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This paper has been prepared within the framework of the association EURATOM - Gesellschaft für Kernforschung mbH. in the field of fast breeder development.

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The principle of venting the fission gas of a fast ceramic reactor to its coolant is wellknown for some years [1], [2]. There is an impressive number of advantages:

1. No stress of the fuel cladding by fission gas pressure. This results in:

   a. Improved safety against canning rupture +)

   b. Smaller wall thickness of cladding

   c. Less structural material in the core, i.e. higher breeding ratio

   d. No need for the use of exotic canning materials.

2. More compact subassembly, since no fission gas plenum is necessary. This results in:

   a. Smaller pressure drop of coolant, smaller pumping power, smaller wall thickness of subassembly-boxes

   b. Smaller height of reactor vessel, shielding, refueling equipment and air locks.

3. No storage of high pressure radioactive gas. This results in:

   a. No sudden uncontrollable gas eruption during reactor operation in case of canning rupture or melt down. This is of special importance in connection with the positive void coefficient.

   b. No sudden uncontrollable gas eruption during the fuel handling and fuel reprocessing.

+) This might not be true for fast excursions with sudden fuel melting and subsequent fission gas release from the oxide.

On the other side we need some special equipment which adds to the capital costs of the station.

The following additional equipment is necessary:

1. Special plugs for the fuel rods
2. The gas purification plant with all equipment (blowers, cooling aggregates, heat exchangers etc.)
3. Additional filtering equipment with high retention ability for halogenes
4. Excessive control system for radioactivity
5. Special flanges and gaskets for high leak tightness.

The most important item is the purification plant for the cover gas. But it should be kept in mind that we by this also save some costs for fission gas treatment at the reprocessing plant.

It is the purpose of this paper to give some answers to the following questions:

1. What are the principal design specifications for the gas purification plant with respect to operation and safety of the reactor?
2. What are the numerical results for a reference reactor?
3. What is the economical balance of the cited advantages and disadvantages of the "vented-to-coolant" concept?

We are aware of the fact that many groups are working on this subject and probably have arrived at similar results. But very few of these have appeared in the literature so far. So this contribution particularly is meant to stimulate the discussion on this very interesting matter.

1. Specifications for the Gas-purification Plant

Fig. 1 shows the principal plant. Room I is the covergas inside the reactor vessel, room II the inside of the safety containment. A flow rate g of fission gas enters room I, $\dot{v}_A$ and $\dot{v}_E$ are the flow rates to and from the purification plant respectively, a leakage flow rate L goes from room I to room II, and flow rates $\dot{V}_A$ and $\dot{V}_E$ are to and from the outer atmosphere.

With the respective activity concentrations c_g, c_E, c_A, c_L, C_E, C_A (all in Curie/cm^3) we get the following balance:

(1) $$g\, c_g + \dot{v}_E\, c_E = \dot{v}_A\, c_A + L\, c_L$$

(2) $$L\, C_L + \dot{V}_E\, C_E = \dot{V}_A\, C_A$$

In general is $c_E = 0$, $\dot{v}_E = \dot{v}_A$, $c_A = c_L$, $C_E = 0$

For $L\, c_L \ll g\, c_g$ the result is

(3) $$\dot{v}_A = \frac{g\, c_g}{\dot{V}_A\, C_A} \cdot L$$

the input of the purification plant.

$\dot{V}_A$ is normally given by the air exchange rate of the containment volume,

C_A is either given by the allowed activity level inside the building or by the allowed activity output at the stack.

The leakage L, therefore, is the most important parameter for the size of the purification plant. There are several flanges for refuelling purposes and control rod drives on the top of our proposed sodium cooled reactor.

The problem is the definition of a feasible leak-tightness on a technical item.

The cover-gas is helium. The most extensive tests on this have been made in connection with the Dragon-project [3, 4, 5]. These results have been converted to the cover gas pressure of 1,2 ata of our reactor according to the Knudsen equation, where the leakage is proportional to the pressure difference.

The result is

$$1{,}5 \cdot 10^{-12} \ \frac{\text{atm} \cdot \text{cm}^3}{\text{sec cm}}$$

or with U = 12 500 cm sealing length we get

$$L = 1{,}87 \cdot 10^{-8} \ \frac{\text{atm cm}^3}{\text{sec}}$$

for the total reactor top.

