EXPERIMENTAL FACILITIES FOR PLATE-OUT INVESTIGATIONS AND FUTURE WORK

K. MÜNCHOW, H. DEDERICHS, N. INIOTAKIS, B. SACKMANN
Kernforschungsanlage Jülich GmbH.
Jülich
Federal Republic of Germany

The safety of HTR under normal operation and accident conditions, the possibility of inspection, maintenance and repair or decontamination of single primary components as well as the safety of maintenance personnel are essentially determined by the transport- and deposition behaviour of the non gaseous fission - and activation products in the primary loop of the reactor. A compreshensive program has been started in 1969 in KFA in collaboration with various industrial firms and foreign institutions to investigate these problems. The program includes in-pile and out-pile experiments, simulating reactor conditions and also different laboratory experiments and extensive theoretical investigations. The aim of these efforts is to test experimentally the models and computercodes, which are used for prediction of transport and deposition behaviour of fission products for HTR's as well under normal as under accident conditions. Further more a verified dataset is to be established.

In this paper a survey is given of the experimental facilities carried out by KFA or in cooperation with KFA.

1. Terminated experiments

1.1 In-pile loop Saphir/Pégase

The first plate-out experiment was started in 197o in the loop Saphir in the reactor Pégase in Cadarache in close cooperation with CEA (fig. 1). This loop consisted of the main circuit with blower, heater and testsection

in an in-pile position and an auxiliary circuit with compressor, purification plant, He- supply and analysis equipment which was connected in a bypass to the main circuit.

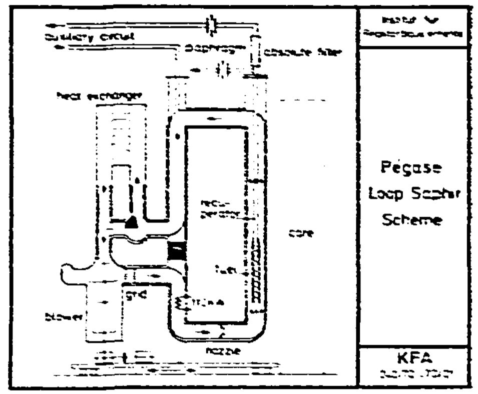


Fig. 1:

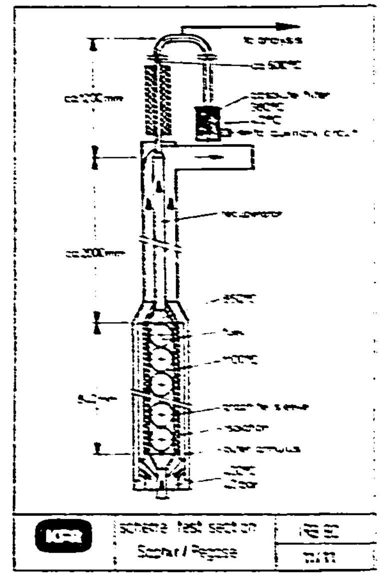


Fig. 2:

The test section (fig. 2) consisted of the fuel unit with 14 HTR spheres mounted inline in an isolated graphite sleeve, the exchangeable test tube of 3o mm inner diameter and 2 m length respectively 2o mm ϕ_i and 1,2 m length, the connection tube of 1 m, in the last runs of 3 m length and 16 mm ϕ_i as well as the absolute and control filter.

A He flow of 12 respectively 1o g/s later on, transported the fission products released from the fuel through test section and filter, in which they were retained quantitatively. In the auxiliary cicuit the gaseous impurities of the He and the gaseous fission products were analysed. In a bypass the required He purification in the ppm range was realized by a filter plant of three different filters connected in series. At last the purified He was pumped back into the main loop by a compressor.

The gas inlet temperature into the testsection (table 1) was about 82o respectively 97o °C, the wall temperatures were nearly isotherm 53o°C in the first four runs. In the two last runs it decreased from 72o to 48o °C respectively from 81o to 61o °C. In total 6 runs were completed successfully.

After each run testsection, connection tube and filter were removed, disassembled and analysed quantitatively for ß- and γ-activity in the laboratories of CEA and KFA. So the axial deposition profiles as well as radial diffusion profiles were measured on 6 different materials. In this experiment we could indicate the penetration of the fission products into the material for the first time.

