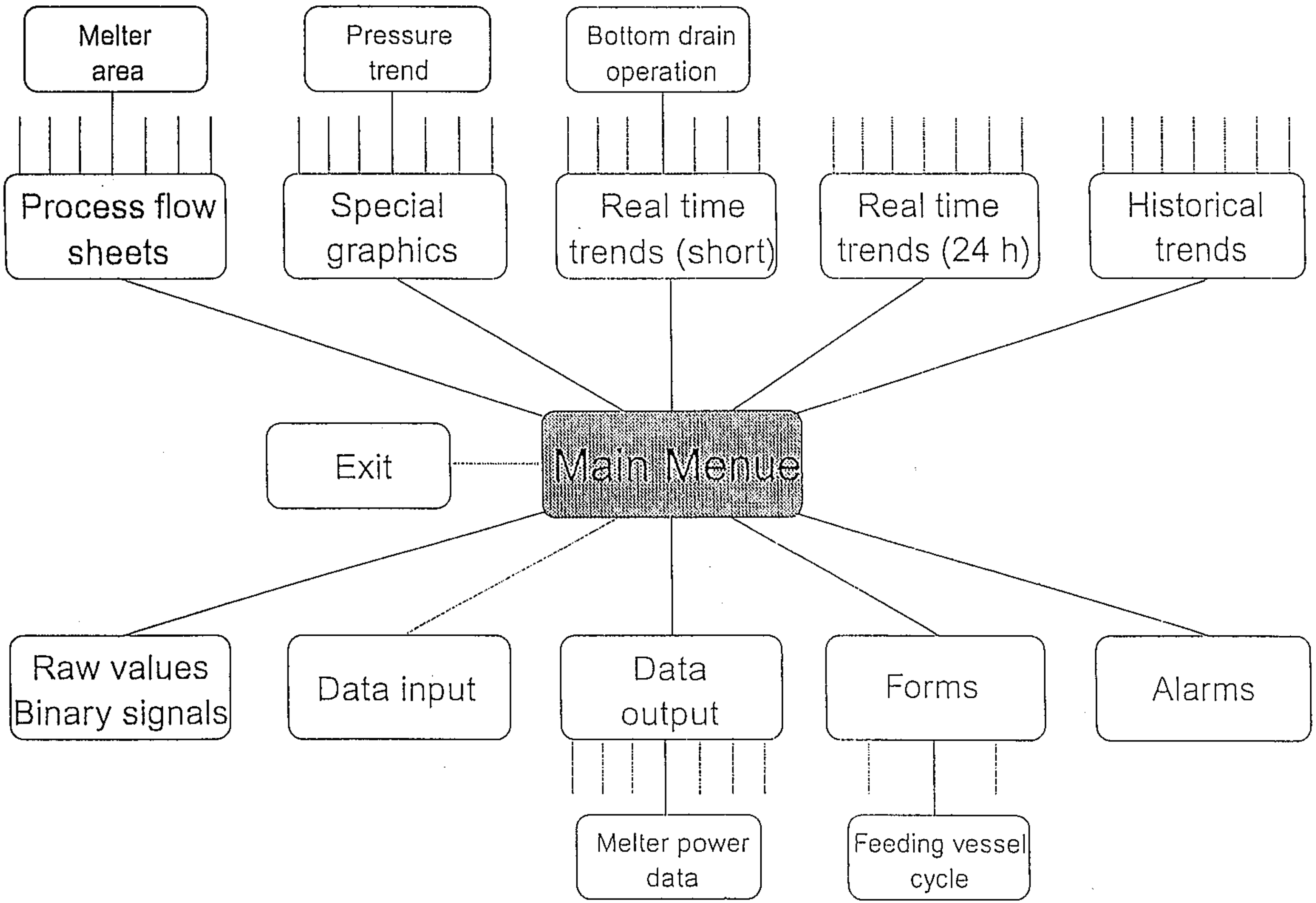
Hardware configuration of GRAVIS



Examples of the dynamic features of InTouch



Software structure of GRAVIS



Graphical user interface of GRAVIS

GRAVIS Calculations

Balances

- HAWC balance via feeding vessel
- HAWC balance via intermediate tank
- Recycle balance via feeding vessel / dust scrubber
- Glass frit balance
- Melter hold-up balance
- Secondary liquid waste balance

Others

- Determination of feeding rate
- Pressure drop along the off-gas line
- Melt level
- Electrical resistance
- Waste loading

3.5 Measurements of DF data for Sr, Cs and Ru for the melter and the off-gas line

~py

C:\winword\WAK\measurem.doc

KfK-INE PNC-KfK meeting

Measurements od DF data for Sr, Cs and Ru for the melter K-6′ and the off gas line

S. Weisenburger

Topics

- System description, HAWC composition
- Variation of processing conditions
- Test results, depending on processing conditions
- Conclusions

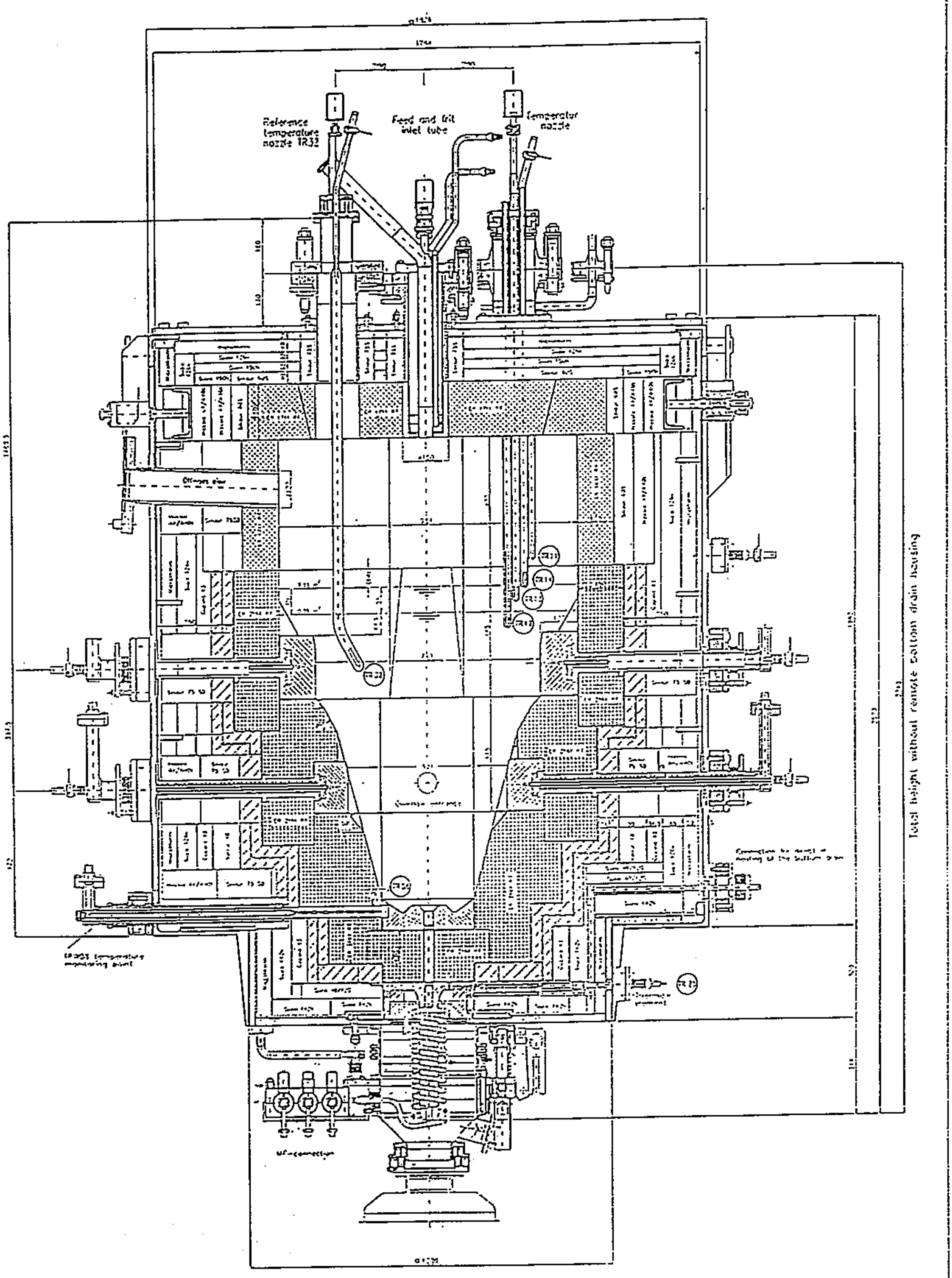


Fig.4-7: Transverse vertical cross section of the K-6' melter with the location of the most important temperature monitoring points TR08,TR11,TR12,TR13,TR14,TR25 etc. and TR32

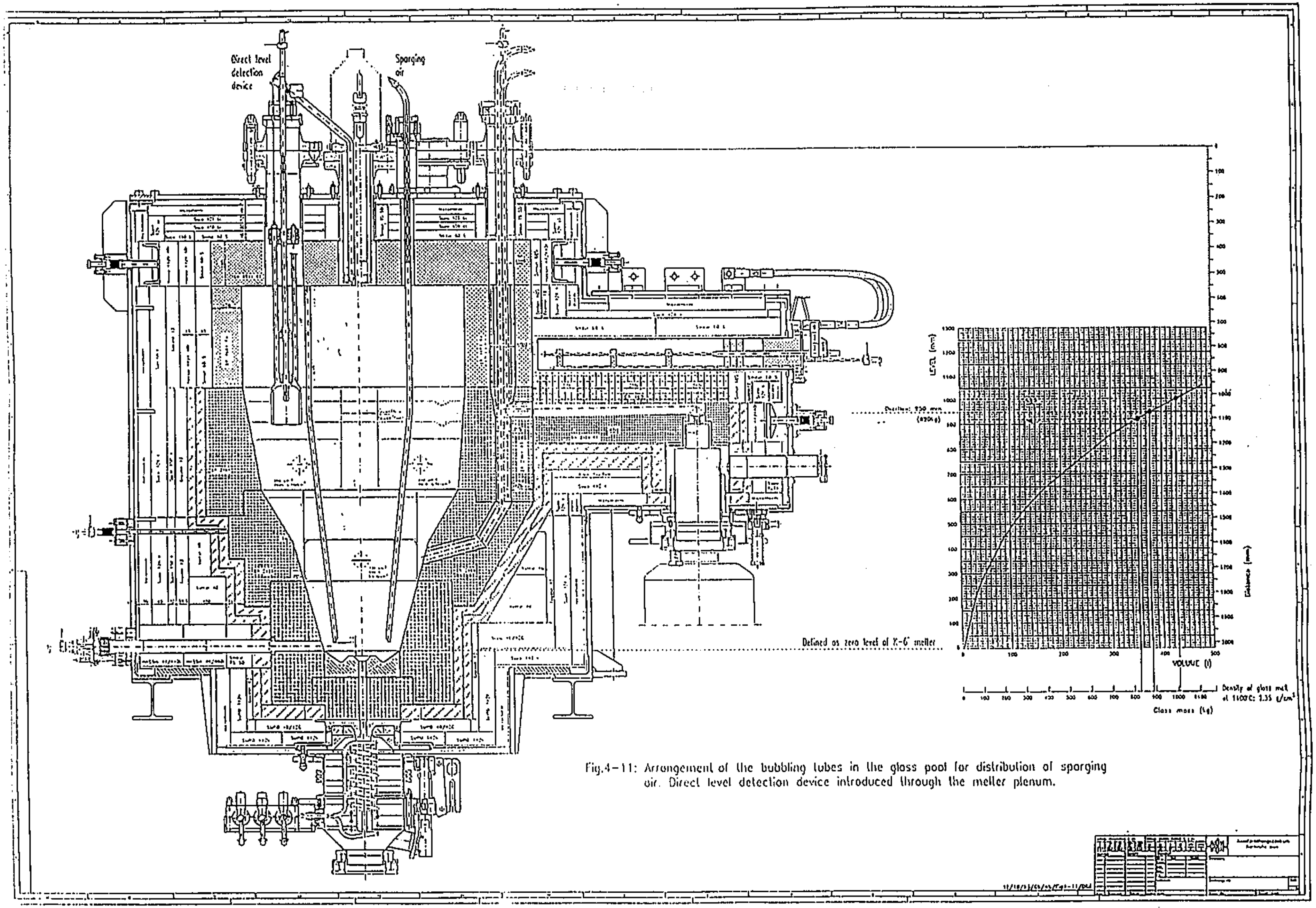


Fig.4-11: Arrangement of the bubbling tubes in the glass pool for distribution of sparging air. Direct level detection device introduced through the melter plenum.

Table 8-IX

Compilation of DF-data obtained from the test runs D2, D4, D5 and D6 of the HAWC-technology program

Component	DF-data obtained in the several test runs																			
	Test run D2					Test run D4					Test run D5					Test run D6				
	Cs	Sr	Ru	Ce	Se	Cs	Sr	Ru	Ce	Se	Cs	Sr	Ru	Nd	Ce	Cs	Sr	Ru	Pd	Na
Melter	19.8	65.1	9.5	91	4.0	8.77	41.3	-	258	1.7	59	228	29	345	449	36.7	96	19.8	182.5	63.5
Dust scrubber	3.0	14.0	31.0	34	4.8	1.92	2.7	-	2.3	2.0	2.3	8.1	5.5	14.4	18.8	2.04	5.16	6.72	4.60	3.31
Condenser	1.40	1.35	2.10	1.2	1.42	4.39	7.2	-	2.2	2.4	1.6	1.5	3.2	1.6	1.5	1.61	1.65	2.01	1.58	1.54
Jet-scrubber	11.7	12.0	4.21	55	34.2	6.03	10.0	-	43	9.8	8.5	3.4	9.5	38.7	2.9	14.0	16.1	10.6	17.4	6.18
NOx-column	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total: Feed to NOx-absorber	973	14765	2604	204204	932	446	8029	-	51135	-	1730	9419	4849	-	-	1687	9458	2835	23144	1995

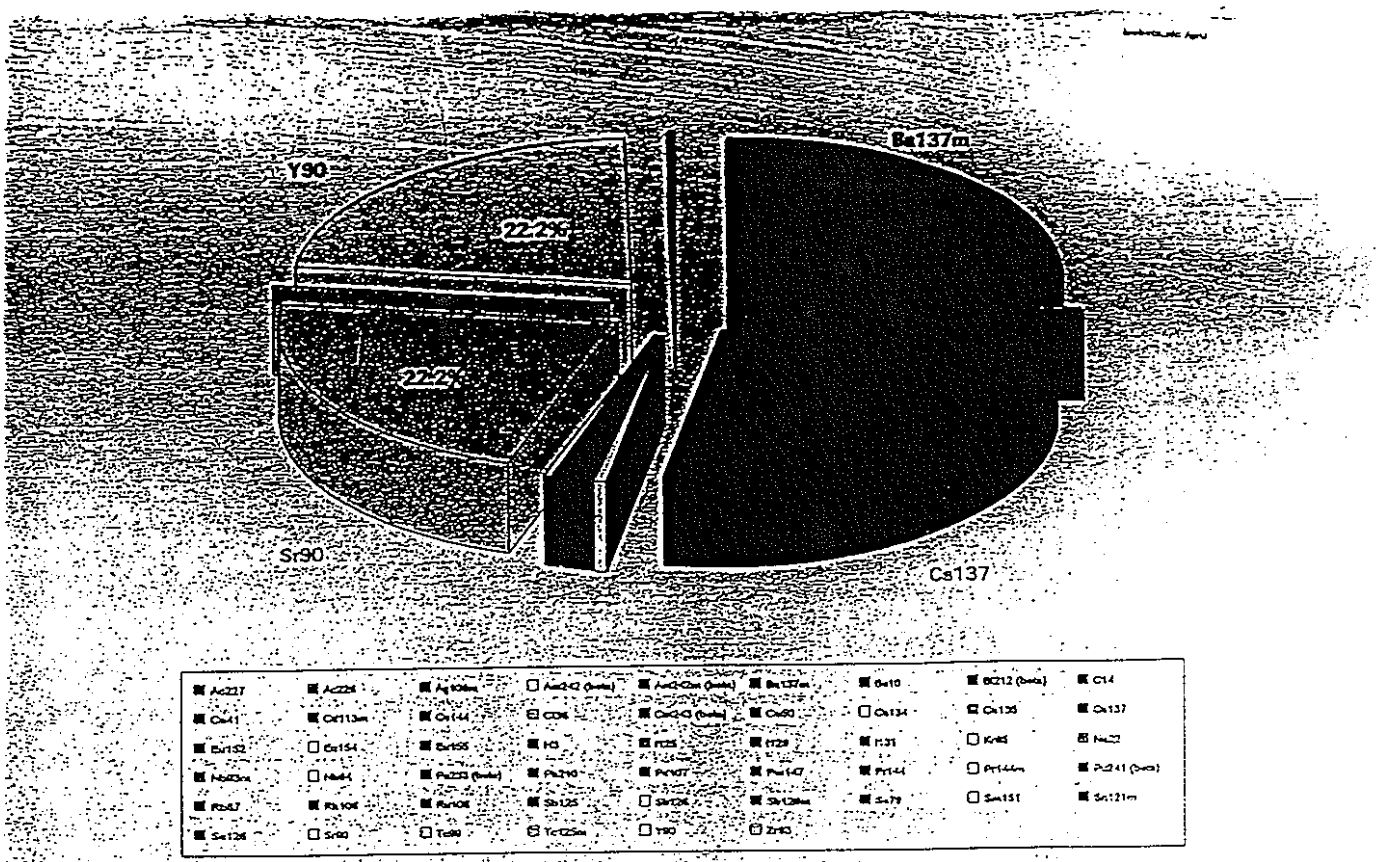


Fig. 8-1: Radioactivity (beta, beta/gamma, gamma) of individual isotopes of the WAK-HAWC refered to 1997