After determination of g and c_g the purification plant can be specified.

We feel it important to underline that these specifications are based on operational safety and not on the analysis of any major accident.

The results of an accident of the vented-to-coolant and the vented-to-reservoir plant are the same, since in this case the destructions of a number of fuel cans in the latter is probable.

2. Fission Gas Production and Numerical Results

The 1000 MWe reference reactor [6] produces 0,775 cm^3/sec of the gaseous fission products Bromium, Iodine, Xenon and Krypton or approximately 1 cm^3 per fuel rod and day. We assume that these stay inside the fuel for a time t_c = 5 days at the ambient pressure of 2 ata. If it is possible to maintain higher gas pressures inside the rod the retention time would rise proportionally, but it is extremely

difficult to build up any overpressure at such a low flow rate.

During a time t_B the gases pass the axial blanket. t_B is a function of pressure, temperature and the free cross section.

Taking into account the production rate [7] of the different isotopes produced directly by fission and radioactive decay of their parents, in the core zone and using the results of Burris and Dillon [8] the activity (Curie/cm^3) leaving the fuel rods can be calculated.

For the burnup of 100 000 MWd/t release fractions of 100 °/o for Xenon and Krypton and 50 °/o for the halogenes are assumed.
The exit activity has been calculated for 2 cases :

a) the fission gas moves through the blanket as a rigid column,

b) the gas entering the blanket zone always is completely mixed with the gas already there.

Tables 1 and 2 show the results for no mixing and complete mixing in the blanket respectively.

I and Br will be chemically bound in Sodium. We assume in accordance with GE [9] that 0,02 °/o of the Iodine arriving at the coolant will be contained in the cover gas. The activity of I in Na is small compared with the activity of the Na itself. The activity of Br in the Na and the cover gas can be neglected.

Taking this into account c_g and g can be evaluated and with eq.(3) the input $\dot{v}_A$ of the purification plant can be calculated. Fig. 2 shows the results as a function of the fuel element pressure for different assumptions for the process in blanket and plenum.
It was assumed that

$$\dot{V}_A = 11\ m^3/sec$$

$$C_A = 10^{-11}\ \mu C/cm^3$$

(1/10 of maximum permissible concentration of unidentified mixture, however without α-emitters and without the ß-emitters Pb^{210}, Ac^{227}, Ra^{228} and Pu^{241})

3. Cost Evaluation

A purification plant for 260 N m^3/h Helium has been planned in connection with Linde AG., Muenchen and evaluated for a fuel inside pressure of 2 ata, no plenum and complete mixing. Xenon and Krypton are removed from the cover gas by low temperature adsorption. The plant will be relatively expensive by the need for continuous operation and the large amount of decay heat. It needs 180 kW pumping power, 75 m^3/h coolant water, and 35 l/h liquid nitrogen. Table 3 shows the heat production for different conditions.

Compared with the reference reactor with "venting to reservoir" the core height with venting to coolant is reduced by 80 cm. The most important changes are:

	Reference reactor [6]	Vented to coolant
Pressure drop	4,25 at	3,20 at
Cladding thickness	0,35 mm	0,15 mm
Cladding fraction of fuel element	0,25	0,096
Breeding ratio	1,42	1,59

Table 4 shows the resulting capital costs.
The main contribution comes from the smaller fabrication cost of the shorter fuel elements with ₰ 205 000 per core. For replacing 1/3 of the core per year this is equivalent to ₰ $1,59 \cdot 10^6$ capital costs for 15 years lifetime. The second largest contribution is the capitalized gain breeding ratio (capitalized for a load factor of 0,8).

The radial blanket is also considerably shorter. For 4 blankets during the reactor lifetime this amount to $1,05 \cdot 10^6$ ₰.

Smaller savings are gained by the reduction of pumping power.

The gas purification and storage at the reprocessing plant is not needed any more. The costs are evaluated according to [10]. Finally, the reduced height of the core allows for some savings for the core vessel and its internals like supporting cylinders, insulation walls, reloading equipment and thermal shielding. However, this contribution is small.

The right column of table 4 shows the additional costs. The net saving amounts to ≙ 2,19 · 10^6 or 2,1 °/o of the total plant cost.

4. Preliminary Tests

The important point is the development of a suitable plug. The diving bell design of GE is wellknown [1]. It promises a very reliable operation, but it must be of considerable length and, therefore, adds in pressure drop and capital costs. We, therefore, thought it useful to study the behaviour of a very simple porous plug of sintered metal.