1.2 Hot gas sampling tube Vampyr I/AVR

At the end of 1972 the hot gas sampling tube Vampyr I was started in close cooperation with AVR. This experiment was installed in one of the three tubes for interchangeable thermocouples in the third layer of the coal bridge, immediately above the core of AVR (fig. 3). By a hole bored in this tube in a distance of 225 mm from the reflector wall, a He stream of about 15 Nm^3/h was led by way of a replaceable test tube of 2,2 m length and

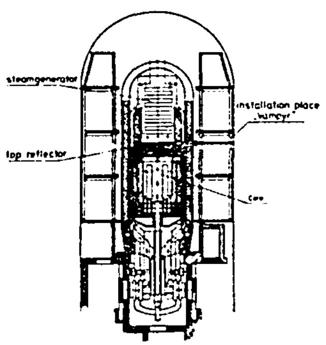


Fig. 3: Cross-section through AVR

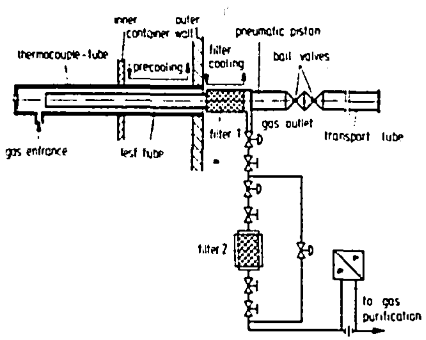


Fig. 4: Vampyr I scheme

2o mm ϕ_i through an absolute filter, installed inside of the thermocouple tube, and a second outside control filter into the purification system and back to the primary loop (fig. 4). After operation times of 4 respectively 12 months test tube and filter were dismounted and quantitatively analysed

OPERATING CONDITIONS

	SAPHIR PEGASE	VAMPYR I AVR	TEST-ISOL. DRAGON
EXPER. TIME (WEEKS)	6,8,1o,12,19	4, 12	7o
FLOW (G/S)	12/1o TURBULENT	o,7 LAMINAR	16oo TURBULENT
PRESSURE (B)	43	11	2o
GASINLET TEMP.(°C)	82o/97o	755-9oo	7oo
WALL TEMP (°C)	53o ISOTH/ 72o-48o 81o-61o	87o-55o/ 55o-15o	7oo ISOTH
MATERIAL	4541, 15Mo3 HASTELLOY, AS 2-5oo INCONEL 625 NIMOCAST 713LC	TI, 15Mo3 4541, 4961 ST 35,8 1oCRMo91o (RESTRICTED)	DIN 4981 INCOLOY 8oo AISI 347 AISI 316 INCONEL 625
GEOMETRY (MM)	3o/2o $Ø_I$ 2ooo/12oo L	2o $Ø_I$ 23oo L	193,7 $Ø_I$ 6oo L/ BOBBIN
RUNS (No)	6	17 (23)	1
PARTIAL PRESSURE	CONST.	CONST.	CONST.
FISSION PROD.	TOT.SPECTRUM	TOT.SPECTRUM	TOT.SPECTRUM

in the laboratories of IRB. The mean He coolant temperature was varied between 77o to 95o ^{o}C and with this also the inlet temperature of the test tube between 755 to 99o ^{o}C. The temperature at the end of the tube was about 1oo to 16o^{o}C (table 1). So far 22 runs were carried out, 17 of them were successful.

The aims of Vampyr I were the measurement of deposition - and as far as possible of diffusion-profiles at different materials under laminar flow conditions and the determination of the concentrations of the non gaseous fission and activation products in the hot coolant of the AVR direct above the core.

1.3 KFA-Hotgasisolation in the Dragon reactor

To investigate the behaviour of hotgas isolations a metallic foil isolation was installed in 1974 in the duct F of the Dragon reactor (fig. 5). After the unexpected shutdown of the reactor this equipment was removed for deposition and decontamination investigations.