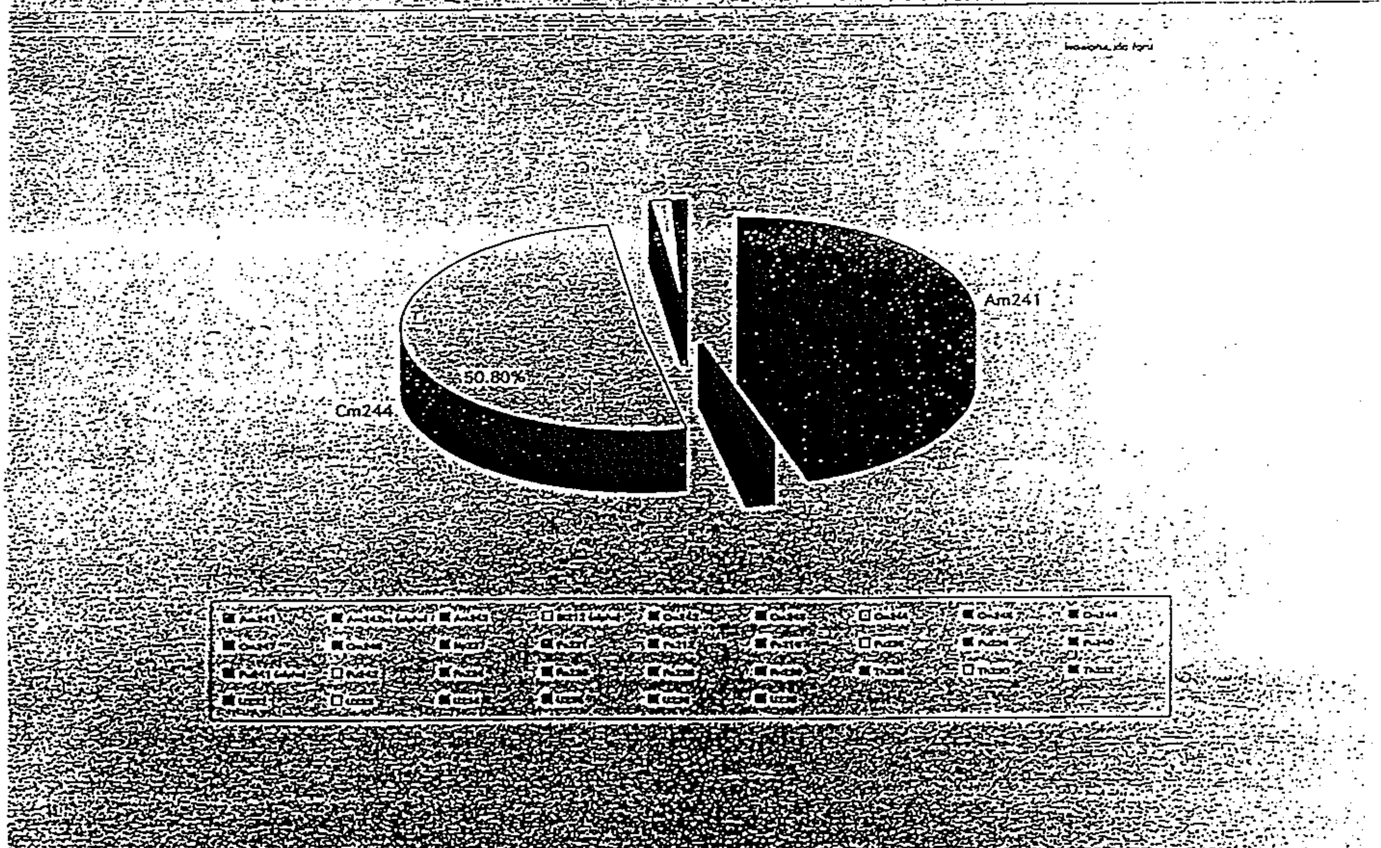


Fig. 8-2: Radioactivity (alpha) of individual isotopes of the WAK-HAWC refered to 1997

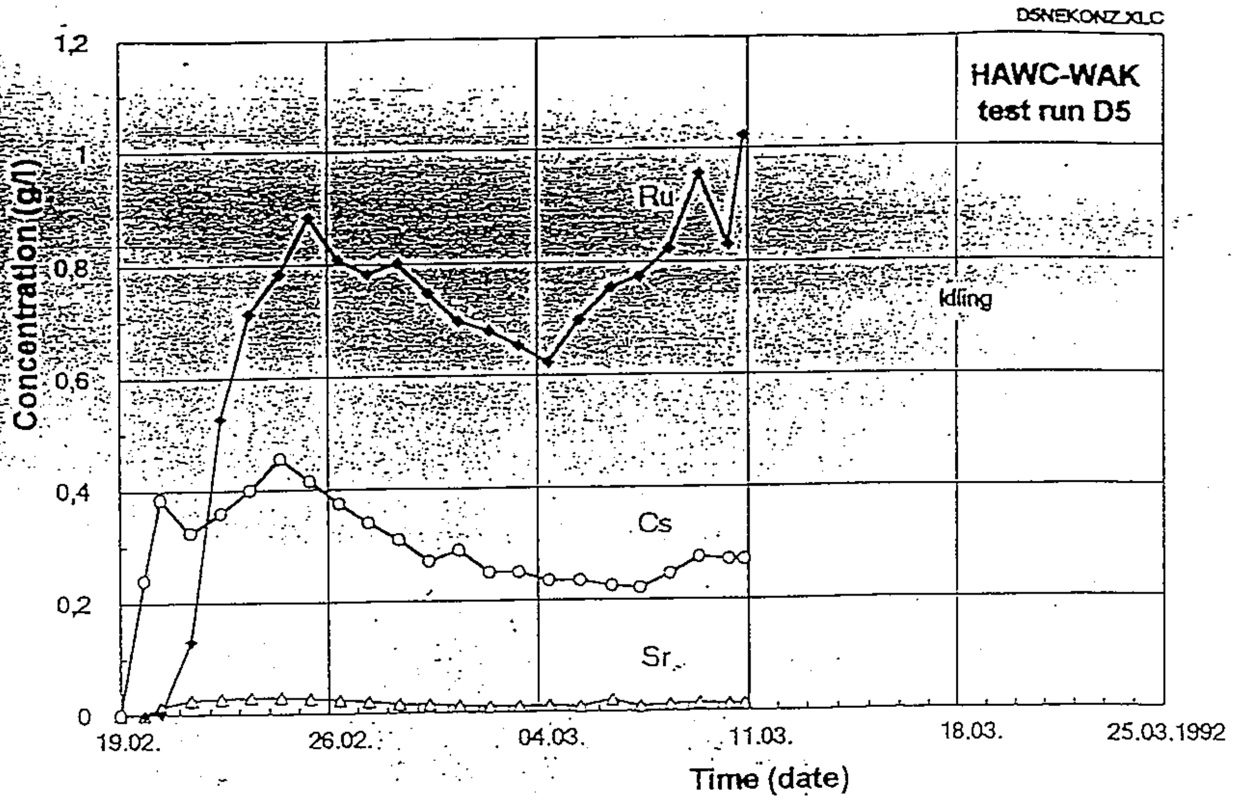


Fig. 8-5 : Concentrations of Ru, Cs and Sr in the dust scrubber wash solution. Test run D5

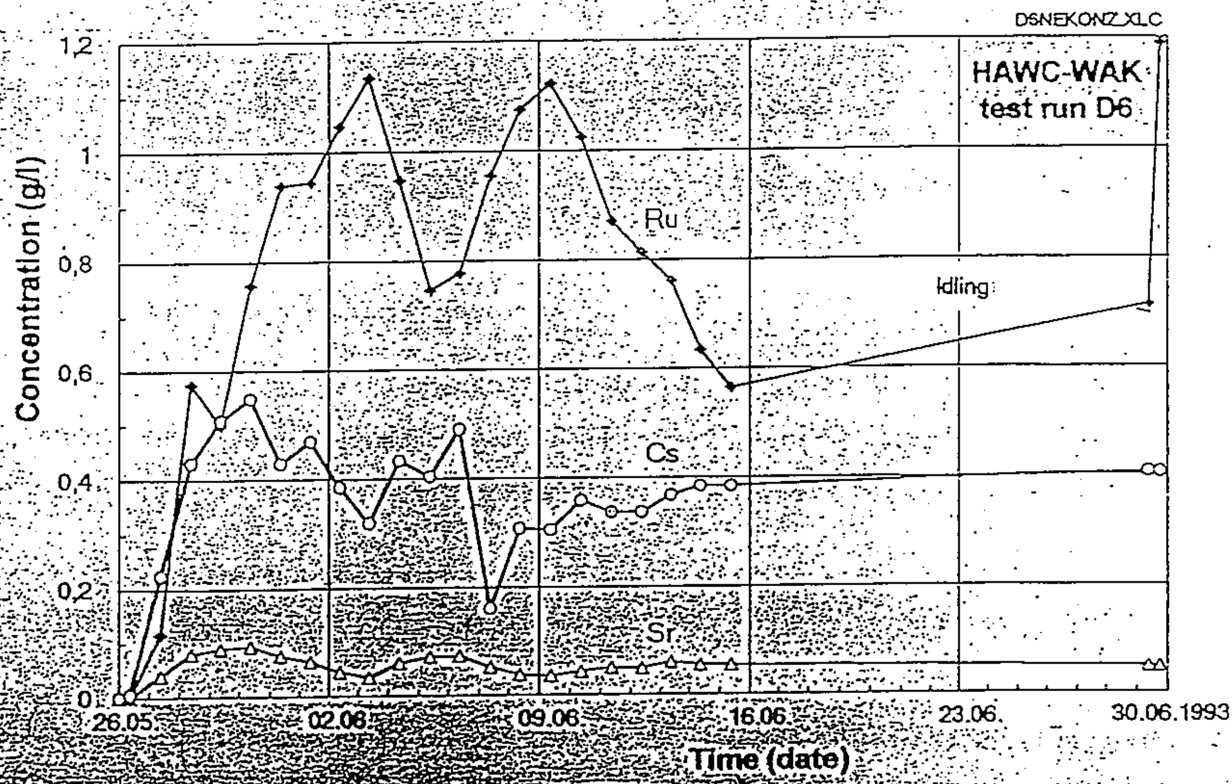


Fig. 8-6 : Concentrations of Ru, Cs and Sr in the dust scrubber wash solution. Test run D6

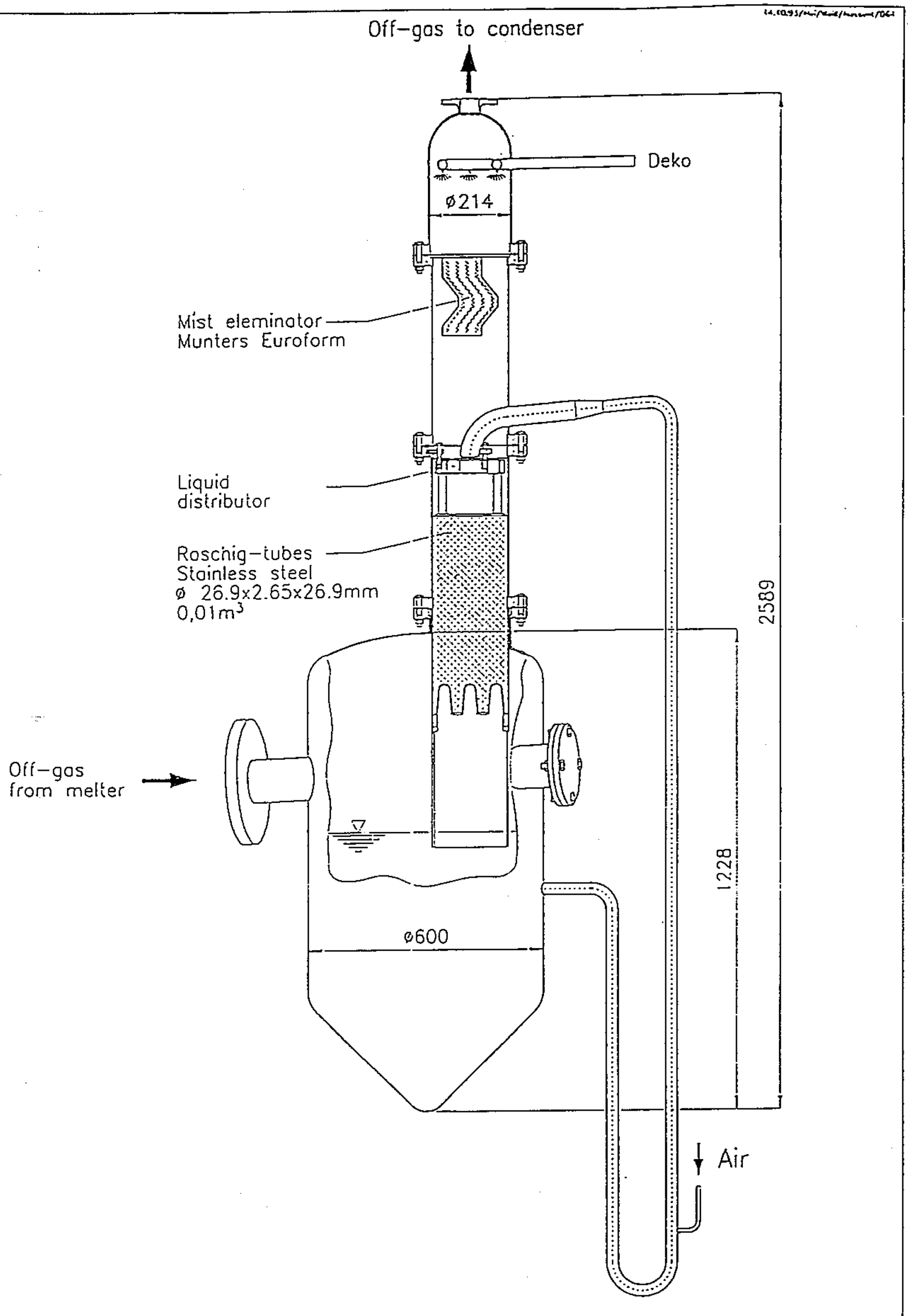


Fig. 8-5: Design of the dust scrubber column used for the test run D6
(design corresponds to current PAMELA spare part dust scrubber)

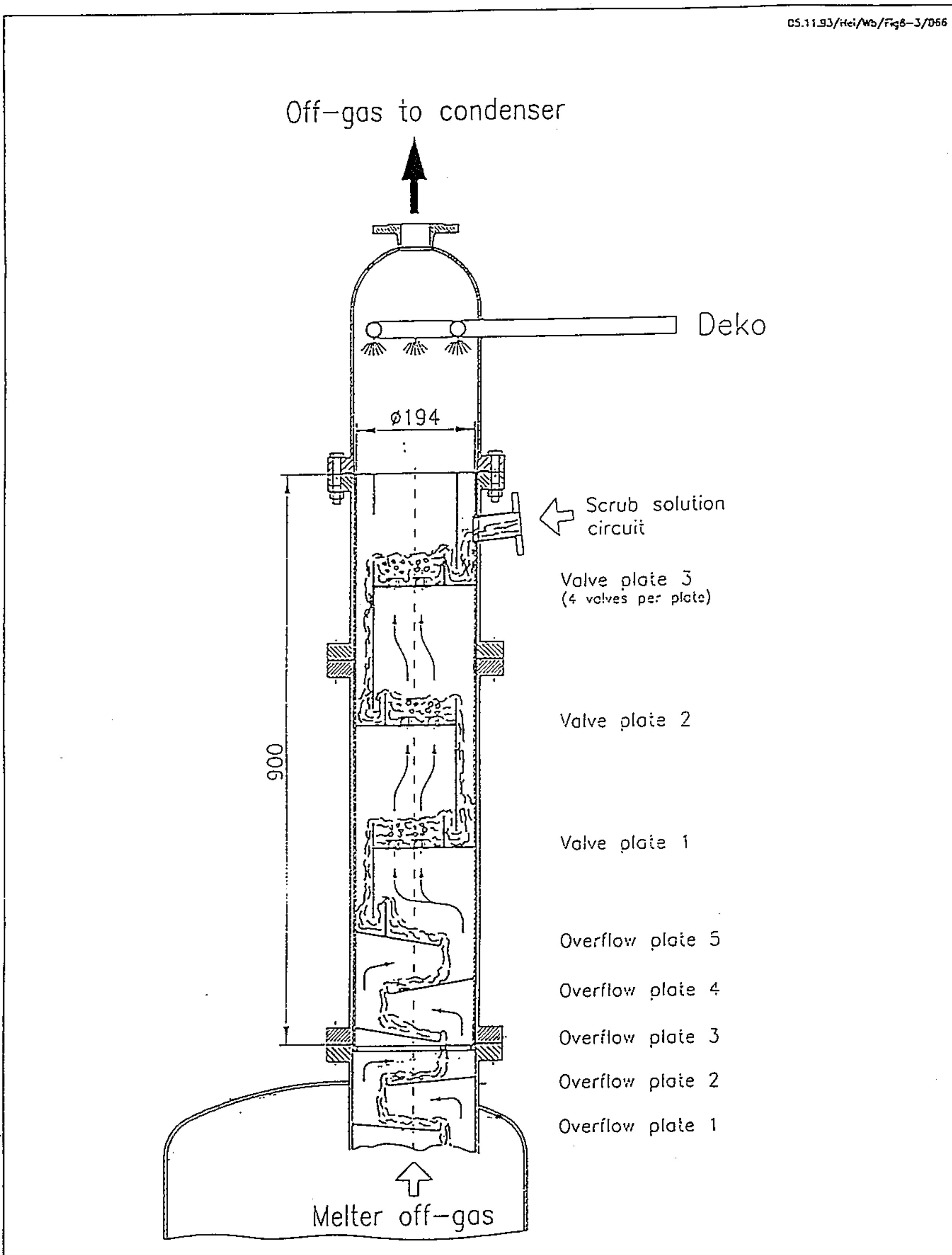


Fig. 8-3: Dust srubber column design used in the test runs D2, D4 and D5

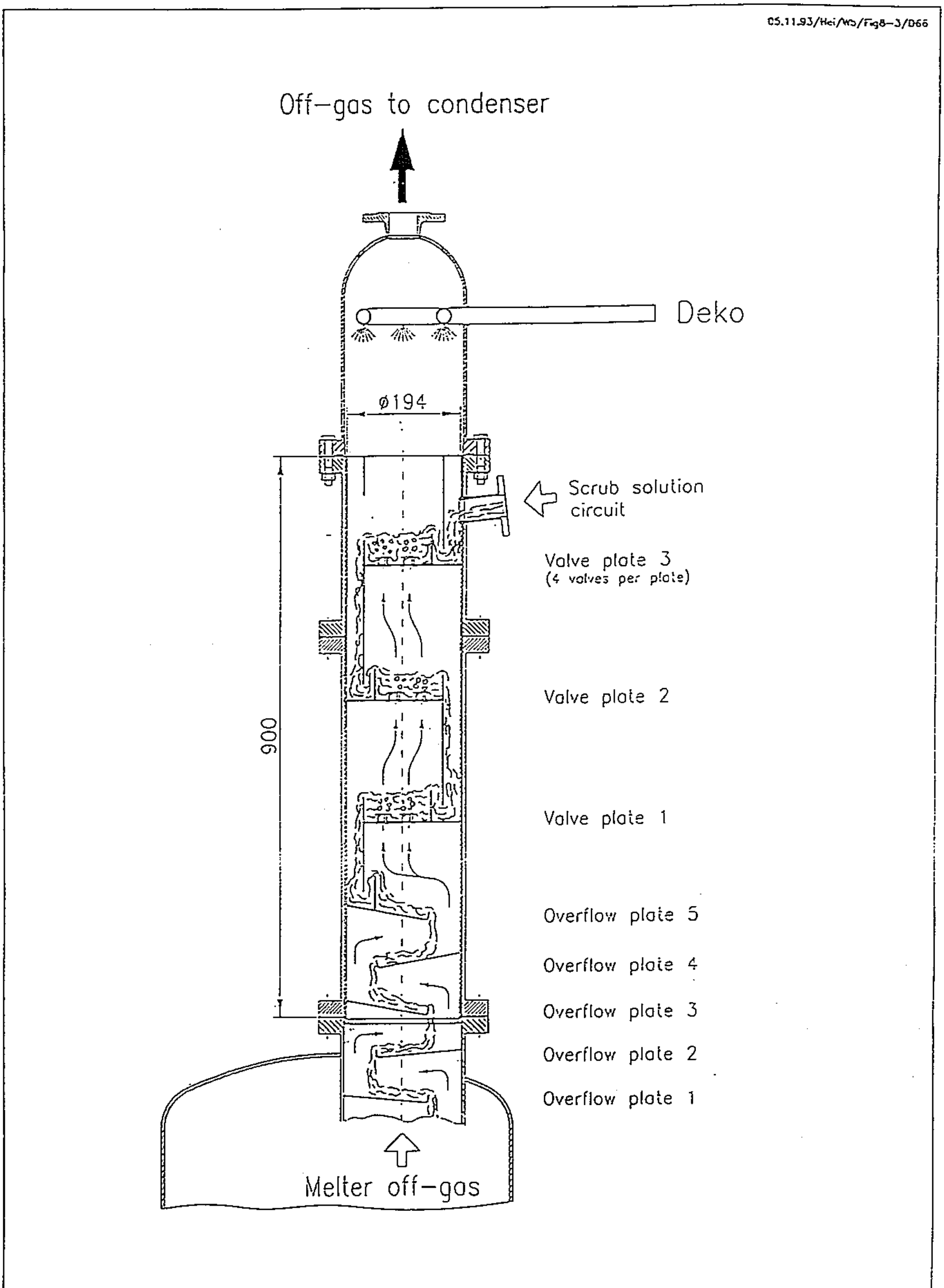


Fig. 8-3: Dust srubber column design used in the test runs D2, D4 and D5

Overview about the quantities of the elements Cs, Sr and Ru removed by the melter, dust scrubber, condenser, jet scrubber and NO_X-column during the test run D6. Compilation of the resulting DF numbers.