Two problems are of importance:

a) The ability to retain sodium from the fuel. In the case of a reactor shutdown and lowering of the fuel temperature the outside overpressure of the sodium amounts to 1 - 2 atm.

b) The ability to stay porous for the fission gases.

In a simple apparatus the following plug materials have been tested:

Ni, CrNi 18/8, Fe, CrNi 18/10

with pore sizes between 1 and 5 µ. Sodium leakage started at a pressure difference of about 1,5 at for sodium temperatures of 500°C, at about 0,5 at for 600°C.

First plugging experiments by artificial evaporation of iodine did not lead to a pressure buildup of the gases. More tests are necessary for the evaluation of the sintered porous plug.

5. Conclusions

From this study the following conclusions can be drawn:

a) The venting of fission gases to the sodium coolant allows for savings in the order of 2 °/o of the total plant cost, if compared to the reference reactor. In comparison to a more optimized reactor the savings are much smaller.

b) The main savings are from lower costs for core and radial blanket resulting from the dismissal of the fission gas plenum and the reduction of cladding thickness which causes a substantial rise in breeding ratio.

c) A low temperature adsorption process seems to be the most suitable for the purification of the cover gas. The main problem is the decay heat of several hundred kW, mainly from Xenon.

d) The input specification of the purification plant comes from operational criteria. The unavoidable leakage into the containment building is the determining factor.

e) As the most important advantage we consider the gain in safety. Sudden bursts of gas into the coolant and the consequences with a positive void coefficient are avoided. The transient behaviour needs further studies.

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Table 1

Exit concentration of gaseous fission products [Curies/Ncm^{3}gas produced in core] as a function of fuel inside pressure.
(no plenum, no mixing in blanket)

isotope	half-life	fuel inside pressure [ata]				
		2	4	8	12	34
Kr 83 m	1,3 h	0,004	-	-	-	-
Kr 85 m	4,4 h	1,2	0,035	0,001	-	-
Kr 85	10,6 a	0,0047	0,0046	0,0045	0,0044	0,0044
Kr 87	78,0 m	0,0033	-	-	-	-
Kr 88	2,8 h	0,9	0,0046	-	-	-
Kr 89	3,2 m	-	-	-	-	-
J 131	8,1 d	50,4	39,5	24,2	16,1	3,0
J 132	2,3 h	0,9	0,0017	-	-	-
J 133	21,0 h	105,5	28,9	4,5	0,9	-
J 134	53,0 m	-	-	-	-	-
J 135	6,7 h	29,6	2,3	0,025	-	-
Xe 133	5,3 d	197,0	127,9	72,2	41,9	5,1
Xe 135 m	15,7 m	-	-	-	-	-
Xe 135	9,2 h	204,9	34,0	1,3	0,038	-
Xe 138	17,0	-	-	-	-	-

Table 2

Exit concentration of gaseous fission products [Curies/Ncm^3gas produced in core] as a function of fuel inside pressure.
(no plenum, complete mixing in blanket)

isotope	half-life	fuel inside pressure [ata]				
		2	4	8	12	34
Kr 83 m	1,3 h	0,4	0,2	-	-	-
Kr 85 m	4,4 h	7,0	1,9	0,5	0,2	0,024
Kr 85	10,6 a	0,0044	0,0046	0,0045	0,0044	0,0044
Kr 87	78,0 m	5,4	1,2	0,3	0,2	0,024
Kr 88	2,8 h	17,2	4,3	1,1	0,5	0,049
Kr 89	3,2 m	0,4	0,2	-	-	-
J 131	8,1 d	52,2	42,2	27,6	19,7	5,4
J 132	2,3 h	36,5	8,4	2,3	1,1	0,1
J 133	21,0 h	144,3	55,5	19,0	8,7	1,2
J 134	53,0 m	13,7	3,5	0,9	0,035	0,005
J 135	6,7 h	87,9	25,3	6,5	1,5	0,4
Xe 133	5,3 d	193,8	132,0	83,4	54,3	12,9
Xe 135 m	15,7 m	1,2	0,6	0,3	0,07	-
Xe 135	9,2 h	310,1	109,3	30,4	10,1	1,8
Xe 138	17,0 m	7,9	1,9	0,5	0,2	0,024

