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Institut für Neutronenphysik und Reaktortechnik
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Considerations on the Accident: „Water Ingress in the Primary Loop of a Helium Cooled Fast Breeder Reactor with Secondary Steam Cycle"

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Contents

Abstract

The rupture of a steam pipe in a heat exchanger of a gas cooled fast breeder reactor with a secondary steam cycle may lead to ingress of steam in the primary circuit. In the present paper the amount of steam in the core region arising from such an accident is estimated. The dependence of the effective multiplication factor K_{eff} on the steam density in the core with different parameters such as the burn up condition, the group cross-section set, and the Pu isotopic composition is investigated.

Kurzfassung

Bricht ein Dampf- bzw. Wasserrohr im Wärmetauscher eines gasgekühlten schnellen Brutreaktors mit sekundärem Dampfkreislauf, so dringt Wasserdampf in den Primärkreislauf ein. Im vorliegenden Bericht wird der Dampfgehalt im Primärkreislauf abgeschätzt, der durch einen derartigen Unfall auftreten kann, und es wird die Variation des effektiven Multiplikationsfaktors als Funktion der Dampfdichte in Abhängigkeit von verschiedenen Parametern wie Abbrand, Gruppenkonstantensatz u.a.m. berechnet.

1. Introduction

The rupture of a steam pipe in a heat exchanger of a gas cooled fast breeder reactor with secondary steam cycle leads to an ingress of steam in the primary circuit, when the pressure in the steam cycle is higher than the pressure in the gas cycle. The consequences of such an accident were already examined as early as 1964 by P. Fortescue et al. [1]. They concluded that small amounts of steam in the reactor core would decrease the effective multiplication factor. Larger amounts would strongly increase K_{eff}.

It is the purpose of this paper to reconsider this accident for the 1000MWe reactor concept of Karlsruhe in more detail. First, the highest possible steam density in the core which can be achieved by an accident such as the rupture of a steam pipe in a heat exchanger was estimated. Then, the dependence of the effective multiplication factor on the steam density was computed for several burn up conditions. Different group cross-section sets and different Pu isotopic compositions were used for these calculations in order to determine their influence on the variation of K_{eff} with steam density.

2. Maximum Steam Density in the Core

In the design of the 1000 MWe reactor concept of Karlsruhe the pressures in the primary gas and in the secondary steam cycle amount to 100 and 180 atm, respectively (a specification of the core design of this reactor concept is given in the Appendix). Due to the higher pressure, water or steam will flow from the secondary into the primary circuit after the rupture of a steam pipe in the heat exchanger. The critical flow rate would be approximately 10 kg/sec. (This value was derived by the safety group in the German "Gas Breeder Memorandum") [4]. Under the assumption of a constant flow rate, discharge into the primary circuit of the whole water content of one of the 8 heat exchangers (6 t) would raise the primary pressure by about 20 atm within approximately 10 minutes. Naturally, this pressure raise and the moisture in the primary gas cycle would be detected.
However, in order to be independent of design details and in order to have an extremely pessimistic value of the steam density in the gas cycle it was assumed in this investigation that the pressure in the secondary cycle would be maintained and the water or steam flow into the primary circuit would continue until the pressures in both cycles are equal (in reality, safety valves would open long before). Then the partial pressure of steam in the primary circuit amounts to 80 atm. In addition, the steam was assumed to be saturated.

The density of saturated steam of 80 atm pressure is 0.04158 g/cm^3 and this value is considered to be the maximum value of steam density in the primary cycle.

3. Methods of Calculation

A great part of the calculations of K_{eff} as a function of steam density have been fundamental mode calculations. Surely, these calculations are accurate enough to reflect the influence of different parameters such as the group cross-section set, the burn up condition or the Pu isotopic composition. Therefore, these methods have been used for these purposes.

However, more precise methods of calculation are necessary to answer the question whether the reactor will become subcritical or not for a certain value of steam density. Therefore, some twodimensional diffusion calculations have been performed also to take into account the twodimensional configuration of the reactor with different core and blanket zones. The "DIXY"-code prepared at Karlsruhe was used. The number of mesh points amounted to 3000. The number of energy groups of the constant group cross-section set was 26.

4. Group Cross-Section Sets

The following group cross-section sets have been used:

a) NAP+PMB: This cross-section set was derived from the well known KFK-SNEAK set of Karlsruhe [2]. The main differences between the older KFK-SNEAK set and the NAP+PMB set are: the capture cross sections of U238 and U235 and the fission cross sections of U235, respectively, were changed according to Pönitz, Menlow and Beckurts. The capture-to-fission ratio of Pu239 (α-value of Pu239) was based on the Knoll Atomic Power Laboratory (KAPL) data. The weighting spectrum used for the calculation of the group constants was that of a sodium cooled breeder reactor.

b) NAP+PMB+α(Pu): The only difference between this group cross-section set and that used before is a change of α of Pu239 in the range from 465 eV to 21.5 KeV. The values of α(Pu) from a lower estimate of the Schomberg data (1967) are incorporated here.

c) MOXTOT: The latest cross-section set of Karlsruhe is the so-called MOXTOT set [3]. It is improved in the following ways:

   1) The values of α of Pu in the energy range from 0.5 to 10 KeV were those from Gwin. These values lie between the older KAPL values and the values indicated by Schomberg (1967).