	Quantity of element (g)			DF		
	Cs	Sr	Ru	Cs	Sr	Ru
Fed to melter						
via HAWC-simulate	49 937	12 564	35 497	-	-	-
via HAWC-simulate and recycled dust scrubber solution	50 599	12 664	36 931	-	-	-
Removed by						
Melter	49 198	12 432	35 065	36.1	96	19.8
Dust scrubber	714	106.4	1588	2.04	5.16	6.72
Condenser	261	10	140	1.61	1.65	2.01
Jet scrubber	395	15	125	14.0	16.06	10.63
NO_X-column	30	1	13	-	-	-

Overview about the quantities of the elements Cs, Sr and Ru removed by the melter, dust scrubber, condenser, jet scrubber and NO_X-column during the test run D6. Compilation of the resulting DF numbers.

	Quantity of element (g)			DF		
	Cs	Sr	Ru	Cs	Sr	Ru
Fed to melter						
via HAWC-simulate	49 937	12 564	35 497	-	-	-
via HAWC-simulate and recycled dust scrubber solution	50 599	12 664	36 931	-	-	-
Removed by						
Melter	49 198	12 432	35 065	36.1	96	19.8
Dust scrubber	714	106.4	1588	2.04	5.16	6.72
Condenser	261	10	140	1.61	1.65	2.01
Jet scrubber	395	15	125	14.0	16.06	10.63
NO_X-column	30	1	13	-	-	-

Thema: DF - data Datum: Dec. 7, 1993 Seite ○

Summary

- Melter DF's for Cs, Sr, Ru depend on "cold cap" conditions on top of the glass pool, and on bubbling

- DF-data variation found

	Melter	Dust scrubber
Cs	8.8 - 59	1.9 - 3
Sr	41.3 - 228	2.7 - 14

- DF data for condenser, jet scrubber may be partly influenced by the concentration of Cs, Sr, Ru in the off gas stream

- Different types of dust scrubber columns used showed similar DF's for Cs, Sr, Ru

- DF data : feed to entrance NO_x-absorber

Test run	D2	D4	D5	D6
Cs	970	446	1730	1687
Sr	14765	8029	9419	9458

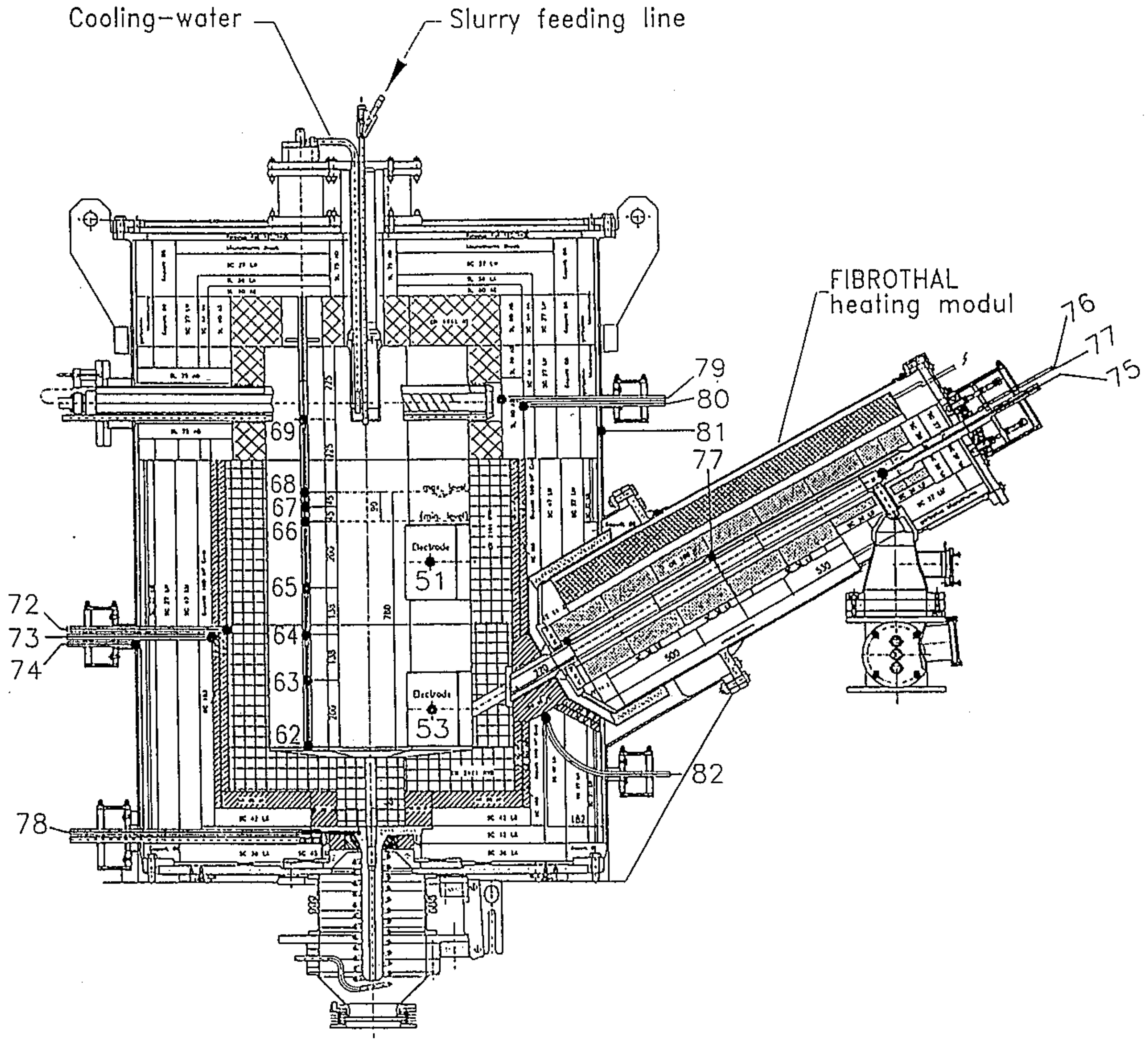
Acceptable ranges for the PAMELA approach to keep the overall feed to stack DF concept of 10^8 as a minimum

- The second recycling circuit (recycling of evaporator concentrate from secondary liquid waste concentration) <u>must</u> be used to keep the amount of conditioned MLW acceptable

3.6 Melt level detection system recently tested in the K-6' and K-W3 melter and New overflow heating technique applied in the ESM melter

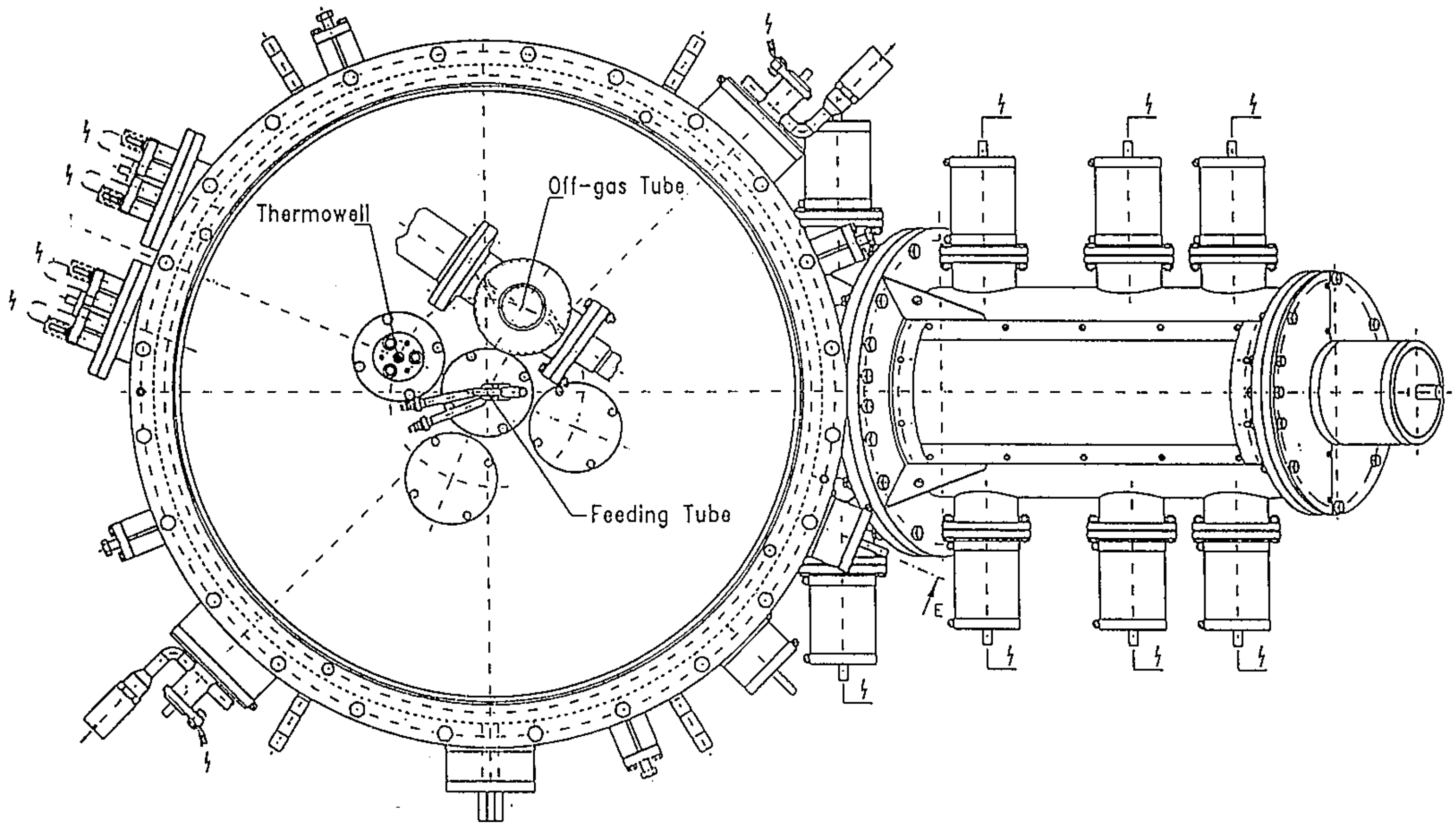
Melter features

- 10 th scale of Hanford Waste Vitrification Plant melter
- flat bottomed melt tank, 550 kg glass capacity
- two paires of uncooled Inconel electrodes
- two SiC melter plenum heaters
- designed throughput of 20 l/h (NCAW)
- routine glass pouring via overflow with underpressure support

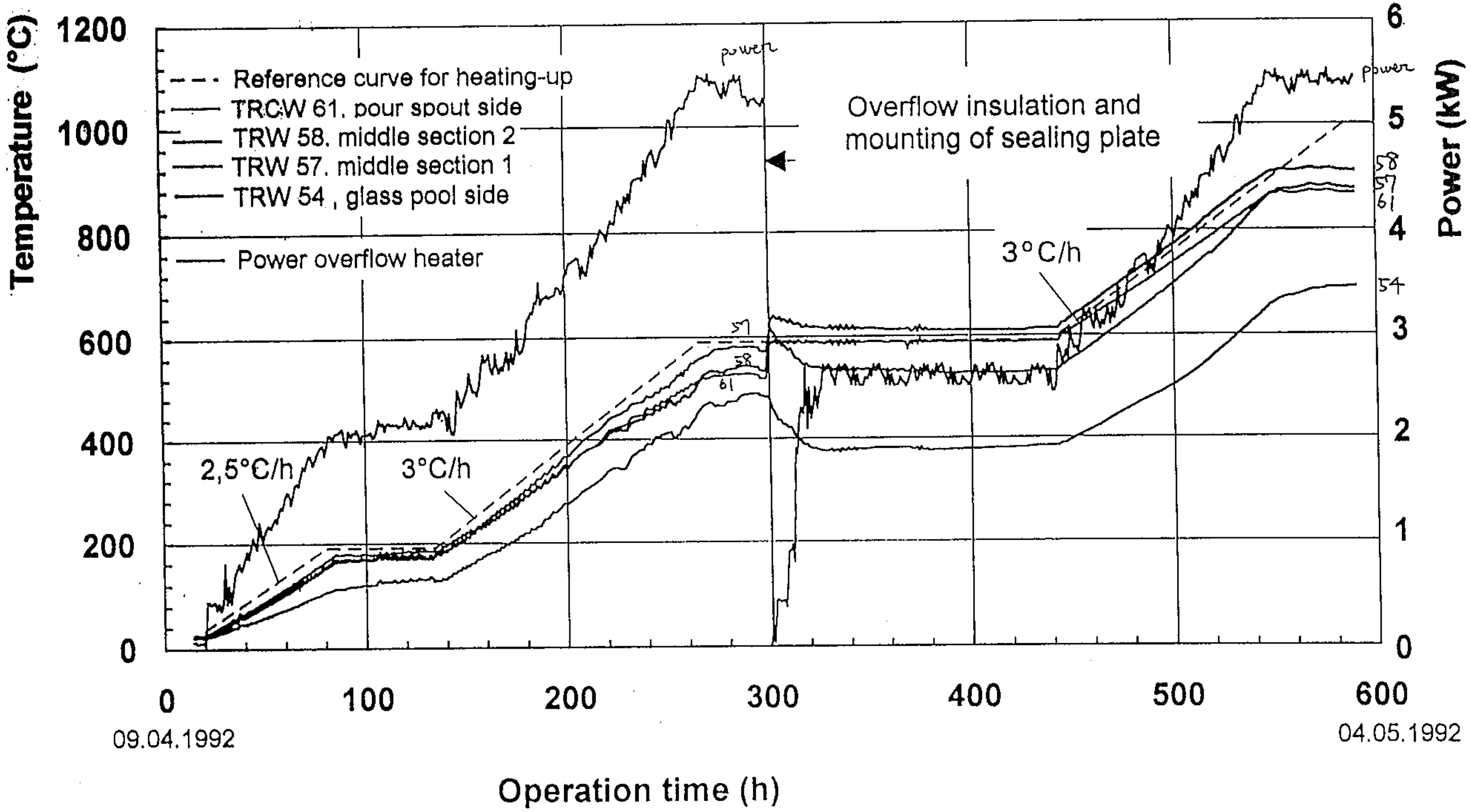


Longitudinal section of ESM with temperature monitoring points

25.11.93/Fe/To/Japan/MS7/D:



Top section view of the **ESM**



Start-up heating procedure for ESM melter overflow

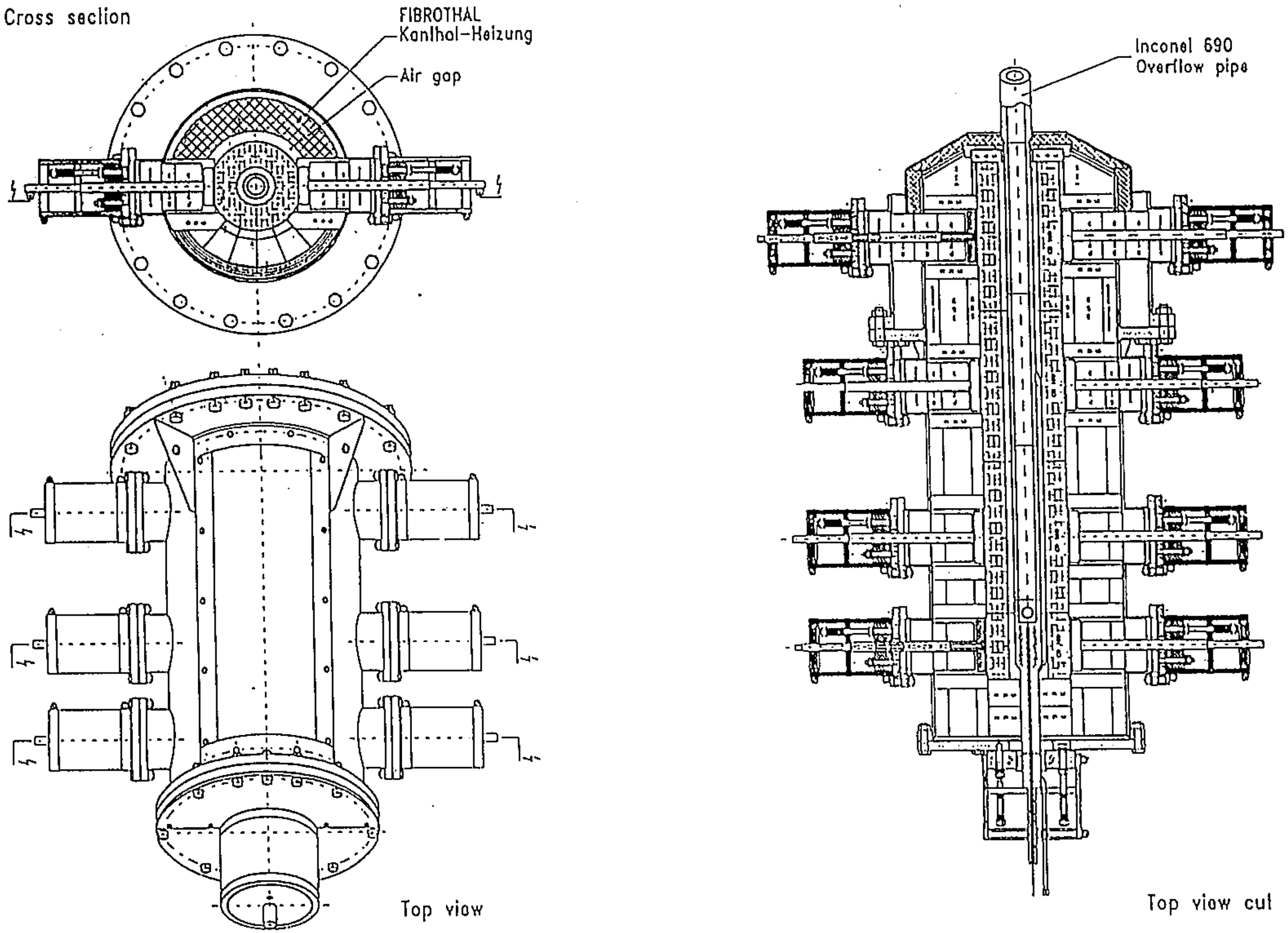
New overflow heating technique applied in the ESM melter