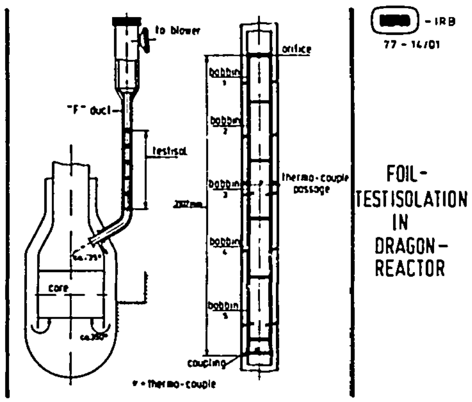


Fig. 5:

The gas leading tube consisted of 5 so called Bobbins of different materials: DIN 4981, Incoloy 8oo, AISI 347, AISI 316 and Inconel 625. The inner diameter was 193,7 mm, the wall temperature about 68o^{o}C, the gas-flow 1,6 kg/s and the experimental time 49o d (table 1).

The Bobbins were cut by EIR in parts of 1o cm length which were γ-spektrometrically analysed in IRB to obtain the deposition profiles along the whole tube. Subsequently each tube was divided in 6 segments. At one part decontamination investigations were performed by EIR, at the other parts KFA carried out diffusion profile measurements. Before starting the experimental investigations, Iniotakis had performed a precalculation of the expected deposition, diffusion and dekontamination factors.

Essential results of these three experiments are:

1. At temperatures above about 68o to 73o^{o}C the deposited nuclides penetrate predominantly into the material, whereas in the colder parts the adsorption dominates.

2. Kind and property of the material surface are of great influence on decontamination and deposition.

3. According to the respective conditions the flow influences decisively the deposition.

4. In AVR Ag-11om was detected for the first time, which has to be considered at all safety aspects besides Cs-, J- and Sr-isotopes.

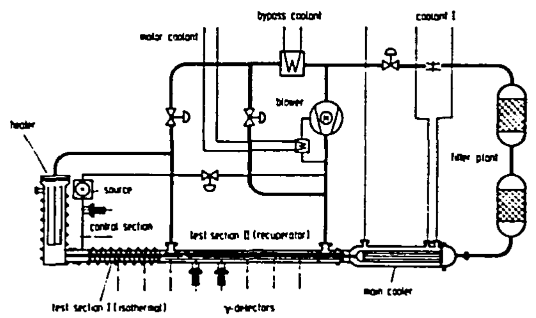
5. The evaluation of the experiments under very different test conditions with special evaluation methods based on the model of Iniotakis and with the code PATRAS-S and the good agreement between experimental and theoretical results confirm the validity of the model of Iniotakis. A first set of deposition data was set up.

Because of the limited variation range of the test conditions and the difficult measuring technique and experimental evaluation conditions in the experiments terminated so far, the following out-of-pile and in-pile experiments were planed, which at present are in the state of cold testing or constructing, in order to confirm and complete the set of plate-out data.

2. Experiments under construction and testing

2.1 Out-of-pile circuit Smoc

In the control section an out-of-pile circuit, Smoc, is mounted which consists of a primary loop (fig. 6), a purification system, 5 coolant circuits and the He supply, as well as extensive safety and regulation equipments. Driven by a gas bearing blower, He flows through an 1 MW heater, a test section of 6 m length and 3o mm ϕ_i, a cooler and 2 filters working at 1oo ^{o}C and utilizing the adsorption on metallic foils. In front of the test section in the first runs Cs-134 is injected by an evaporating source, installed in a bypass, into the main circuit. Here the activity concentration is controlled by measuring the adsorption at 3 points of the control tube. The nuclides deposited along the inner surface of the test tube are measured quantitatively by 15 NaJ-detectors during the run. The measured data are registered by an analysator operator system.



Main-Circuit Smoc

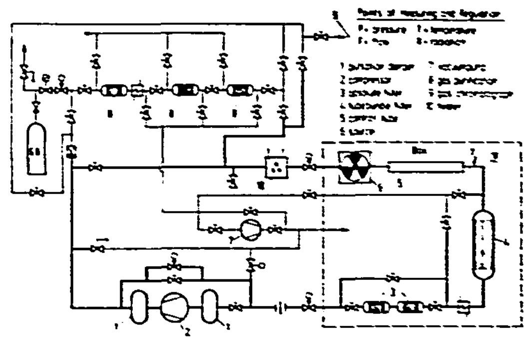
Fig. 6:

In the auxiliary bypass He is purified by three different kinds of filters. The gaseous impurities in the He are measured continously. The operation conditions (table 2) are variable in a wide range: gastemperatures from 2oo to 9oo ^{o}C, wall temperatures from 15o to 9oo ^{o}C, flow till 24o g/s at 9oo ^{o}C, 8o bar and 83o g/s at 1oo ^{o}C, 8o bar, pressure from 5-8o bar.