   2) The capture cross sections of U238 were replaced by the lower MOXON data.

3) Improved cross sections for the higher Pu isotopes were incorporated according to Yiftah et al. and J.J. Schmidt. Especially for Pu 240, this results in a reduction of the capture cross sections by a factor of approximately 2. The deviation from the capture cross sections of U238 is now small and this implies a smaller influence of the Pu isotopic composition on nuclear data.

5. Results

The results of all calculations are illustrated in Figs. 1 to 6.

Fig. 1 shows the variation of the effective multiplication factor with increasing steam density in the whole range of steam densities from the normal to the flooded condition. This curve was derived from fundamental mode calculations. The group cross-section set used was the NAP+PMB set. The burn up was 27 500 MWd/t and the Pu isotopic composition was the equilibrium composition for the used cross-section set.

In agreement with Fortescues results, Fig. 1 yields a decrease of K_{eff} for small steam densities and a strong and almost linear increase for higher values of steam density. These changes of the effective multiplication factor are caused by the changes of K_{∞} and leakage which both decrease with increasing steam density. At small steam densities the decrease of K_{∞} leads also to a decrease of K_{eff}, but for higher steam densities the reduction of leakage is predominant and the balance of leakage and K_{∞} causes the indicated variation of the effective multiplication factor.

The interesting range of variation of K_{eff} with steam density in the accident considered is the small range indicated in Fig. 1 at the beginning of the scale.

Fig. 2 shows a section of the picture displayed before. The range of steam densities extends from 0 to 0.04158 g/cm^3, the maximum value considered in section 2. The three curves of variation of K_{eff} are related to the respective burn up conditions indicated. The strong dependence of the curves on the burn up condition results from the absorption of neutrons in the fission products. These curves and the curves drawn in Figs. 3, 4 and 5 were also derived from fundamental mode calculations.

In Fig. 3 the same curves are shown, but the calculations were made by using the group cross-section set NAP+PMB+α(Pu). As already mentioned, the only difference between this set and that used before is an increased value of α of plutonium in the range from 465 eV to 25.5 KeV. The Pu isotopic composition is the stationary one for this cross-section set. In comparison with Fig. 2, a much greater decrease of K_{eff} is observed due to the enhanced capture in Pu239.

Fig. 4 shows the situation for the latest cross-section set of Karlsruhe, the MOXTOT set. In the figure the solid and dashed lines correspond to the indicated Pu isotopic compositions. As stated in section 4, there is only a comparatively small influence of different Pu isotopic compositions on the behaviour of the curves. Besides, it should be mentioned that these curves derived from the MOXTOT set lie within the range defined by the curves of Figs. 2 and 3.

All these calculations were made for the oxide fueled reactor concept of Karlsruhe. Finally, Fig. 5 shows the situation attained with carbide fuel (a specification of this concept is given in the Appendix). As compared with oxide fuel the decrease of the effective multiplication factor is more pronounced with carbide. This is due to the harder spectrum. Because the power density of a reactor with carbide fuel is higher, the core volume being smaller which results in a harder spectrum. Then the changes of K_{∞} and leakage with variable steam density are greater. This can be seen from Figs. 7 and 8 where the variation of K_∞ and leakage for both fuel types are shown. The differences in K_∞ are more pronounced than the differences in leakage, and this leads to the shown differences in the K_{eff}-curves of Figs. 4 and 5. Therefore, in the case of the accident considered, carbide fuel seems to be safer from a nuclear point of view.

Summarizing Figs. 2 to 5 one can conclude for the accident considered:

a) The multiplication factor as a function of the steam density depends strongly on the group cross-section set, the burn up condition, and the hardness of the spectrum.

b) There is only a slight dependence on the Pu isotopic composition in case that the MOXTOT set is used. Since the cross-section sets NAP+PMB and NAP+PMB+α(Pu) are two extreme sets, the range of variation of the effective multiplication factor, depending on the group cross-section set as a parameter, is shown.

As mentioned at the beginning, the question whether a reactor will become subcritical or not for a certain value of steam density cannot be answered with the help of fundamental mode calculations because such calculations are not accurate enough. Therefore, twodemensional diffusion calculations with 26 energy groups were performed. Since performing these calculations requires a lot of computer time only one curve of Fig. 4 was recalculated (for the clean reactor where the decrease in K_{eff} is the smallest). Fig. 6 shown a comparison of the variation of K_{eff} derived from fundamental mode calculations and twodimensional diffusion calculations. It appears that the curve obtained by twodimensional diffusion calculations is characterized by a lager decrease of the effective multiplication factor and the values of K_{eff} are lower than 1 in the entire interval considered. These differences can be understood in the following way: In the case of the fundamental mode calculations only one universal buckling was used. This buckling was related to the reactor under normal condition, i.e., in the absence of steam. It describes correctly the leakage in this case. However, with increasing steam density, the savings which determines the buckling will decrease because the spectrum gets softened. This effect was neglected in the fundamental mode calculations, and therefore the leakage becomes more and more underestimated as the steam density increases. This effect can be seen from Fig. 9 where the leakage obtained from the two methods of calculation is shown. The decrease of leakage is much more pronounced in the case of the fundamental mode calculations. Furthermore, the wrong representation of leakage has its drawback on the spectrum and, therefore, as shown in Fig. 10, the values of K_{∞} show also a certain deviation from those derived by twodimensional calculations. The differences, however, are smaller. Both the wrong representation of leakage and the differences of K_{∞} lead to the differences in K_{eff} which are shown in Fig 6.