ESM **E**ngineering **S**cale **M**elter

- ☞ designed, constructed, installed and operated by KfK/INE under contract and in cooperation with

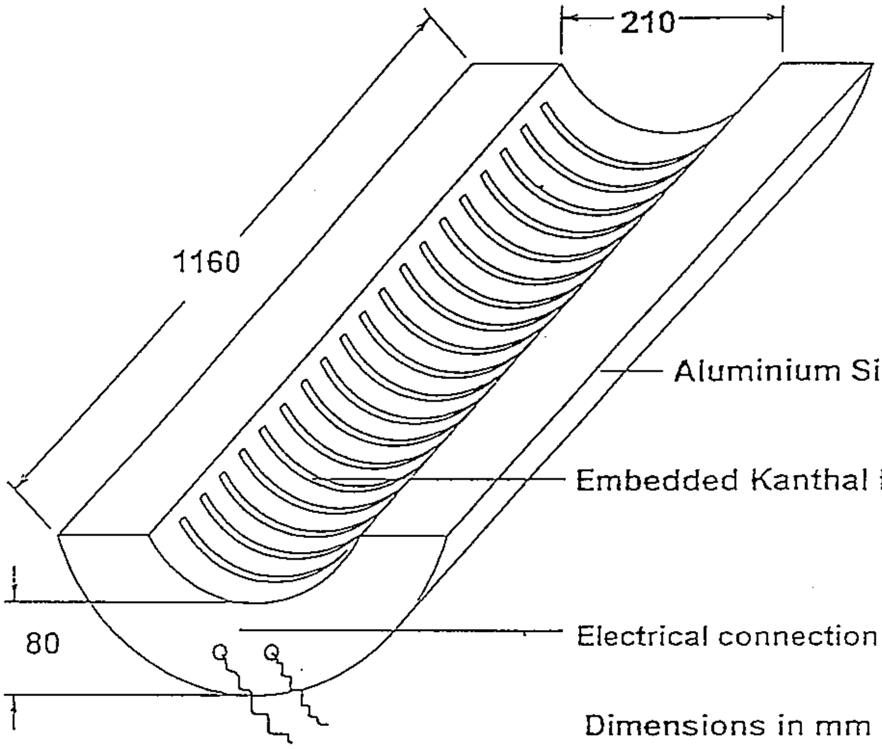
PNL **P**acific **N**orthwest **L**aboratories

- ☞ in 1991 - 1992



Glass overflow system of ESM and heating technique applied

Used overflow *FIBROTHAL* heating modul



- heating surface 0.3 m^2
- power loading 6.0 kW / 220 VAC
- thermal conductivity 0.242 W/mK (at 1150°C)

Advantages of *FIBROTHAL* heating modul

- even temperature distribution
- temperature flexibility
- easy replacement of modul
- low furnace weight (specific weight 200g/dm^3)
- low price

3.7 Characterization and quality assurance for the HAWC-WAK waste glass if produced in the PAMELA and disposed in Germany

9. Results of the process control referred to glass product composition

9.0 Description of the problem

The composition of the waste glass poured from melter primarely results from a number of key parameters governing HAWC-processing. Those parameters include

- the composition of the waste solution
- the composition of the glass frit
- the waste glass loading
- the actual mass ratio of HAWC to frit under which the melter is fed and the variation of this ratio with time

The composition of the HAWC and that of the glass frit determines - together with the waste loading number - the target value for each individual constituent of the glass product. However, a number of processing parameters are involved. They can more or less influence the concentration in the final glass product. Such parameters include the

- Variation of the HAWC-composition
- Variation of the glass frit composition
- Inaccuracies caused by the HAWC- and glass frit feeding system, regarding especially the ratio between HAWC- and glass frit
- Inhomogenities of the glass melt due to poor homogenization of the melt pool or due to insufficient residence time
- Phase separation in the melt pool (noble metals for example)

These and a number of other influences, as for example excessive loss of waste elements into the off-gas line, can also cause more or less differences in the composition of the final glass product. A band width of scatter had therefore been established which must be tolerated. The actual glass product composition must be within this band. Usually concerns about glass product quality do not arise due to these allowed variations which can be within 1 to 2 wt% as to give an order to magnitude only. In the course of the HAWC-WAK technology program it had been tested what band width of scatter result with reasonable effort in comparison to the "target glass product composition".

9.1 Reference composition of the inactive glass product

The target values of the glass product for each individual constituent of the glass are listed in Table 9-I. The first column shows the target numbers in case of vitrification of the active

HAWC. They are based on both the reference composition of the HAWC and the nominal waste glass loading of 16 wt%. The second column shows the corresponding numbers for the inactive HAWC-simulate and a waste glass loading of 14 wt %. The waste glass loading is lower compared to the active case due to the fact that the heavy actinides in the actual HAWC are not present in the simulate. The numbers of the second column are the targets by which the inactively produced glass product must be compared. The numbers refer to the nominal composition of the HAWC-simulate used for the D6 test run, and to the glass frit type GG WAK 1.

9.2 Actual composition of the produced glass compared to the target data

9.2.1 Selected guide elements

For comparison of the technically produced waste glass with the target composition, seven guide elements have been selected: Si, Cs, Sr, Nd, Na, Fe and Zr. The selection criteria included that

- the elements are relatively easy measurable
- they are homogeneously distributed in the glass matrix i.e. they do not show phase separations, or are insoluble or segregate in the melt (like the noble metals)
- they are not too much influenced by other elements regarding their uniform distribution
- they represent typical constituents of the frit and waste stream fed to the melter (Si and Na for the glass frit; Cs, Sr and Nd for the most active part of the HAWC; Zr for representing undissolved material, Na for process chemicals and Fe for corrosion product).

In the final glass product sodium represents both, a part of the frit and the dominant constituent of the HAWC referred to the mass. It is the strategy of the advanced process technique to achieve and assure the correct composition within a given band width of scatter, and this without the need for glass sampling and analysing. The assurance of the composition within the established tolerance band should be based on the process control itself - and not on a direct product control. The results achieved in this respect in the inactive test run D6 are presented as an example that this is well possible.

9.2.2 XRF-results achieved for the glass product of the D6 run

The XRF-results initially gained for the glass product of the D6 run are plotted in the Figs. 9-1 to 9-3. Figure 9-1 shows the concentration of SiO_2 in the glass versus the mass of poured

Table 9-IV
Analytical data of SiO_2, ZrO_2, SrO and Cs_2O measured by the analytical glass lab of Company Schott/Mainz. Date of analysis Nov. 4, 1993 under code FEA-2/Mec. Glass samples taken from glass pouring stream into canister No. 13 of the D6 test run

D6 test run

Pouring of canister No. 13, D6 run	Concentration (wt %)			
	SiO_2	ZrO_2	SrO	Cs_2O
Target 1)	51.60	0.508	0.16	0.569
Pouring batch A				
Sample No. 1	51.84 ± 0.136*)	0.50	0.14	0.46
2	51.77 ± 0.097	0.49	0.14	0.46
3	51.91 ± 0.144	0.49	0.14	0.47
4	51.66 ± 0.093	0.49	0.14	0.46
5	51.58 ± 0.098	0.49	0.14	0.46
6	51.81 ± 0.137	0.51	0.14	0.46
7	51.65 ± 0.212	0.49	0.14	0.47
8	51.68 ± 0.115	0.47	0.14	0.48
9	51.75 ± 0.232	0.48	0.15	0.47
10	51.81 ± 0.281	0.49	0.14	0.47
11	51.76 ± 0.241	0.49	0.15	0.48
12	51.90 ± 0.137	0.50	0.14	0.47
13	51.90 ± 0.047	0.49	0.14	0.47
14	51.73 ± 0.064	0.51	0.15	0.47
15	51.75 ± 0.165	0.50	0.14	0.48
16	51.81 ± 0.127	0.50	0.15	0.47
Pouring batch B				
Sample No. 1	51.85 ± 0.099	0.49	0.14	0.47
2	51.85 ± 0.098	0.49	0.14	0.46
3	51.89 ± 0.193	0.51	0.14	0.47
4	51.57 ± 0.076	0.50	0.14	0.46
5	51.72 ± 0.095	0.51	0.14	0.46
6	51.68 ± 0.095	0.51	0.14	0.47
7	51.64 ± 0.199	0.49	0.14	0.46
8	51.66 ± 0.158	0.48	0.15	0.48
9	51.54 ± 0.135	0.49	0.15	0.47
10	51.73 ± 0.240	0.49	0.14	0.47
11	51.84 ± 0.075	0.49	0.15	0.47
12	51.76 ± 0.089	0.50	0.14	0.47
13	51.75 ± 0.039	0.52	0.14	0.47
14	51.73 ± 0.110	0.52	0.15	0.48
15	51.83 ± 0.220	0.50	0.15	0.47
16	51.84 ± 0.203	0.50	0.15	0.48

1) Referred to the technically produced simulated HAWC-glass

*) standard deviation ± s

C:\winword\wak\tab3-IV.doc

Table 3-IVa: Composition of the radioactive HAWC reference solution, compared with the simulate used for the D6 campaign

Element	Filtrate (dissolved)				Solids (not dissolved)			Total			Simulate, D6 (total)		
	Element concentration g/l	Oxide	Oxide residue g/l	Oxide residue Wt %	Element concentration g/l	Oxide residue g/l	Oxide residue Wt %	Element concentration g/l	Oxide residue g/l	Oxide residue Wt %	Element concentration g/l	Oxide residue g/l	Oxide residue Wt %
34 Se	0,046	SeO_2	0,065	0,080	0,016	0,022	0,237	0,062	0,087	0,096	0,062	0,087	0,106
37 Rb	0,268	Rb_2O	0,293	0,361	0,019	0,020	0,218	0,286	0,313	0,347	1)	1)	1)
38 Sr	0,788	SrO	0,932	1,150	0,003	0,003	0,033	0,791	0,935	1,035	0,791	0,935	1,140
39 Y	0,570	Y_2O_3	0,724	0,893	0,005	0,007	0,073	0,575	0,731	0,808	0,575	0,731	0,894
40 Zr	0,054	ZrO_2	0,073	0,090	2,141	2,893	31,011	2,196	2,966	3,281	2,196	2,966	3,628
42 Mo	1,535	MoO_3	2,303	2,841	1,840	2,761	29,602	3,375	5,064	5,602	3,375	5,064	6,194
43 Tc	0,901	TcO_3	1,339	1,651	0,011	0,017	0,180	0,913	1,355	1,499	2)	2)	2)
44 Ru	2,120	RuO_2	2,791	3,443	0,112	0,147	1,579	2,232	2,939	3,251	2,232	2,939	3,595
45 Rh	0,560	Rh_2O_3	0,690	0,851	0,019	0,024	0,256	0,579	0,714	0,790	-	-	-
46 Pd	0,916	PdO	1,054	1,300	0,356	0,409	4,389	1,272	1,464	1,619	1,272	1,464	1,791
47 Ag	0,002	Ag_2O	0,002	0,003	0,111	0,119	1,279	0,113	0,121	0,134	-	-	-
48 Cd	0,078	CdO	0,090	0,111	0,004	0,005	0,055	0,083	0,095	0,105	-	-	-
50 Sn	0,046	SnO_2	0,059	0,073	0,012	0,015	0,157	0,058	0,074	0,082	0,058	0,074	0,091
51 Sb	0,003	Sb_2O_3	0,004	0,004	0,008	0,009	0,100	0,011	0,013	0,014	-	-	-
52 Te	0,400	TeO_2	0,500	0,616	0,123	0,154	1,647	0,523	0,653	0,723	0,523	0,653	0,799
55 Cs	2,762	Cs_2O	2,928	3,612	0,375	0,398	4,265	3,137	3,326	3,679	3,137	3,326	4,067
56 Ba	2,231	BaO	2,491	3,073	0,096	0,107	1,150	2,327	2,598	2,875	2,327	2,598	3,178
57 La	2,027	La_2O_3	2,378	2,934	0,023	0,027	0,286	2,050	2,405	2,660	2,050	2,405	2,942
58 Ce	2,923	CeO_2	3,591	4,429	0,088	0,108	1,156	3,011	3,699	4,092	3,011	3,699	4,524
59 Pr	1,417	Pr_2O_3	1,658	2,045	-	-	-	1,417	1,658	1,834	1,417	1,658	2,028
60 Nd	5,040	Nd_2O_3	5,878	7,252	0,019	0,022	0,236	5,059	5,900	6,528	6,313	7,362	9,005
61 Pm	0,004	Pm_2O_3	0,004	0,005	-	-	-	0,004	0,004	0,005	3)	3)	3)
62 Sm	1,117	Sm_2O_3	1,295	1,597	0,004	0,005	0,054	1,121	1,300	1,438	3)	3)	3)
63 Eu	0,129	Eu_2O_3	0,149	0,183	-	-	-	0,129	0,149	0,164	3)	3)	3)
64 Gd	0,383	Gd_2O_3	0,442	0,545	0,002	0,002	0,027	0,385	0,444	0,491	0,385	0,444	0,543
92 U	5,705	U_3O_8	6,728	8,299	0,026	0,030	0,324	5,731	6,758	7,476	-	-	-
93 Np	0,455	Np_2O_3	0,501	0,618	0,004	0,005	0,052	0,459	0,506	0,559	-	-	-
94 Pu	0,146	PuO_2	0,165	0,204	0,038	0,043	0,459	0,183	0,208	0,230	-	-	-
95 Am	0,424	Am_2O_3	0,467	0,576	0,001	0,001	0,009	0,425	0,468	0,518	-	-	-
96 Cm	0,017	Cm_2O_3	0,019	0,023	-	-	-	0,017	0,019	0,021	-	-	-
24 Cr	1,728	Cr_2O_3	2,525	3,115	0,132	0,192	2,063	1,860	2,718	3,007	1,860	2,718	3,324
25 Mn	0,211	MnO_2	0,334	0,412	0,004	0,007	0,075	0,215	0,341	0,377	1,128	1,789	2,188
26 Fe	6,869	Fe_2O_3	9,821	12,115	0,189	0,270	2,890	7,058	10,091	11,163	7,058	10,091	12,343
28 Ni	1,244	NiO	1,584	1,953	0,040	0,051	0,547	1,284	1,635	1,808	1,284	1,635	2,000
29 Cu	-	CuO	-	-	0,015	0,018	0,197	0,015	0,018	0,020	0,015	0,018	0,022
30 Zn	-	ZnO	-	-	0,009	0,011	0,117	0,009	0,011	0,012	0,009	0,011	0,013
82 Pb	-	PbO	-	-	0,003	0,003	0,032	0,003	0,003	0,003	0,003	0,003	0,004
11 Na	18,310	Na_2O	24,682	30,447	-	-	-	18,310	24,682	27,305	18,310	24,682	30,189
12 Mg	0,410	MgO	0,680	0,839	-	-	-	0,410	0,680	0,752	0,410	0,680	0,831
13 Al	0,057	Al_2O_3	0,108	0,133	-	-	-	0,057	0,108	0,119	0,057	0,108	0,132
19 K	0,217	K_2O	0,261	0,323	-	-	-	0,217	0,261	0,289	0,503	0,605	0,740
20 Ca	0,353	CaO	0,494	0,609	-	-	-	0,353	0,494	0,546	0,353	0,494	0,604
F^-	0,019	F^-	0,019	0,024	-	-	-	0,019	0,019	0,021	0,019	0,019	0,023
Cl^-	0,014	Cl^-	0,014	0,017	-	-		0,014	0,014	0,015	0,014	0,014	0,017
P	0,406	P_2O_5	0,931	1,149	0,621	1,422	15,243	1,027	2,353	2,603	1,027	2,353	3,098
Fiss.Prod.	Σ 26,322		31,731	39,144	5,388	7,275	77,992	31,710	39,006	43,153	-	-	-
Actinides	Σ 6,747		7,880	9,721	0,069	0,079	0,844	6,815	7,958	8,804	-	-	-
Cor.Prod	Σ 10,052		14,264	17,596	0,391	0,552	5,291	10,443	14,816	16,391	-	-	-
Chemicals	Σ 19,786		27,188	33,540	0,621	1,422	15,243	20,406	28,610	31,652	-	-	-
Total	Σ 62,907		81,063	100,00	6,468	9,328	100,00	69,376	90,391	100,00	-	81,757	100,017
Free HNO3	4 M		-	-	-	-	-	-	-	-	4 M	-	-

1) Rb portion replaced by K 2) Tc portion replaced by Mn 3) Pm, Sm and Eu portions replaced by Nd