In this experiment the time slope of the axial deposition profiles of particular nuclides is measured under turbulent flow conditions on all interested materials with special regard to the surface conditions. By disconnecting the source the desorptionphenomena are investigated. The main aim of these investigations are the determination of all plate-out parameters in a wide and very exactly measurable range of test conditions and the verification of the validity of the heat-mass analogy.

2.2 Laboratory circuit Scafex

Because of the great difficulties in the realisation of sources for out of pile experiments in the range $<1o^{-12}$ bar and of their control, the laboratory circuit Scafex was planed and mounted in IRB. The task of this loop is the test of different source conceptions for Cs, Ag, J and Sr as well as the kind of source control. Based on the filterconcept, developed in IRB, the characteristic of different filter geometries and structures are investigated /1/.



SCAFEX-CIRCUIT

Fig. 7:

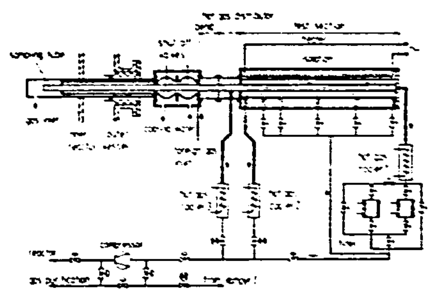
LAY OUT CONDITIONS

	VAMPYR II AVR	SMOC IRB	SCAFEX/FILTER IRB
EXPER. TIME (WEEKS)	16,24	-2	-1
FLOW (G/S)	-7 TURBULENT	-83o(1oo °C) -24o(9oo °C) TUBULENT	-3,6 LAM.+TURB.
PRESSURE (B)	11	5-8o	2-6
GASINLET TEMP (°C)	4oo-85o	2oo-9oo	1oo
WALL TEMP (°C)	25o-85o	15o-9oo	
MATERIAL	UNRESTRICTED	UNRESTRICTED	UNRESTRICTED
GEOMETRY (MM)	3o $Ø_I$ 54oo L	2o-8o $Ø_I$ ISOTH:2oooL REKUP:4oooL	5, 1o $Ø_I$ -3oooL
PARTIAL PRESSURE	CONST	VARIABLE	VARIABLE
FISSION PROD.	TOT. SPECTR.	SINGLE	SINGLE

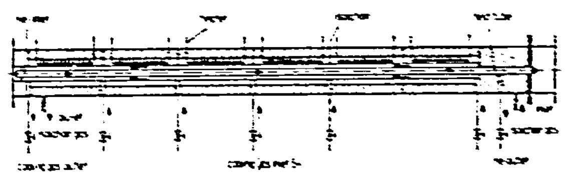
The He purified in a bypass (fig. 7) is pumped by a compressor about the source, through the control tube with a length of 15oo mm and an inner diameter of 1o mm and the testfilter section, in which 1-8 tubes of different lengths and diameters can be investigated. In an absolute filter behind this section the radioactive nuclides are adsorbed quantitatively. The main test conditions are shown in table 2: flow 2-12 m^3/h, gastemperature 1oo °C, pressure 2-6 bar. The time slope of the deposition of the investigated nuclide is measured at 3 points of the control tube as well as before and behind the filter section.