Table 3

Decay heat to be removed from the adsorbers after 3000 h operation time for different mechanism of fission gas release. (2 ata fuel pressure)

release mechanism	decay heat of isotopes [kW]			decay heat [kW]
	Xe 133	Xe 135	Kr 85	total
no plenum no mixing	280,0	57,5	0,15	337,7
no plenum complete mixing	276,2	94,0	0,15	370,4
plenum (40 cm) complete mixing	200,0	11,7	0,15	211,9
plenum (80 cm) complete mixing	139,0	6,9	0,15	146,1

Table 4

Cost balance for application of a vented fuel concept

savings	10^6 ₰	additional costs	10^6 ₰
core fabrication	1,59	gas purfication plant	2,30
breeding ratio	1,58	operational costs	0,77
radial blanket	1,04		
circulation pumps	0,50		
gas treatment at reprocessing	0,34		
reactor vessel	0,21		
	5,26		3,07

basic equations:

1. $g \cdot c_g + \dot{V}_E \cdot c_E = \dot{V}_A \cdot c_A + L \cdot c_L$ room I

2. $L \cdot c_L + \dot{V}_E \cdot c_E = \dot{V}_A \cdot c_A$ room II

3. $$\dot{V}_A = \frac{g \cdot c_g}{\dot{V}_A \cdot c_A} \cdot L$$

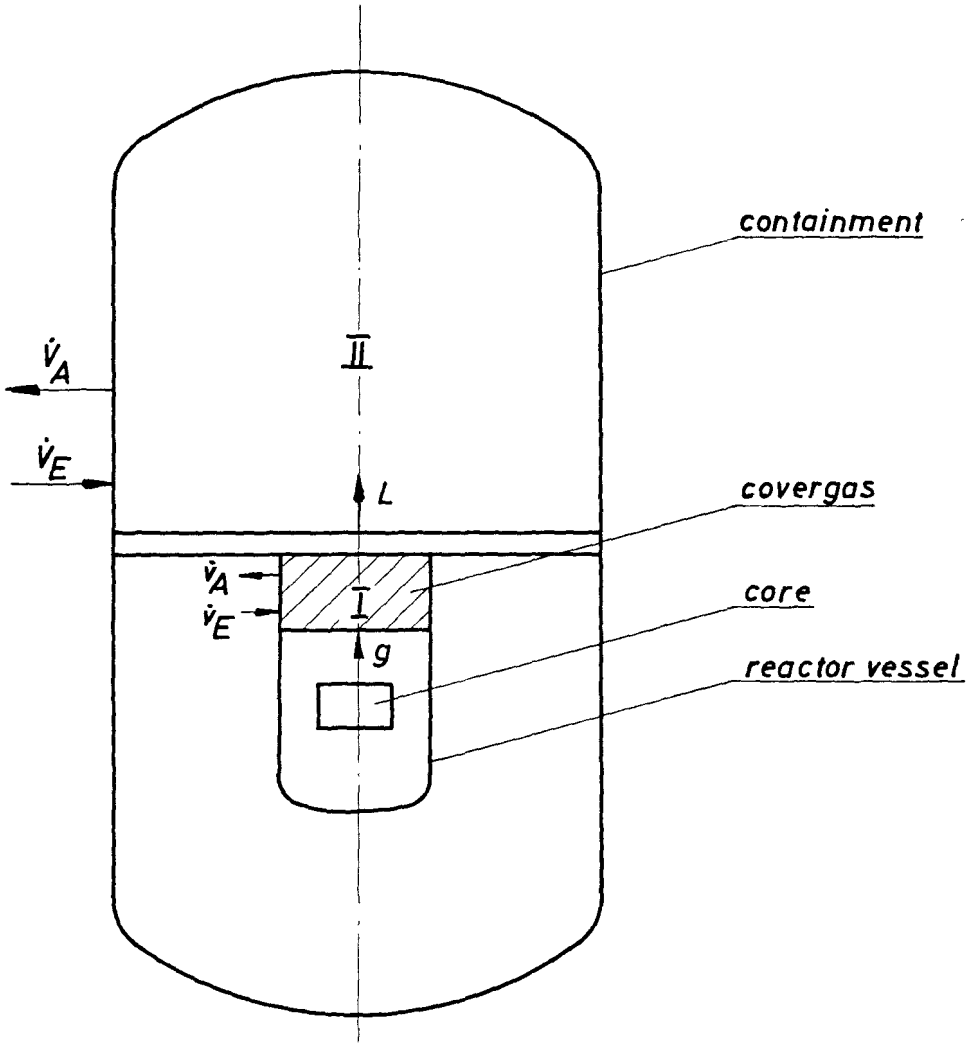

Fig. 1 principal reactor layout

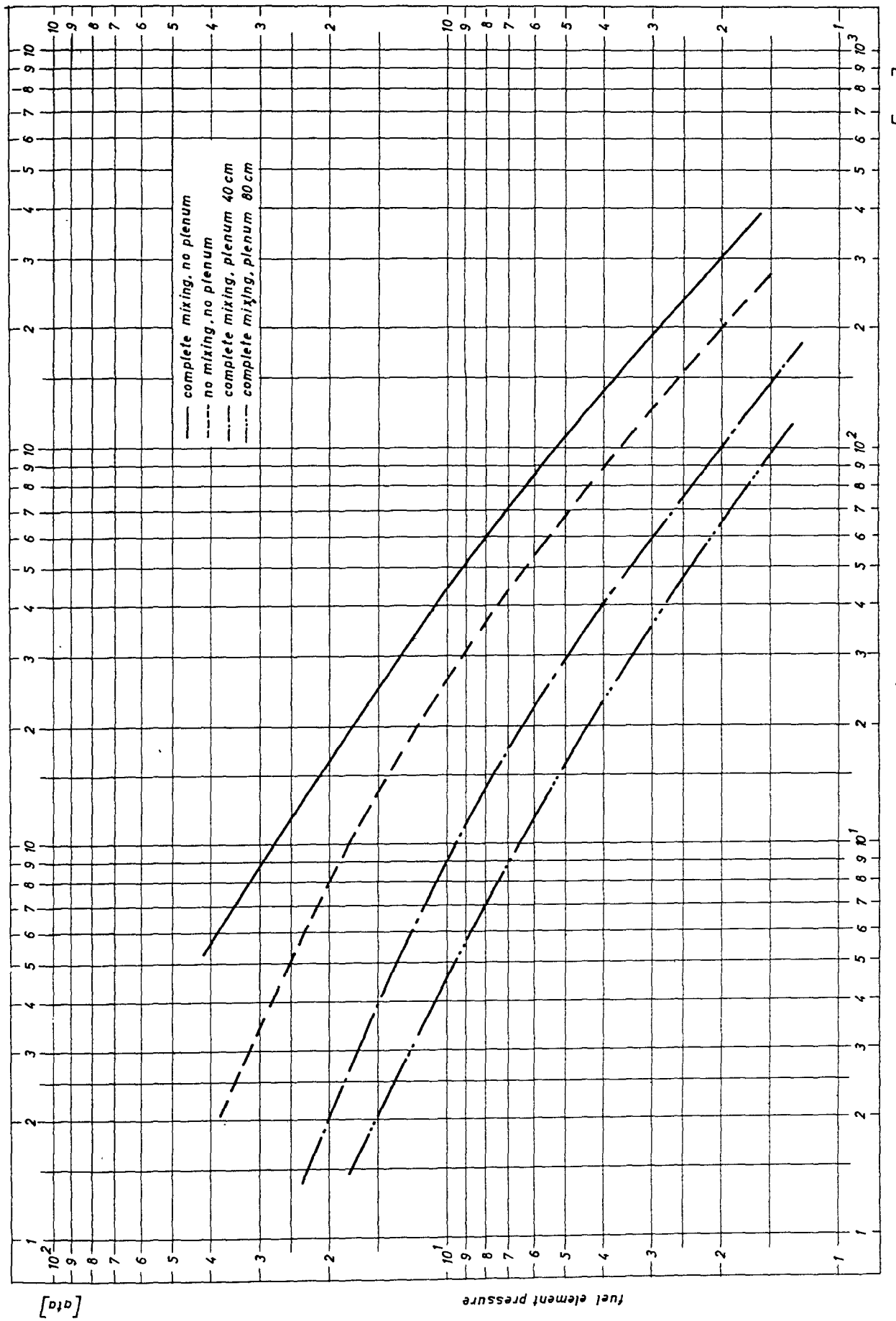

Fig. 2 Theoretical input into purification plant