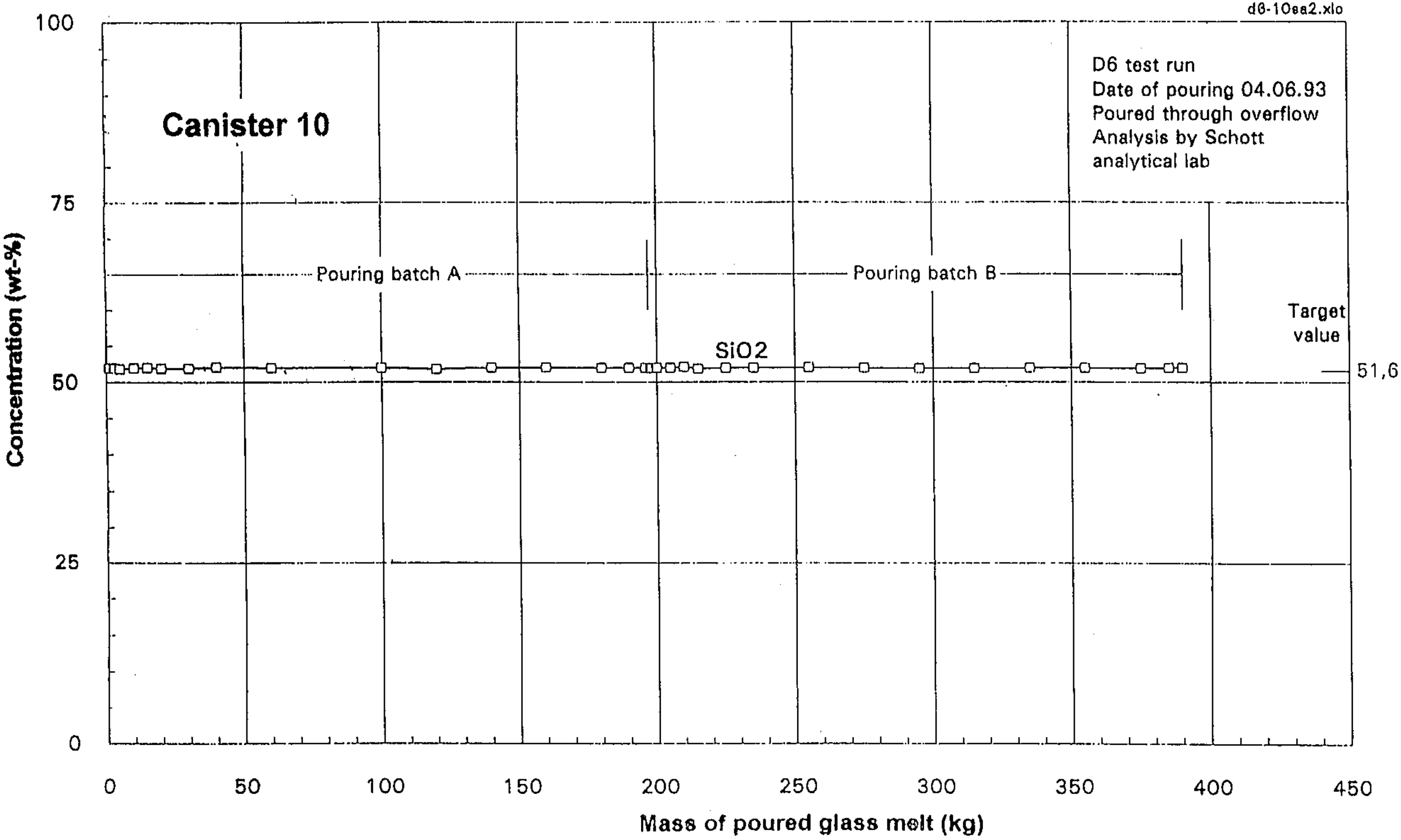


Fig. 9-4a: Concentration of SiO2 in glass samples taken from overflow glass pouring stream while filling canister 10 of the D6 test run. Analysis data obtained from analytical lab of company Schott/Mainz.

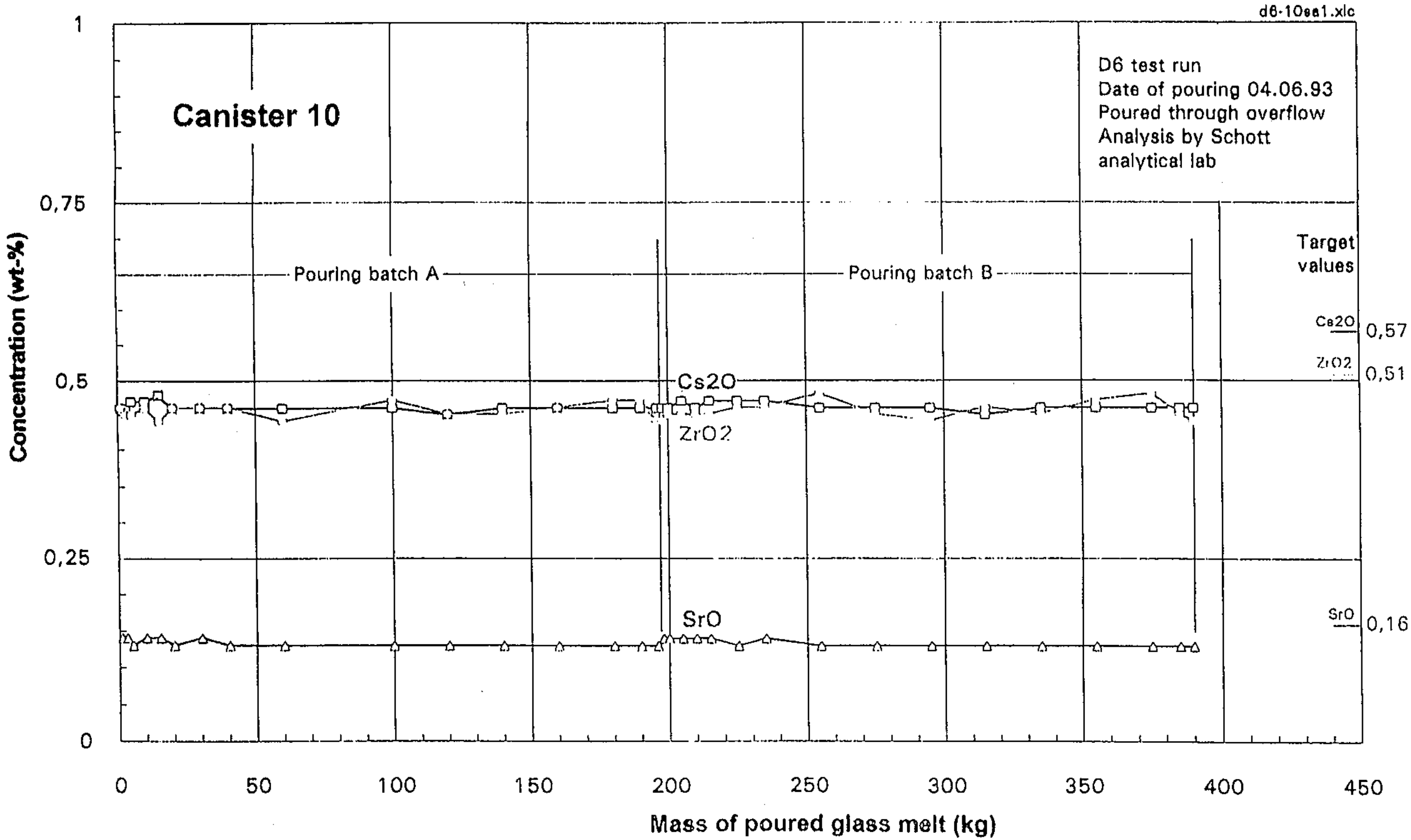


Fig. 9-4b: Concentration of ZrO2, Cs2O and SrO in glass samples taken from overflow glass pouring stream while filling canister 10 of the D6 test run. Analysis data obtained from analytical lab of company Schott/Mainz.

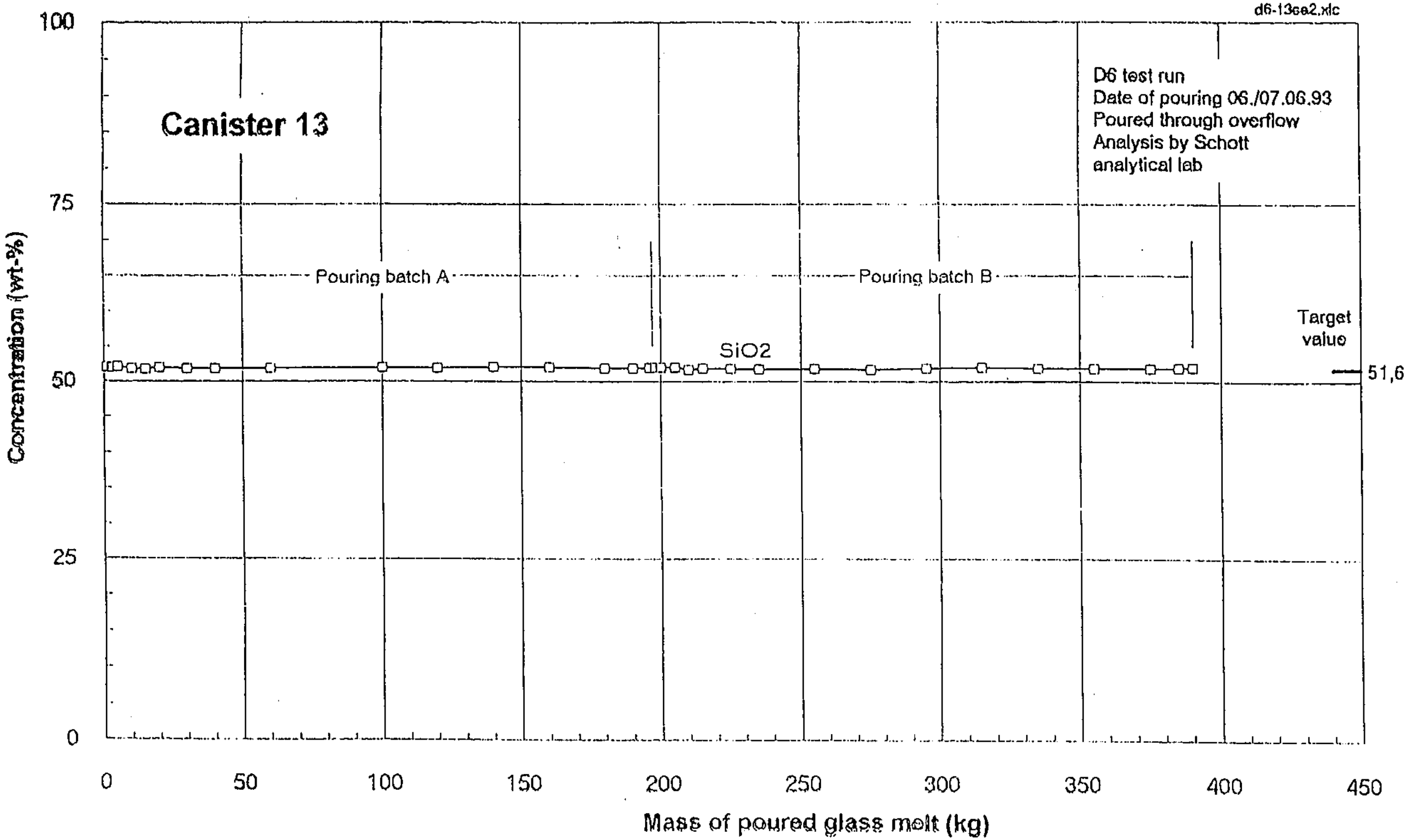


Fig. 9-5a: Concentration of SiO2 in glass samples taken from overflow glass pouring stream while filling canister 13 of the D6 test run. Analysis data obtained from analytical lab of company Schott/Mainz.

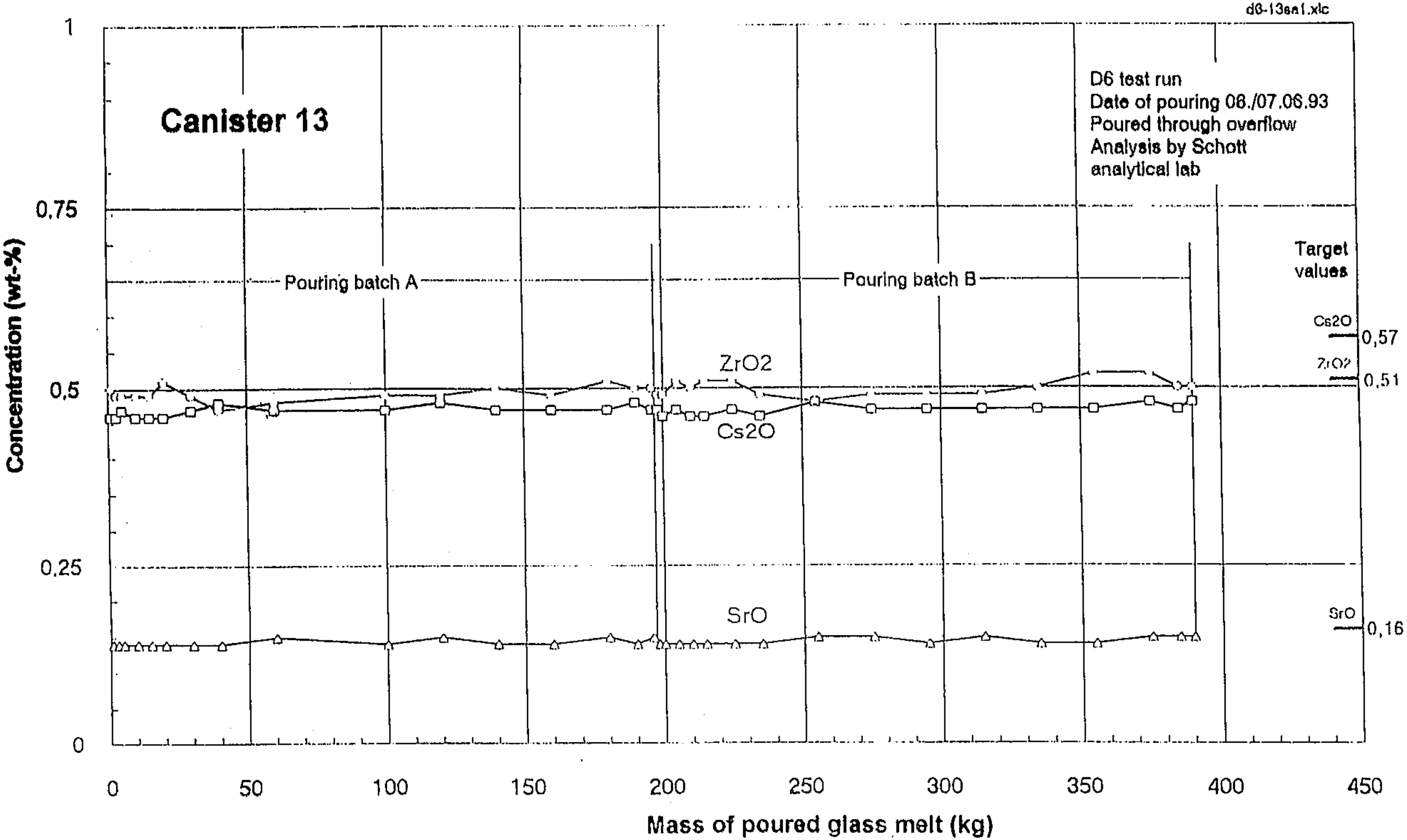


Fig. 9-5b: Concentration of ZrO2, Cs2O and SrO in glass samples taken from overflow glass pouring stream while filling canister 13 of the D6 test run. Analysis data obtained from analytical lab of company Schott/Mainz.

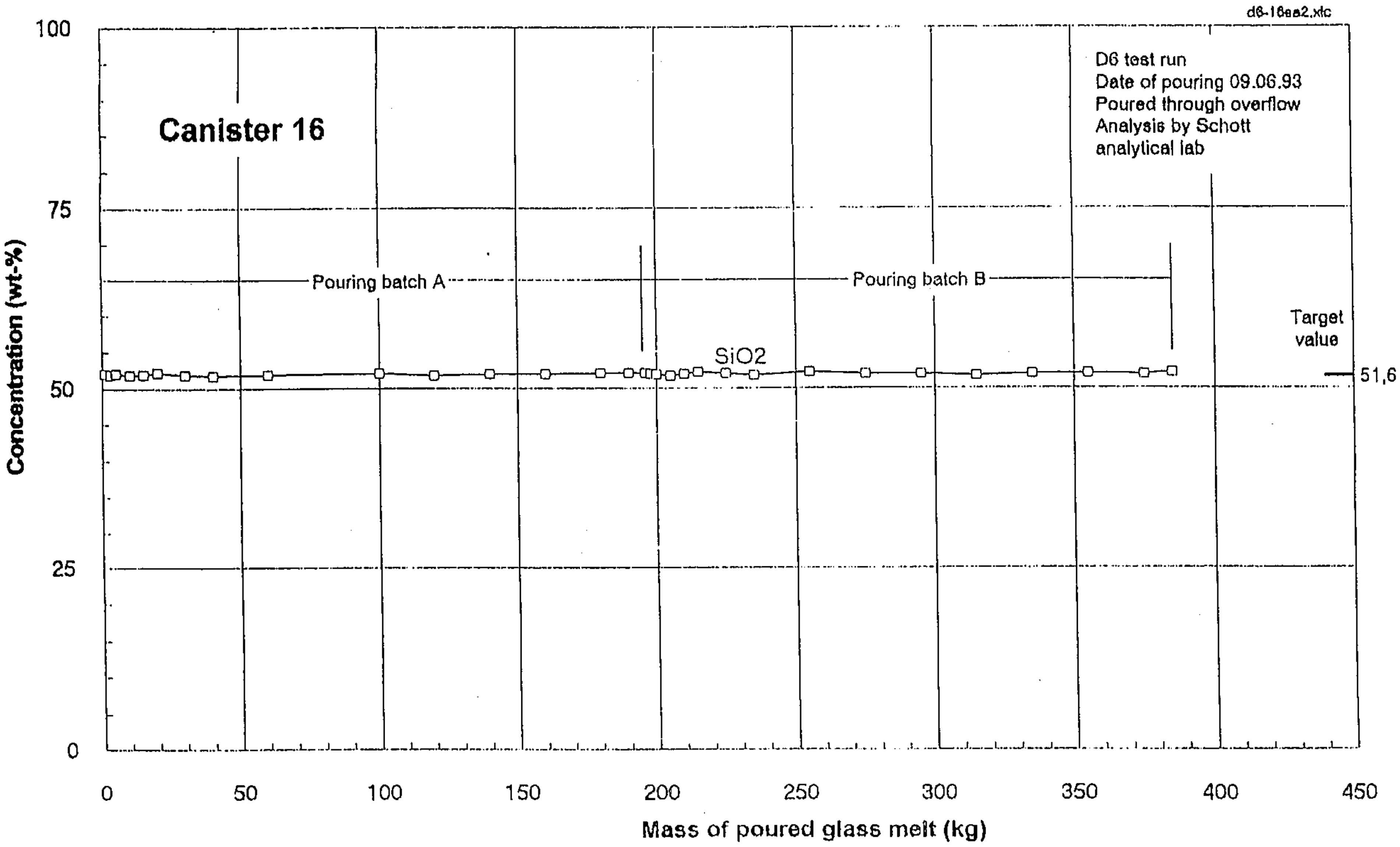


Fig. 9-6a: Concentration of SiO2 in glass samples taken from overflow glass pouring stream while filling canister 16 of the D6 test run. Analysis data obtained from analytical lab of company Schott/Mainz.