2.3 Deposition loop Vampyr II in AVR

Due to the high activity level by neutron activation in the forward part of the test section of Vampyr I the choice of material was severely limited in this interest temperature range above 55o°C. More over it was not possible to measure the temperature during the runs. The temperature profiles had to be determined in premilinary runs. So in 1973 KFA and AVR started the design of a second experiment Vampyr II in AVR only for plate out examinations. At present the manufacturing of the main components is terminated (fig. 8). In this experiment hot cooling gas is led through an insulated tube installed in the coal stone bridge 12o° shifted against Vampyr I into the test equipment in the protection room of AVR. Here activation of test material is excluded so that all interesting materials can be installed. Gas- and wall temperatures can be measured accurately during the runs. By means of a hot gas distributor in front of the hot equipment the gas inlet temperatures can be changed between about 85o and 4oo °C. Behind the hot section the gas flows through a cooler, two absolute filters and a compressor, which allows to adjust turbulent flow till to 15o Nm^3/h or 7 g/s. The test equipment (fig. 9) has a length of 5,4 m, the inner diameter of the test tube is 3o mm. Through an annular clearance, cooled He can be led counter currently along the outside of the test tube effecting axial temperature gradient conditions. Between this tube and the outer pressure pipe a heater



scheme Vampyr II Fig. 8:



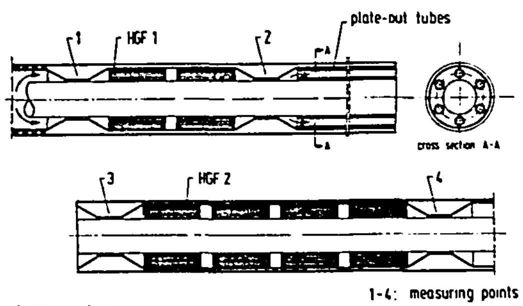
test section Vampyr II Fig. 9:

and a fiber insolation is mounted. This allows to provide experiments also under isothermal conditions. The wall temperature can be varied between 25o and 85o °C.

Because of the AVR accident this experiment can start not before the end of 1981. So the number of possible runs is stroughly restricted against the origional planning. It is intended to perform runs of 6 months to measure deposition - and diffusion profiles in some of the most interesting HTR-materials. Because it is not possible to determine the concentration of the fission products in the AVR coolant with Vampyr II, furthermore Vampyr I will run parallel to Vampyr II restricted to this task.

2.4 Hot gas filter experiment in OGL1 of JMTR/JAERI

An important result of the knowledge obtained so far from the above described experiments was the development of a hot gas filter for the primary circuit of HTR /1/. In this filter the diffusion of fission - and activation products into the material above about ca. 45o °C is utilized, to exclude the non noble gaseous nuclides out of the He coolant so reducing the contamination of the primary components remarkably. To investigate the efficiency of such kind of filter a hot gas filter experiment was layed out by KFA and fabricated and mounted in the mean time by JAERI in the loop OGL1 of JMTR (fig. 1o). This consists of the hot gas filter HGF1, outer ø 81 mm, kernel ø 4o mm, length 125 mm, a plate-out section with 6 tubes circularly arranged around the axial kernel with a length of 4oo mm and a second hot gas filter



hot gas filter experiment in OGL 1 / JMTR

Fig. 1o:

LAY OUT CONDITIONS OF HOT GAS FILTER EXPERIMENT IN OGL1/JMTR-JAERI

EXPERIMENTAL TIME	5 MONTHS
FLOW	5o G/S
PRESSURE	3o B
GASINLET TEMP.	73o °C
MATERIAL/GEOMETRY (MM)	
HGF1	INCONEL 6oo 81 $Ø_A$, 4o $Ø_I$, 25o L SHEET THICKNESS 2
PLATE-OUT TUBES	
JAERI	HASTELLOY X; HASTELLOY XR, STAINLESS STEEL TYPE 316
KFA	HASTELLOY X, INCOLOY 8oo, INCOLOY 6oo 1o $Ø_I$, 4oo L
HGF2	INCONEL 6oo 81 $Ø_A$, 4o $Ø_I$, 5oo L SHEET-THICKNESS 2