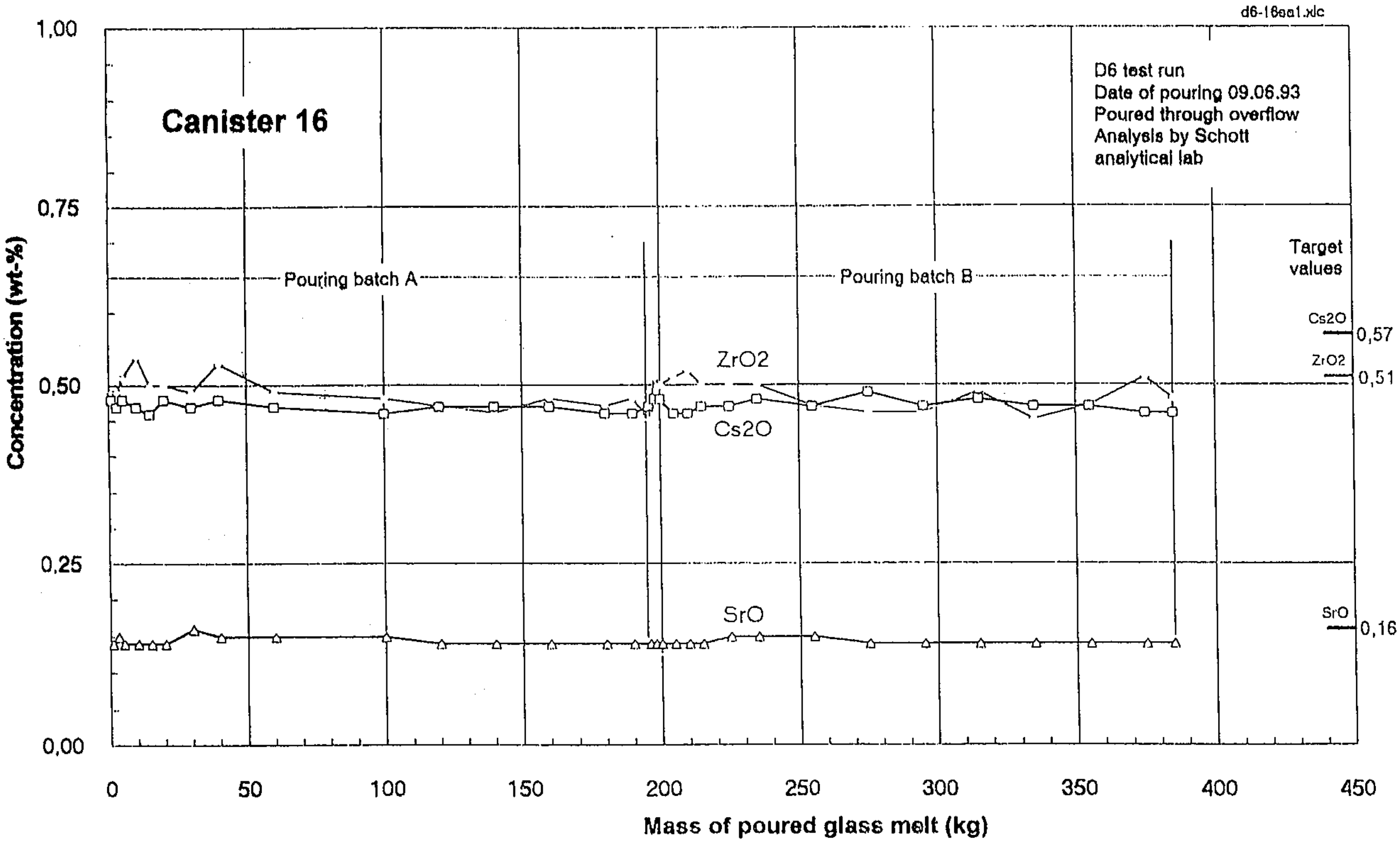


Fig. 9-6b: Concentration of ZrO2, Cs2O and SrO in glass samples taken from overflow glass pouring stream while filling canister 16 of the D6 test run. Analysis data obtained from analytical lab of company Schott/Mainz.

ENTWURF

TEA/WK/Vo/933400
24.07.1993

~~HEA/2382/7A~~

HEA/1250/7A

W0788359

Specification

of the Vitrified Residue

of WAK High Level Waste

GNS B TE 002/93

Revision:	"00"
Date:	24.07.1993

	Name	Signature
Author:	Dr. W. Kunz / TEA	
Verification:	E. Ewest / TQ1	
Release GNS:	R. Weh / TE	

This report has been written on behalf of
Wiederaufarbeitungsanlage Karlsruhe BGmbH (WAK),
Eggenstein-Leopoldshafen, Germany

Introduction

Within a period of nearly 20 years the Karlsruhe Reprocessing Plant (Wiederaufarbeitungsanlage Karlsruhe - WAK), which was designed as a pilot plant for the development of the future commercial reprocessing, has reprocessed spent fuel by the PUREX process of several German nuclear reactor types.

Up to its shut down in late 1990 the plant has processed a total of 212 t_E of oxide fuel reloaded from the following reactor types:

— PHWR fuel with natural uranium: MZFR, FR2

— BWR fuel with low enriched uranium (≤ 3.5 %): VAK, HDR and KRB

— PWR fuel with low enriched uranium (≤ 3.5 %): KWO, GKN, KKS and NS Otto Hahn.

— PWR mixed oxide fuel (MOX, equivalent to 2.8 % enrichment): KWO and GKN (very small amount).

Liquid waste concentrate (HAWC)

The remaining high active liquor (the so-called HAWC) of about 60 m^3 shall be converted into a solid waste form with a high chemical stability being suitable for final disposal.

In order to reach that goal the production of an borosilicate glass product is intended by using the recommended PAMELA vitrification process. By a highly sophisticated process developed by KfK/Germany and successfully demonstrated during the hot operation of PAMELA plant at Dessel/Belgium the high quality standard of the glass product will be ensured.

In this specification the resulting product will be characterized by both nominal and guaranteed values, taking the 16 relevant properties for final disposal into account as identified by the recommendation of the 'BMFT Arbeitskreis HAW-Produkte' /1/.

Table of Contents

1. *Description of the PAMELA Vitrification Process*

The PAMELA vitrification process as shown in fig. 1 is based on a liquid fed Joule heated ceramical melter. By this one-step process (throughput about 30l/h) a liquid acid HLLW-solution is fed together with solid borosilicate glass particles (the so-called frit) into an oven. There, at a maximum temperature of about 1,150 °C, chemical and physical reactions take place, as following:

— Drying of the aqueous fission product solution by evaporation,

— Calcination (i.e converting nitrates into oxides) by heat impact,

— Vitrification by forming a homogeneous glass melt of frit and fission product oxides.

After a mean residual time of about 80 hours the molten glass product is poured into a 180 l stainless steel canister. The canister is, however, filled by up to four pouring steps.

Having passed a controlled cooling-down procedure the canister's lid is welded and the surface is decontaminated, hereafter. Up-to-its-transportation the canister is stored for further cooling down in a plant own pit storage.

The vitrification process will be carried out in the Belgian Belgoprocess-owned PAMELA Plant, taking quality measures as defined in DIN ISO 9000 into consideration. Furthermore the process control will ensure that the a.m. relevant properties will be taken into consideration. Although operating under Belgian responsibility, quality control checks and audits by German authorities or their representatives are possible to be carried out as agreed in the contract between WAK/KfK on the German side and ONDRAF/NIRAS and Belgoprocess on the Belgian side

Details concerning the product quality are described in the Handbook of Process Qualification /2/ which is a document related to this specification.

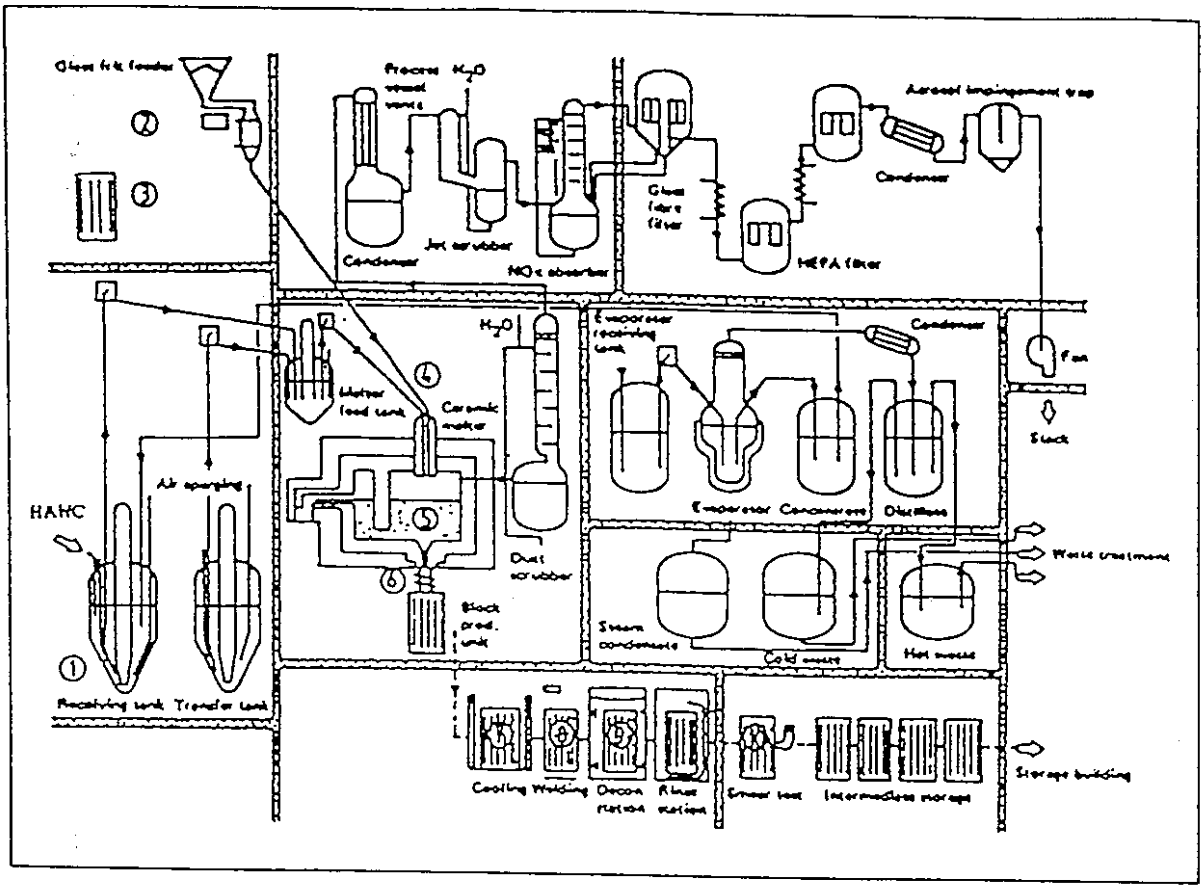


Figure 1: Simplified Flowsheet of PAMELA-Process

2. *Characteristics of the Raw Waste*

2.1 *General Aspects*

The aqueous liquid waste is presently stored in two tanks:

— about 43 m^3 liquor resulting from reprocessing in the time between 1971 up to 1987,

— about 16 m^3 liquor resulting from reprocessing up to 1990 including rinsing solutions,

the tank contents being of a slightly different chemical composition. Vitrification will be carried out by using a blend produced by a sophisticated mixing procedure /3/ to guarantee a uniform product quality.

The maximum specific total β-activity of these liquor is: .... 1.85 E13 Bq/l,

and minimum concentration of nitric acid is: .... 3.5 mol/l.

Due to WAK's function of being a pilot plant the burn up of the reprocessed fuel varies in a wide range between 2,000 and 40,000 MWd/t, whereas a mean of about 25,000 MWd/t has to be taken into consideration.

As reprocessing in WAK was terminated in late 1990 and the fuel elements processed in WAK had a minimum discharge time of 3 years, and as vitrification will not take place earlier than 1997, every compound of the HAWC will have been cooled down at least for 10 years.

2.2 *Chemical Composition of the Liquid Waste - HAWC*

The High Level Liquid Concentrate (called 'HAWC') is a composition of four main types of constituents:

— *Fission products*, especially cesium and strontium as main sources of β/γ-activity, reduced by the amount which was removed by feed clarification;

— *Uranium, plutonium and higher actinoids*, as main sources of α-activity;

— *Corrosion elements*, especially iron and nickel, as inactive parts;

— *Chemicals* of the reprocessing process, especially sodium, as inactive parts, too.

While most of these elements or nuclides are ionogenically solved in the highly acid liquor, there is a certain amount of them left either undissolved or reprecipitated, forming a suspended solid phase. The mean concentration of this phase is about 14 g/l (as in store for the time being).

The nominal element concentrations as well as calculated maximum and minimum values, evaluated by the uncertainty margins either of the analytical methods or of the expected dilution by steam jets and air lifts, are listed in table 1. Beside the element concentration a calculated value is given for a virtual oxide concentration (≙ calcinate) as those numbers are relevant for the vitrification process itself.

Table 1: Nominal element concentrations and fractions of ~~virtual~~ oxide ~~composition~~ (residues) (mean, minimum and maximum values) of the blend of both tanks storing WAK-HAWC.

Element	Minimum values Oxide [wt.-%]	Nominal values Element [g/l]	Nominal values Oxide [wt.-%]	Maximum values Oxide [wt.-%]
34 Se	0.08	0.06	0,.10	0.11
37 Rb	0.39	0.29	0.35	0.32
38 Sr	0.75	0.79	1.04	1.22
39 Y	0.77	0.58	0.81	0.83
30 Zr	2.64	2.20	3.28	3.78
42 Mo	5.92	3.38	5.60	5.40
43 Tc	1.55	0.91	1.50	1.46
44 Ru	3.63	2.23	3.25	2.99
45 Rh	0.88	0.58	0.79	0.73
46 Pd	1.16	1.27	1.62	1.92
47 Ag	0.13	0.11	0.13	0.14
48 Cd	0.10	0.08	0.11	0.11
50 Sn	0.07	0.06	0.08	0.10
51 Sb	0.01	0.01	0.01	0.02
52 Te	0.72	0.52	0.72	0.72
55 Cs	4.17	3.14	3.68	3.35
56 Ba	3.26	2.33	2.88	2.61
57 La	3.00	2.05	2.66	2.43
58 Ce	2.12	3.01	4.09	4.73
59 Pr	1.75	1.42	1.83	1.89
60 Nd	4.30	5.06	6.53	8.00
62 Sm	0.44	1.12	1.44	2.10
63 Eu	0.13	0.13	0.16	0.19
64 Gd	0.52	0.39	0.49	0.47
92 U	9.15	5.73	7.48	6.35
93 Np	0.64	0.46	0.56	0.50
94 Pu	0.26	0.18	0.23	0.21
95 Am	0.60	0.43	0.52	0.47
96 Cm	0.03	0.02	0.02	0.02
24 Cr	3.05	1.86	3.01	2.97
25 Mn	0.33	0.22	0.38	0.41
26 Fe	11.84	7.06	11.16	10.69
28 Ni	1.76	1.28	1.81	1.83
11 Na	30.12	18.31	27.31	25.38
12 Mg	0.00	0.41	0.75	1.25
13 Al	0.00	0.06	0.12	0.20
19 K	0.10	0.22	0.29	0.42
20 Ca	0.62	0.35	0.55	0.41
F	2.02	0.02	0.02	0.02
Cl	0.02	0.01	0.02	0.02
P	1.97	1.03	2.60	3.08
Σ Total	100.00	69.38	100.00	100.00

There is to point out that more than 25 % of the mentioned material is inactive sodium nitrate (or as calcinate Na$_2$O) which was added as nitrite to the reprocessing process in order to stabilize a certain plutonium oxidation stage needed for obtaining a high factor of separation.

As concentration values are subject to changes due to dilution effects the total amount of the a.m. types of constituents is given in table 2.

Table 2: Total amount of HAW constituents

Total amount, as oxides (calcinate):	7,940 kg
Total amount, as elements:	6,095 kg
• Fission products:	2,785 kg
• Actinoids:	560 kg
• Corrosion elements:	918 kg
• Process chemicals:	1,792 kg
Part of elements as suspended particles:	820 kg

These total values are deemed to remain unchanged. The decay of the radionuclides will cause a certain conversion into stable elements of equivalent mass. However, there is no significant change in the chemical composition within the near future.

2.3 *Activity Inventory of the HAWC Blend*

While the chemical composition - as characterized above - is based on a chemical analysis, the activity-related data have been evaluated by burn up calculations performed with the *KORIGEN* code /4/, as they have to be predicted for the probable time of vitrification in 1997. Nevertheless, a detailed verification programme was carried out in order to confirm the reliability of the code and to introduce correction factors, taking all effects on the waste composition of the chemical reprocessing process of WAK into account /5/.

Hence, the totals of the radiological data will be as following.

Table 3: Totals of activity related data (valid for 01.01.1997)

Total α-activity: .... 8.0 E15 Bq
Total β-activity: .... 8.9 E17 Bq
Total photon emission: .... 4.2 E17 s^{-1}
Total neutron emission: .... 1.6 E10 n/s
Total heat generation: .... 76.4 kW

In addition the activity of main α- and β-nuclides are listed in Table 4.

Table 4: Nuclide activity of the WAK-HAWC blend, total values, valid for 01.01.1997 /4,5/.

Nuclide inventory***		Values
H-3**	[Bq]	7.5 E 12
Sr-90/Y-90 *	[Bq]	4.0 E 17
Tc-99	[Bq]	5.6 E 13
Ru-106/Rh-106 *	[Bq]	1.1 E 14
Sb-125	[Bq]	6.8 E 14
Cs-134	[Bq]	2.4 E 15
Cs-135	[Bq]	1.8 E 12
Cs-137/Ba-137m*	[Bq]	4.7 E 17
Ce-144/Pr-144 *	[Bq]	4.2 E 13
Eu-154	[Bq]	4.1 E 15
Eu-155	[Bq]	1.0 E 15
U-235	[Bq]	2.7 E 08
U-238	[Bq]	6.2 E 09
Np-237	[Bq]	1.0 E 12
Pu-238	[Bq]	1.1 E 14
Pu-239	[Bq]	2.2 E 13
Pu-240	[Bq]	3.8 E 13
Pu-241 (β)	[Bq]	2.7 E 15
Am-241	[Bq]	3.6 E 15
Am-242	[Bq]	2.4 E 13
Cm-242	[Bq]	2.0 E 13
Cm-244	[Bq]	4.1 E 15

* = Sum of activity of mother and daughter nuclide

** = 1 % of activity of KORIGEN burn up calculation

*** = Based on KORIGEN calculation, taking analytical values for U, Pu and actinoids into regard.

3. *Characteristic Data of the Glass Frit*

Borosilicate glass called GG WAK 1 has been chosen as a matrix material, having a composition as given in table 5. This granulated material is delivered by the manufacturer in the shape of small cylindric bodies, having a mean length and a diameter of 2 mm each.

Table 5: Composition of the glass frit GG WAK 1 including the tolerable bandwidth

Oxide	Fraction [wt. -%]	Tolerances
SiO_2	60.0	± 0.5 *
B_2O_3	17.6	± 0.6 *
Al_2O_3	3.1	± 0.2
Li_2O	3.5	± 0.2
Na_2O	7.1	± 0.4
CaO	5.3	± 0.4
MgO	2.2	± 0.4
TiO_2	1.2	± 0.2

* = In case of SiO_2 and B_2O_3 a bandwidth of 1.5 wt.-% should be tolerable by way of exception due to reasons concerning the highly sophisticated manufacturing process. However the product should never be outside guaranteed parameters which will be ensured by suitable QA procedures.

4. *Characteristic Data of the Empty Canister*

The canister is made of heat-resistent stainless steel, being a cylindrical package with an outer diameter of 430 mm. The purpose of the canister is

— to be the mould for the drained molten glass product,

— to provide attachment means for handling,

— to guarantee the integrity of the package during interim storage and handling.

The main dimensions are listed up in table 6, while a workshop drawing of the canister is given in figure 2. It is possible to stack a number of 10 filled canisters on each other. Top and bottom of the canister are formed in such a way that stacking can be easily done.

Table 6: Dimensions of the stainless steel canister

Main data of the canister	Value
Total volume Net volume	180 l 150 l
Wall thickness Weight of empty canister	5 mm ca. 80 kg
Height including lid at room temperature Stacking height at storage temperature	1.338 mm ≤ 1.275 mm
Diameter at room temperature Maximum diameter at storage temperature	430 ± 2 mm ≤ 435 mm

In addition some characteristical properties of the canister's material are listed up which are relevant for the product quality, the heat flux, on the integrity during cooling down procedure of the glass and the interim storage period.

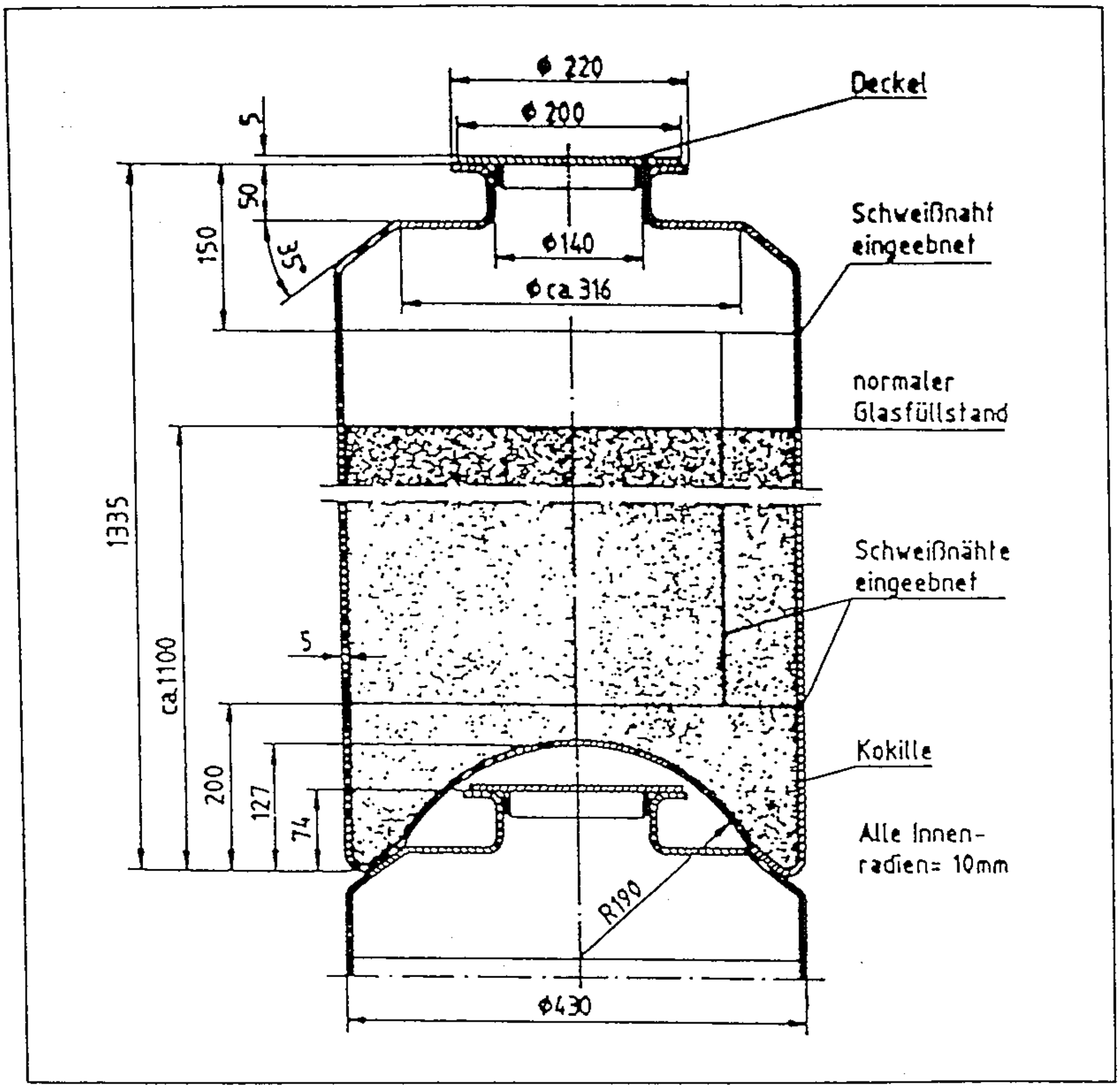


Figure 2: Workshop drawing of the stainless steel canister, dimensions valid for room temperature conditions only.

Table 7: Main characteristic data of the canister's material

Property	Data						
Material	X15CrNi24/3 (1.4833 at DIN)						
Composition [wt.-%], * = max. value	C* 0.08	Si 1.0	Mn* 2.0	P* 0.045	S* 0.03	Cr 21-23	Ni 12-15
Density Hardness 0.2-% Elasticity limit Tensile strength	7.9 g/cm³ (20 °C) HB 192 210 N/mm² 500 - 750 N/mm²						
Expansion coefficient [1E-06·1/K]	200 °C 16		400 °C 17.5		600 °C 18		1000 °C 19.5
Thermal conductivity [W/mK]	20 °C 15		500 °C 19				
Spec. heat capacity Max. temperature of scaling resistance	0.5 J/gK (20 °C) 1000 °C in air						
Emissivity - 200 °C - 300 °C	rolled, new 0.23 0.23		annealed 0.61 0.51		decontaminated 0.62 0.45		

Table 8: Mean composition of the WAK HAW glass product, calcinate incorporation 16 wt.-%

Compound	wt.-%
SiO_2	50.4
B_2O_3	14.8
Al_2O_3	2.6
Na_2O (frit)	6.0
Li_2O	2.9
CaO	4.5
MgO	1.8
TiO_2	1.0
Total, frit	84.0
ZrO_2	0.5
MoO_3	0.9
(Ru, Rh, Pd)O_x	0.9
Cs_2O	0.6
other fission products	4.0
U_3O_8	1.2
other actinoides	0.2
Fe_2O_3	1.8
CrO_3	0.5
other corrosion elements	0.3
Na_2O	4.4
PO_4^{3-}	0.4
other chemicals	0.5
Total, calcinate	16.0

5.2 Mean Radionuclide Inventory

The main radiological data of a waste glass canister are listed up in table 9 assuming that all the liquid waste will be conditioned in no more than 124 packages.

5. *Characteristic Data of the Vitrified Product*

The target value of waste calcinate incorporation into the glass product will be 16 wt.-%. The product yielded is a borosilicate glass having certain properties as discussed as following taking requirements of the melting process, interim storage and final disposal into regard.

5.1 Chemical Composition

By use of a target composition 84 % of the glass frit as specified in chapter 3 and 16 % of the average liqid waste composition as described in chapter 3, a borosilicate glass product will result as given in table 8.

Basing on an average filling level of 150 l for each canister the weight of the glass product will be about 400 kg, i.e. a load of waste calcinate of 64 kg.

Table 9: Mean total radiological data of a 150 l waste glass package (data valid for 01.01.1997)

total activity:	7.2 E15 Bq
α-activity:	6.5 E13 Bq
Photon emission:	3.4 E15 s^{-1}
Neutron emission:	2.6 E08 n/s
Heat generation:	0.62 kW
Contact dose rate:	< 550 Gy/h
Dose rate in 1 m distance:	< 52 Gy/h

In table 10 the main radionuclides are listed up in addition. The nuclides have been selected by criteria as following:

- actual activity and surface dose rate,
- fissile material content,
- long term safety of a repository.

The data are the result of burn-up calulations /4/.which They were verified by several radiochemical invesigations /3, 5/ under the provision that volatile nuclides (especially the rare gases, carbon and iodine) will not be incorporated in a glass matrix.

Table 10: Mean nuclide inventory of a waste glass canister (150 l glass, 16 wt-% calcinate incorporation, nominal raw waste composition, data valid for 01.01.1997)

Nuclide inventory	Activity [Bq/Canister]
Sr-90/Y-90 *	3.2 E 15
Tc-99	4.5 E 11
Ru-106/Rh-106 *	8.9 E 11
Pd-107	3.4 E 09
Sb-125	5.5 E 12
Cs-134	1.9 E 13
Cs-135	1.5 E 10
Cs-137/Ba-137m *	3.8 E 15
Ce-144/Pr-144 *	3.4 E 11
Pm-147	9.2 E 13
U-235	2.2 E 06
U-238	5.0 E 07
Np-237	8.1 E 09
Pu-238	8.9 E 11
Pu-239	1.8 E 11
Pu-240	3.1 E 11
Pu-241 (β)/Am-241 *	5.7 E 13
Am-242	2.0 E 11
Cm-242	1.6 E 11
Cm-244	3.3 E 13

* = Sum of activity of mother and daughter nuclides

For long-term studies the decrease of the total activity, α-activity, the γ photon emission, the neutron emmission rate, and the heat generation are of certain importance. The curves are shown in figures 3 a, b, c, d, e /4/.