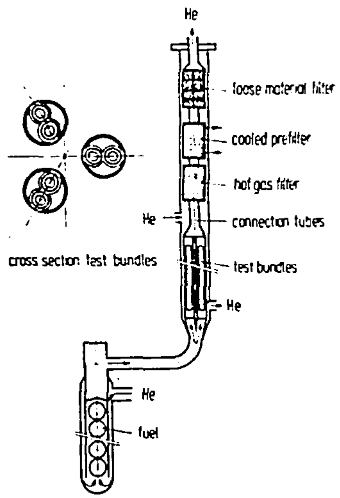
similar to HGF1 but 5oo mm long, serving as an absolute filter. The operation conditions (table 3) are: flow 5o g/s, pressure 3o bar, gas inlet temperature at HGF1 73o °C, operation time 5 months. The filter foil material is composed of Inconel 6oo with a wall thickness of 2 mm, the plate out tubes of Hastelloy X, Hastelloy XR, Inconel 6oo, Incoloy 8oo and stainless steel type 316 with an inner Ø of 1o mm. The radiation will start ad the end of 198o and will be stopped in the beginning of 1982. In the post irradiation examinations the activity of the nuclides deposited on the measuring points

1 to 4 is analysed quantitatively to determine the efficiency of the filters. Besides the activity distribution along the filter is measured by γ -scan and the deposition profiles of the plate-out tubes and if possible also diffussion profiles are determined γ -spectrometricly.

3. Planned experiments

3.1 Deposition loop Comedie in Siloe/CEA

Because of the strougly restricted test program of Vampyr II and in order to guarante the whole plate-out program and to clear up open questions not investigated till now by experiments, CEA, EIR, HRB and KFA agreed to perform additional and complementary plate-out-, decontamination-, material- and also fuel specific investigations in the Comedie-loop in Siloe/Grenoble.



scheme Comedie Loop/ Siloe

Fig. 11:

In the fuel section (fig. 11) 8 HTR-spheres with 58 mm ϕ_a, consisting of 6 driver and 2 source elements, are arranged in line in a graphite sleeve of 64 mm ϕ_i. A He-flow transports the released fission products through the test section into the filter plant. The test section consist of 3 test bundles and 3 connection tubes. Each test bundle is composed by 2 tubes with 14 mm ϕ_i length of about 26oo mm and a concentrically adjusted rod of 1o mm diameter with a length of about 27oo mm. Each bundle is connected with the filter plant by a tube of 18 mm ϕ_i and about 6oo mm length.

Test bundles and connection tubes are cooled by He which flows countercurrently along the outside of the test tubes. The filter plant consists of a hot gas filter, a cooled prefilter designed similar to the hot gas filter and a filter with loose material.

In the out-of-pile section the He passes a so called comparison loop with the same test conditions as fixed in the test section and with samples of the same material inserted in the test section. In this zone are also placed the purification plant, the He supply and the control - safety - and analyse equipments.

The operation conditions (table 4) are: pressure 2o bar, flow 16 g/s, gas temperatures along the test section 835 - 5oo ^{o}C, wall temperatures 78o - 45o ^{o}C. Test tube materials are composed of Incoloy 8oo H, Hastelloy X, test rods of IN 617, IN 519, Incoloy 8oo H, Nimonic 86, TZM and Nimocast 713 LC, connection tubes of 15Mo3, 1oCrMo91o and 4541.

During the runs the gaseous impurities before and behind the test section are measured continously just as the gaseous fission products to estimate the R/B values. During each normal shut down γ-spectrometric measurements are performed at the entrance of test bundles, connection tubes and hot gas filter to control the time slope of the source strength. In the post irradiation examinations deposition and diffusion profiles are measured and extensive material investigations are performed.

The following aims are predominant:

- Performing 3 runs with 12, 2 and 4 months under always equal operation conditions, which simulates the HTR conditions as realistically as possible, the time dependence shall be determined so that the extrapolation of the data evaluated till now to realistic reactor operation times can be confirmed with more assurance.

LAY OUT CONDITIONS OF COMEDIE-LOOP

EXPERIMENTAL	12.2. 4 MONTHS
FLOW	16 G/S
PRESSURE	2o B
PARTIAL-PRESSURE: Cs-137	1,5 $1o^{-12}$ B
Ag-11oM	4 $1o^{-14}$ B
TEST SECTION:	
GASTEMPERATURE	835-5oo °C
WALL TEMPERATURE	78o-45o °C
MATERIAL/GEOMETRY (MM)	INCOLOY 8oo H
TEST TUBES	HASTELLOY X 16 Ø$_A$, 14 Ø$_I$, 26oo L
TEST RODS	INCOLOY 8oo H, NIMONIC 86 IN 617, IN 519, TZM NIMOCAST 713 LC 1o Ø, 27oo L
CONNECTION TUBES	15Mo3, 1oCrMo91o, 4541 21 Ø$_A$, 18 Ø$_I$, 6oo L
GAS IMPURITIES	CO = 2,5 VPM CH_4 = 0,25 VPM N_2 = 0,25 VPM H_2O = 0,5 VPM H_2/H_2O = 1o ± 5