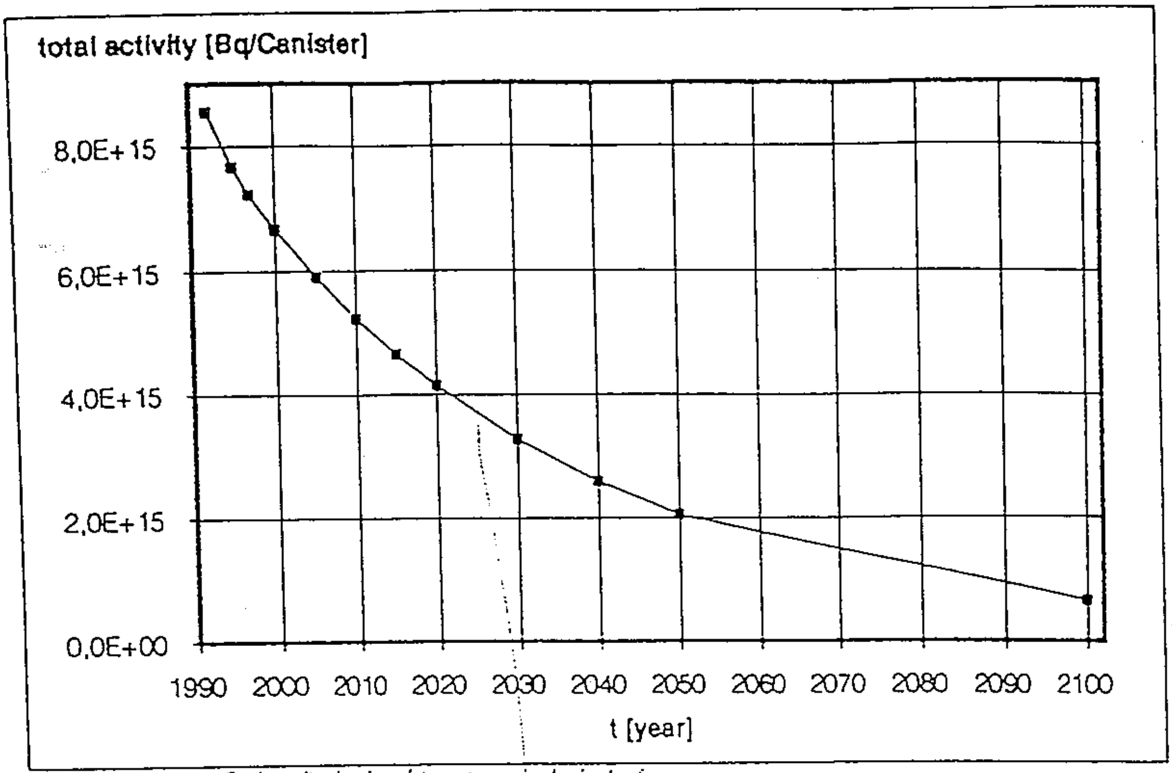


Figure 3 a: Total activity vs. time diagramme

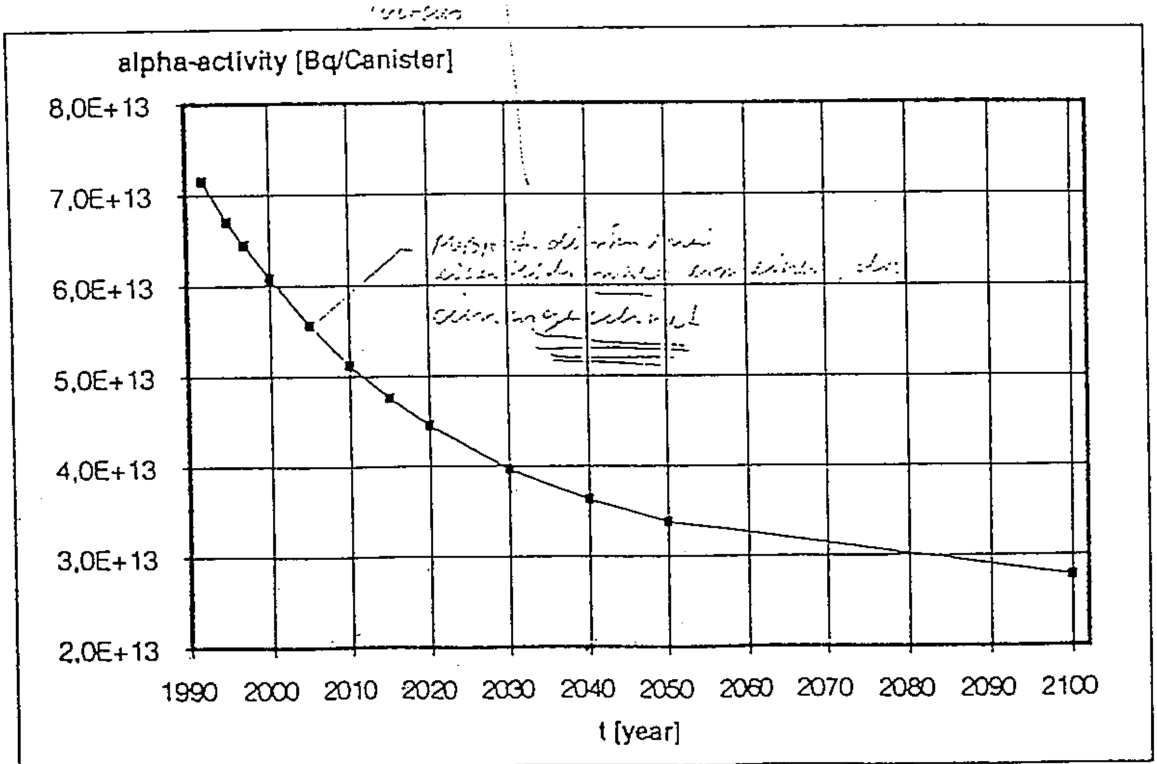


Figure 3 b: α-activity vs. time diagramme

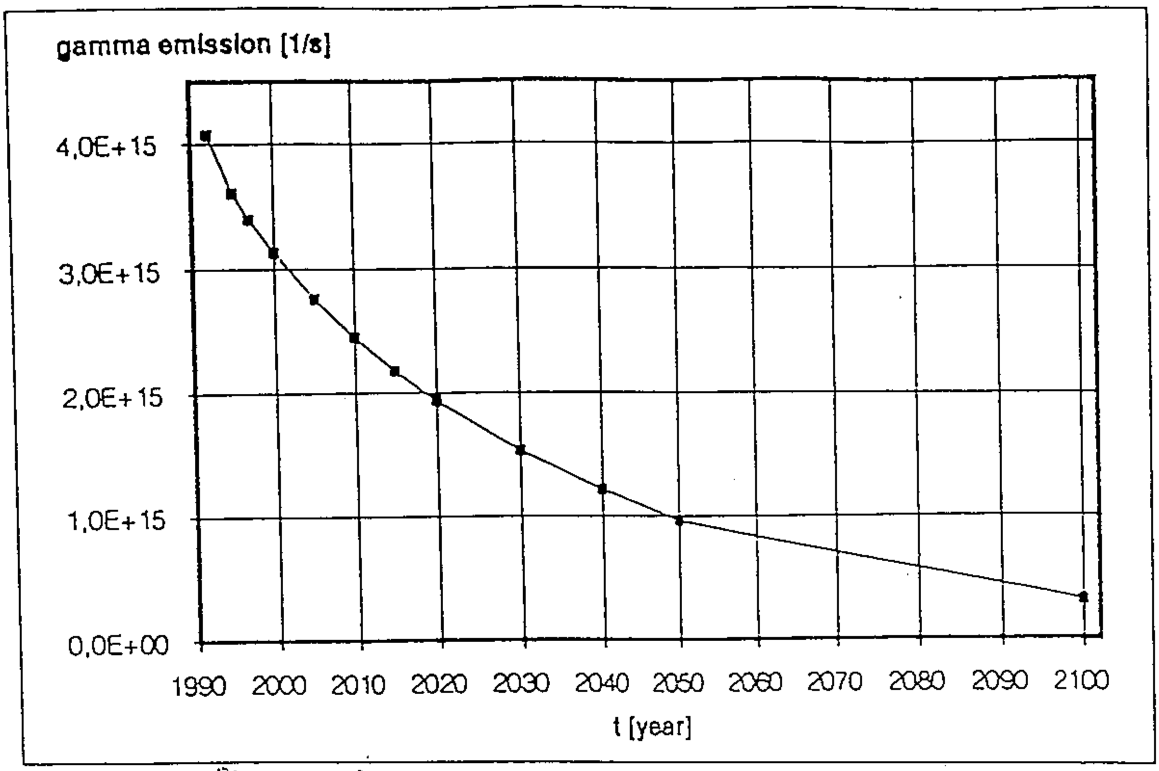


Figure 3 c: Photon emission vs. time-diagramme

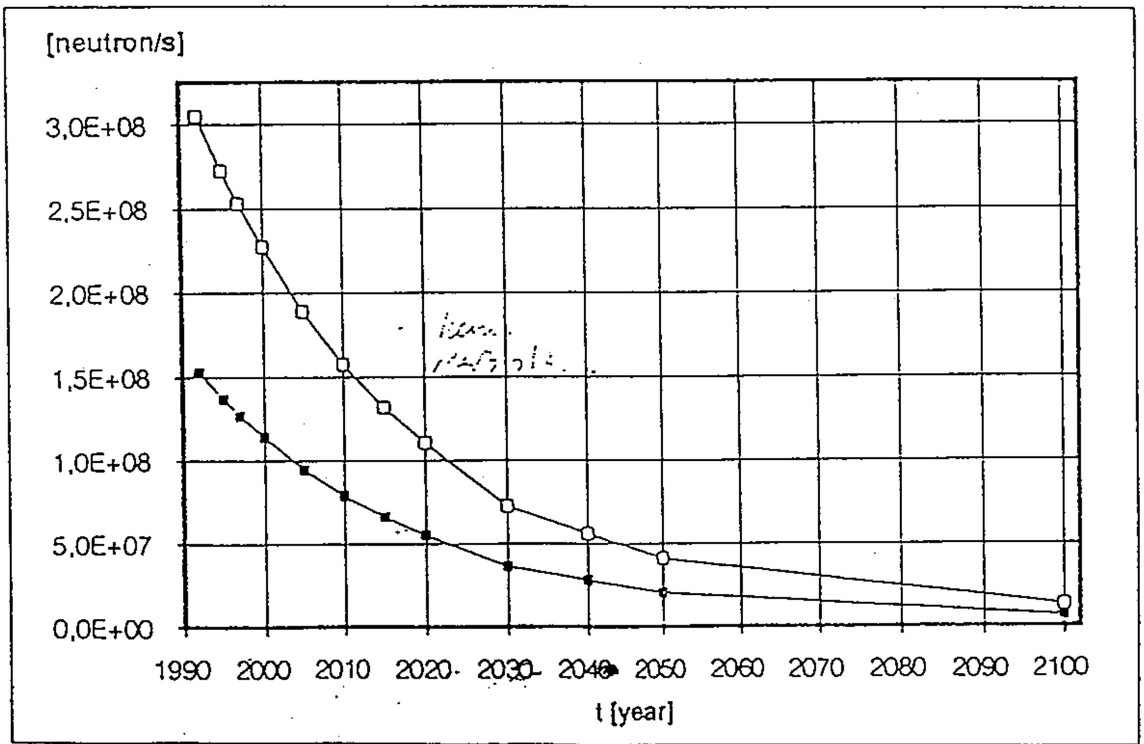


Figure 3 d: Neutron emmission rate vs. time-diagramme

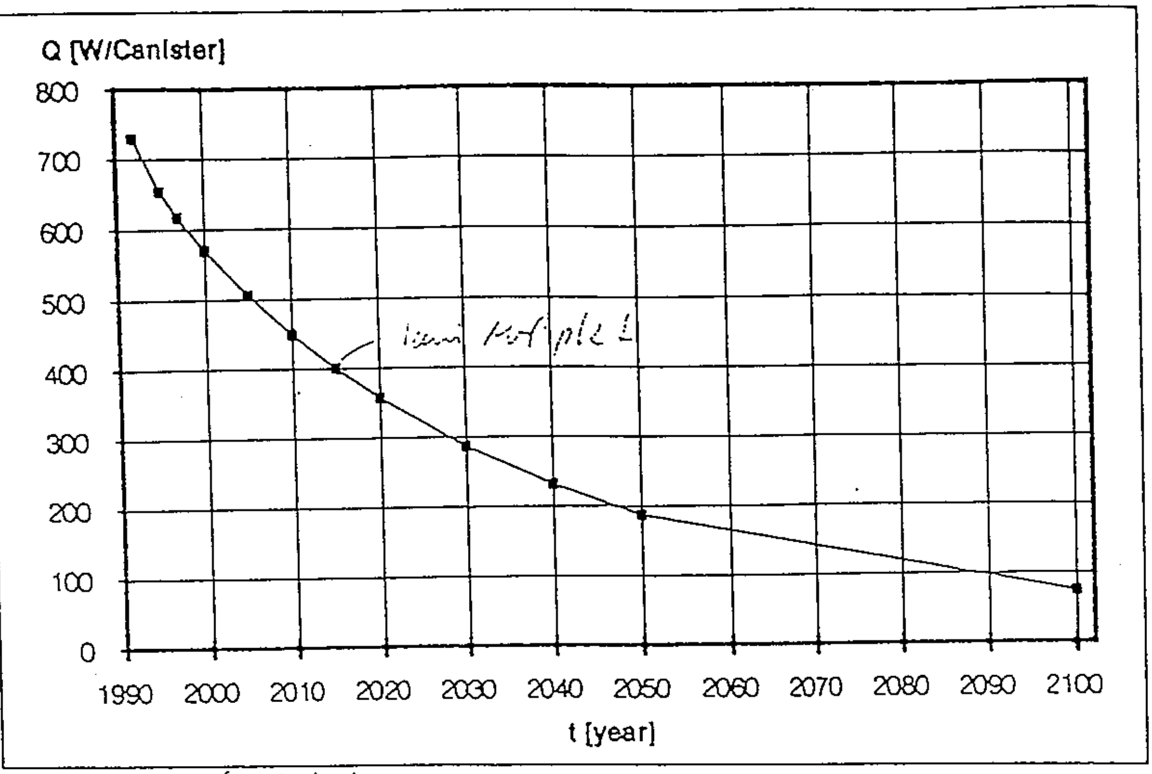


Figure 3 e: Heat decay rate vs. time diagramme

5.3 Characteristical Physical Data /6/

For operation of the melter, for interim storage and final disposal a series of various physical properties has to be taken into consideration, which are listed up as following.

Dynamic Viscosity: A-value which characterises the fluidity behaviour of the melt during the vitrification process and while pouring the product into the canister. The viscosity is specified as following:

Viscosity of glass product at 1,150 °C: .... 45 dPa•s
Viscosity of glass product at 950 °C: .... 513 dPa•s
Viscosity of pure frit at 1,150 °C: .... 101 dPa•s
Viscosity of pure frit at 950 °C: .... 1390 dPa•s

Specific electrical resistance: This property is a key value for the operation of a Joule heated ceramical melter.

Spec. electrical resistance of the glass product at 1,150 °C: .... 7 Ω•cm

Spec. electrical resistance of the glass product at 950 °C: .... 19 Ω•cm
Spec. electrical resistance of pure frit at 1,150 °C: .... 9.4 Ω•cm
Spec. electrical resistance of pure frit at 950 °C: .... 27 Ω•cm

Density: By pycnometrical measurements the following data were determined:

Density of the glass product at 20°C: .... 2.70 g/cm²
Density of the glass frit at 20°C: .... 2.48 g/cm²
Density of the glass melt at 1,150°C: .... 2.38 g/cm²

Characteristical Temperatures and Thermal Expansion: These figures describe the influence of heat on a glass product. The transformation temperature (T_G) indicates a viscosity of 1 E 13 dPa•s. Up to this temperature the thermal expansion behavior can be described by a linear coefficient (α). In excess of T_G the softening temperature (T_E) is reached when a glass sample looses its shape rapidly by melting. Another important value is the temperature of maximum cristal growth (T_K). It characterises a range of temperature where cristallisation leads to thermodynamical stable products of a cristalline phase supported by kinetic factors at elevated temperatures. T_G, T_E and α are determined by dilatometric measurements.

Transformation temperature, T_G: .... 513 °C
Softening temperature, T_E: .... 569 °C
Temperature of maximum cristallisation rate, T_K: .... 750 °C
Thermal expension coefficient (20 - 400 °C), α: 9.3E-06/K

Heat conductivity and heat capacity: These data are relevant for the heat dissipation especially during the initial interim storage phase:

Heat conductivity at 400 °C: .... 1.42 W/m•K
Heat conductivity at 130 °C .... 1.20 W/m•K
Specific heat capacity at 400 °C: .... (22) 1.22 **) 1.xx J/g•K
Specific heat capacity at 300 °C: .... (22) 1.15 **) 1.xx J/g•K

Volatilisation: An overall value for volatilisation has been measured for the glass melt:

Specific
Rate of volatilisation at 1,150 °C: .... 5.0 E-03 g/cm²/h

**) WAK - Ermittlung

In case of interim storage conditions (< 450 °C) the release of volatile compounds is negligable. Slightly volatile oxides of Cs and Ru will become solid at least at the canisters inner surface which is cooler than the glass product's center. The production of gaseous nuclides by spontaneous fission (like Kr-85 and I-129) and the decay chaines of U- and Pu-Isotopes (Rn-220) will not cause a significant contribution to any activity release of the package /7/.

Cristallisation and Phase Seperation: During the cooling down procedure (600 - 800 °C) some cristalline phases may grow, however the fraction of cristalline phases is expected to be lower than 1 % by volume. In addition the formed phases like Diopside do not have less favorable properties as the glass itself. Furthermore the comprehensive R&D-work did not give any hints for the occurance of highly soluble 'yellow phase'.

Noble metals like Ru, Rh and Pd may also form seperate phases like RuO_2 needle like cristals or spherical alloys separation ($RhPd_x$), both at micron scale. However, these phases do not have any relevance concerning long term safety as there is no significant activity contribution of highly radiotoxic nuclides with long half lives. By the layout of the melter geometry a homogeneous distribution of these phases will be ensured. In addition they will be completely imbedded by the glass.

5.4 Corrosion in Aqueous Solutions and Brines

By an Soxhlet-Leach-Test in destilled water at temperatures of 100 °C an indicative rates (R_L) for short term corrosion were yielded

$R_{L,1}$ (mean value after 1d): .... x,x E-xx g/cm²/d
$R_{L,3}$ (mean value after 3d): .... x,x E-xx g/cm²/d
$R_{L,10}$ (mean value after 10d): .... x,x E-xx g/cm²/d
$R_{L,30}$ (mean value after 30d): .... 9,0 E-04 g/cm²/d

using inactive samples with a waste load of 16 wt.-%.

With resepect to long term safety static corrosion experiments which were carried out following the MCC-rules at 110 °C and 190 °C in brines as:

– solution 1: $NaCl\text{-}KCl\text{-}MgCl_2\text{-}Na_2SO_4\text{-}H_2O$

– solution 2: $NaCl$-$CaSO_4$-(KCl-$MgCl_2$)-H_2O

changing the (sample)-surface to (brine)-volume ratio S/V from 1.000 to 10.000 m^{-2} using inactive samples with a 13, 16 and 19 wt.-% waste incorporation. The results are given in fig. 4.

[Hinweis von INE über die Art der Ergebnisdarstellung benötigt] /8/.

6. *Guaranteed Parameters*

The data provided in chapter 5 are nominal or indicative values describing an standard glass product on basis of an average acitivity level and an average chemical composition of wase solution and of glass frit. By an accepted bandwidth of the waste load of 13 to 19 wt.-%, several data are subject to vary, however they will always be covered by the guarenteed parameters.

Table 11: Guaranteed parameters (maximum values) of the vitrified product of WAK-HAWC

Guaranteed parameters		Guaranteed value
Maximum load of calcinate		19 wt.-%
Bandwidth of glass composition		see table 12
Mass of package		≤ 550 kg/package
Dimensions at room temperature		see fig. 2
Max. stacking height		1,275 mm
Transferable surface contamination:	α-Emitters	≤ 0.4 Bq/cm²
	β-Emitters	≤ 4.0 Bq/cm²
Maximum activity Sr-90/Y-90 *		4.4 E15 Bq/package
Maximum activity Cs-137/Ba-137m *		5.3 E15 Bq/package
Maximum total β/γ-activity		1.0 E16 Bq/package
Neutron emission		≤ 4.0 E08 n/s/package
Uranium, total weight		≤ 6,880 g/package
Plutonium, total weight		≤ 206 g/package
Curium, total weight		≤ 20.2 g/package
Dose rate:	β/γ at surface	≤ 762 E2 Gy/h
	β/γ at 1 m distance	≤ 72 E1 Gy/h
	Neutrons at surface	≤ 5 E-3 Gy/h
	Neutrons at 1 m distance	≤ 8 E-4 Gy/h
Heat generation		≤ 850 W/package

* = Sum of activity of mother and daughter nuclide.

Taking the mentioned bandwidth of composition into account as well as the most unfavorable activity distribution in the HAWC, and accepting a filling level of 175 l of glass product in the canister, the main maximum values of a package are as listed up in table 11.

The guaranteed and accepted bandwidth of the chemical composition is provided in table 12.

Table 12: Guaranteed bandwidth of glass product composition

Compound	Minimum load* [wt.-%]	Maximum load* [wt.-%]
Fraction of frit	87.0	81.0
• SiO_2	≤ 52.7	≥ 48.1
• B_2O_3	≤ 15.9	≥ 13.7
• Al_2O_3	≤ 2.9	≥ 2.3
• Na_2O	≤ 6.6	≥ 5.4
• Li_2O	≤ 3.3	≥ 2.6
• CaO	≤ 4.9	≥ 4.0
• MgO	≤ 2.2	≥ 1.5
• TiO_2	≤ 1.2	≥ 0.8
Fraction of calcinate	13.0	19.0
• Fission products + Zr	≥ 4.6	≤ 9.4
- ZrO_2 (hulls)	≥ 0.3	≤ 0.8
- MoO_3	≥ 0.7	≤ 1.2
- (Ru, Rh, Pd)O_2	≥ 0.6	≤ 1.3
- Cs_2O	≥ 0.4	≤ 0.8
- others	≥ 2.6	≤ 5.3
• Actinoids	≥ 0.9	≤ 2.1
- U_3O_8	≥ 0.8	≤ 1.8
- others	≥ 0.1	≤ 0.3
• Corrosion elements	≥ 1.9	≤ 3.3
- Fe_2O_3	≥ 1.3	≤ 2.3
- CrO_3	≥ 0.3	≤ 0.6
- others	≥ 0.3	≤ 0.4
• Process chemicals	≥ 3.6	≤ 6.8
- Na_2O	≥ 3.2	≤ 5.8
- P_2O_5	≥ 0.4	≤ 0.6
- others	≥ 0.0	≤ 0.4

*) = Due to the maximum/minimum calculation mode the sum of certain wt.-% data is ≠ 100 g.

7. *Container Data Sheet*

Following the list of relevant properties and characteristical values of HAW glass products in a final storage facility, and the requirements for non-heat generating residues /9/ - as already practiced /1/ the data sheet will provide information data as listed hereafter:

- Type of waste product, name of specification referred
- Package indentification label
- Type and dimensions of canister [mm]
- Name and adress of conditioner
- Type of conditioning process
- Date of conditioning
- Process qualification certificate
- Total β/γ-activity [Bq/canister]
- Total α-activity [Bq/canister]
- Activity of relevant nuclides [Bq/canister]
- Code used for calculating the actual nuclide spectrum
- U-233 and U-235 content [g/canister]
- Pu-239 and Pu-241 content [g/canister]
- Content of neutron absorber elements [g/canister]
- Activities of other fissile actinoids [Bq/canister]
- Thermal power [W/canister]
- γ contact dose rate [Gy/h]
- γ dose rate in 1 m distance [Gy/h]
- Neutron contact dose rate [Gy/h]
- Neutron dose rate in 1 m distance [Gy/h]
- Transferable α-surface contamination
- Transferable β/γ-surface contamination
- Fraction of incorporated waste calcinate [wt.-%]
- Total weight of package [kg]

Data which are defined as guaranteed parameters were listed up seperately and were always compared with the limits agreed upon in chapter 6.

8. *Quality Assurance Policy*

The main goal of the operation of the PAMELA vitrification process is to yield a glass product whose properties are at least within the limits of the a.m. *Guaranteed Parameters* while, however, it is worth striving for to be as close as possible to the *Nominal Values*.

In order to achieve that goal certain measures have been taken which were described in the following:

- The company policy of the operater of the vitrification plant is laid down in the companie's Quality Assurance Handbook, which will clearly point out that the safe operation and a high quality of the product are the main goals.
- Relevant quality standards like the ISO 9000 series are guiding the operational and administrative work, especially in dealings with suppliers of goods, materials and services.
- To ensure independence on matters which relate to the product quality the QA-Manager will have direct acess to the company's directors, being independent from the operational manager.
- To make sure that requirements of the final disposal in Germany can be fulfilled a handbook for the process qualification has been written /2/ which is a related document to this specification. The handbook describes In the measure to be taken in order to ensure the reliability and tolarable band-width of the data provided in the container data sheet (as described in chapter 7), which are in concordance with the a.m. mentioned relevant properties for final disposal /2,9/.

Documents related/Literature

/1/ BMFT - Arbeitskreis HAW-Produkte: Stellungnahme Nr. 6 "Endlager-relevante Eigenschaften und Kenngrößen für HAW-Glasprodukte" (im Entwurf).

/2/ E. Ewest, W. Kunz: Handbuch zur Verfahrensqualifikation: Verglasung des WAK-HAWC in der PAMELA, GNS-B 130/91 (Rev. 4), Feb. 1992.

/3/ WAK-Dokument W 0784375 von 2/93, Technische Notiz: Vermischung des HNWC der WAK.

/4/ WAK-Dokument W 0961806 von 2/93, HAWC-Datensatz (KORIGEN-Rechnung für WAK-HAWC).

/5/ WAK-Dokument W 0784382 von 2/93, Berechnungsverfahren zur Tabelle 2.2 des Handbuches zur Verfahrensqualifikation.

/6/ B. Luckscheiter, M. Nesovic: Entwicklung und Charakterisierung eines Glasproduktes für die Verglasung des HAWC der WAK, KfK-Primärbericht 19.03.01 P12 A, Juli 1991.

/7/ S. Anton, P. Kraft: Abschätzung der Freisetzungen aus HAW-Glaskokillen während der Zwischenlagerung in Transport- und Lagerbehältern, WTI-Bericht 05/88.

/8/ W. Lutze et al.: KfK-Bericht, in Vorbereitung.

/9/ P. Brennecke, E. Warnecke (Hrsg.): Anforderungen an endlagernde radioaktive Abfälle (vorläufige Endlagerungsbedingungen, Stand April 1990 in der Fassung vom Juli 1991) - Schachtanlage Konrad - , BfS-Bericht ET-3/90, Rev. -1, Salzgitter (1991).