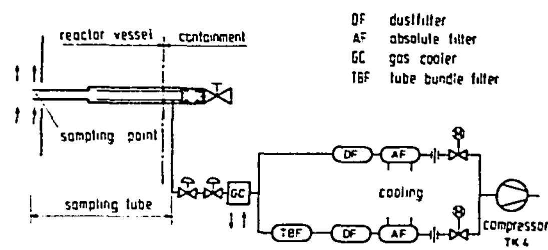
- The test time of 12 mounths and the requested Cs and Ag partial pressure shall enable the examination of long time effects as evaporation respectively solubility.
- The arrangement of the test bundles enables to investigate the influence of the deposited and penetrated nuclides as well as the influence of the decontamination on the properties of the different HTR specific materials. More over deposition and decontamination are investigated on replaced and already decontaminated samples.
- The installation of a comparison loop in the out-of-pile section operating under the same conditions as the testsection enables the performance of comparative material investigations about the influence of the He-atmosphere and the fission products to the material properties.

The first run shall start in beginning of 1982.

3.2 Dust experiment in AVR

In the primary circuit of HTR dust quantities can result of some tons after 3o years operation time by abrasion of graphitic fuel elements and by corrosion of graphitic core components. Therefore it is necessary to obtain more evidence about the behaviour of dust in the primary circuit, it's interaction with the fission - and activation products, the portion of free and dust bound activity, its quantity and grain size distribution.

To get more knowledge of these problems in the cold part of AVR a dust experiment shall be installed at the bifurcation to the purification system (fig. 12). The design has been started in the middle of 198o.



dust experiment in AVR Fig. 12:

Directly at the bifurcation valve cold He is led through a sampling tube of 2,5 m length, 2 shutoffvalves and a gas cooler. Behind the cooler the He is divided into a parallel flow. In one tube there is mounted a dust and a cooled absolute filter, in which all activity and dust is trapped. In the other one an addional tube bundle filter is connected in series, which filters the free activity respectively the activity not dust bound out of the He cool gas.

Behind the parallel arms the He flows through a compressor laied out for 7o Nm^3/h. After different operation times between 8 days and 8 weeks the filters are removed and analysed relative to dust and activity. One obtains the total dust quantitiy, the grain size distribution and the free and dust bounded activity. By means of the cooler the gas temperature can be varied between 27o and 5o ^{o}C enabling the investigation of the interaction between dust and fission products, of reversible and irreversible dust bound activity and of aerosolfraction in AVR-primery cooling gas. This experiment is performed in close cooperation with AVR. The design is performed by KFA-ZAT. The runs shall start end of 1982.

4. Future planning

The total activity deposition program provides for following further experiments:

- In THTR-3oo sampling tubes shall be installed in the hot and cold part of the primary circuit, by means of which the concentration of non gaseous fission - and activation products in both parts and if possible also the dust quantity shall be measured.
- The CEA hot gas isolation mounted in duct D of the Dragon reactor as well as the main cooler belonging to the same duct by EIR and KFA with regard to decontamination and plate-out. The operation time of the cooler amounted to 12oo days that of the isolation to 49o days.
- To the present there are no experimental investigations about the fission product behaviour under accident conditions. Therefore lateron definite accident conditions shall be simulated if possible in Smoc and Scafex, or in new test circuits.
- The knowledge about the influence of the solubility respectiveely evaporation, rising with increasing operation time, on the deposition respectively contamination and also on the possibility of decontamination and maintenance of primary components in the higher temperature range of the HTR could not be investigated in experiments till now. At present we are checking the possibility of realizing such investigations at different institutes.
- Specific experiments for transport and deposition of dust will be aspired in the furture.

/1/ Iniotakis, N.
Filterkonzept für Spaltprodukte im Hauptkühlkreislauf von HTR's.
Jül-1353 (1976)