It can be concluded from these considerations that all the values of K_{eff} shown in Figs. 1 to 5 are too high. Twodimensional calculations would yield values which are lower by approximately the same amount as indicated in Fig. 6.

Literature

[1] P. Fortescue et al., ANL 7120, Oct. 1965, pp. 230 - 260

[2] H. Huschke, KFK 770, April 1968

[3] E. Kiefhaber, BNES Conference, London, June 1969, Paper 1.9

[4] KFK 1375, Feb. 1971

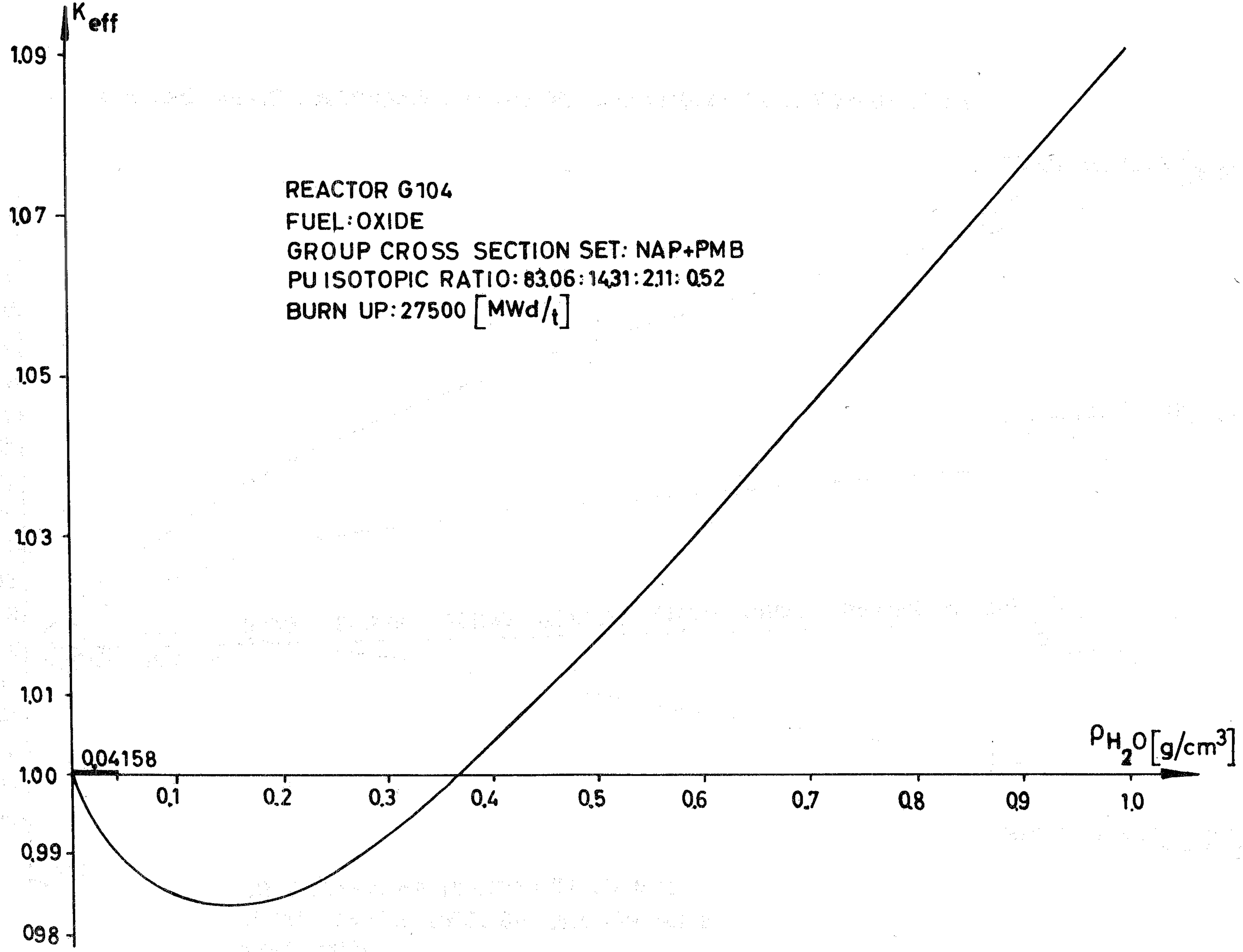

FIG.1 EFFECTIVE MULTIPLICATION FACTOR AS A FUNCTION OF STEAM DENSITY

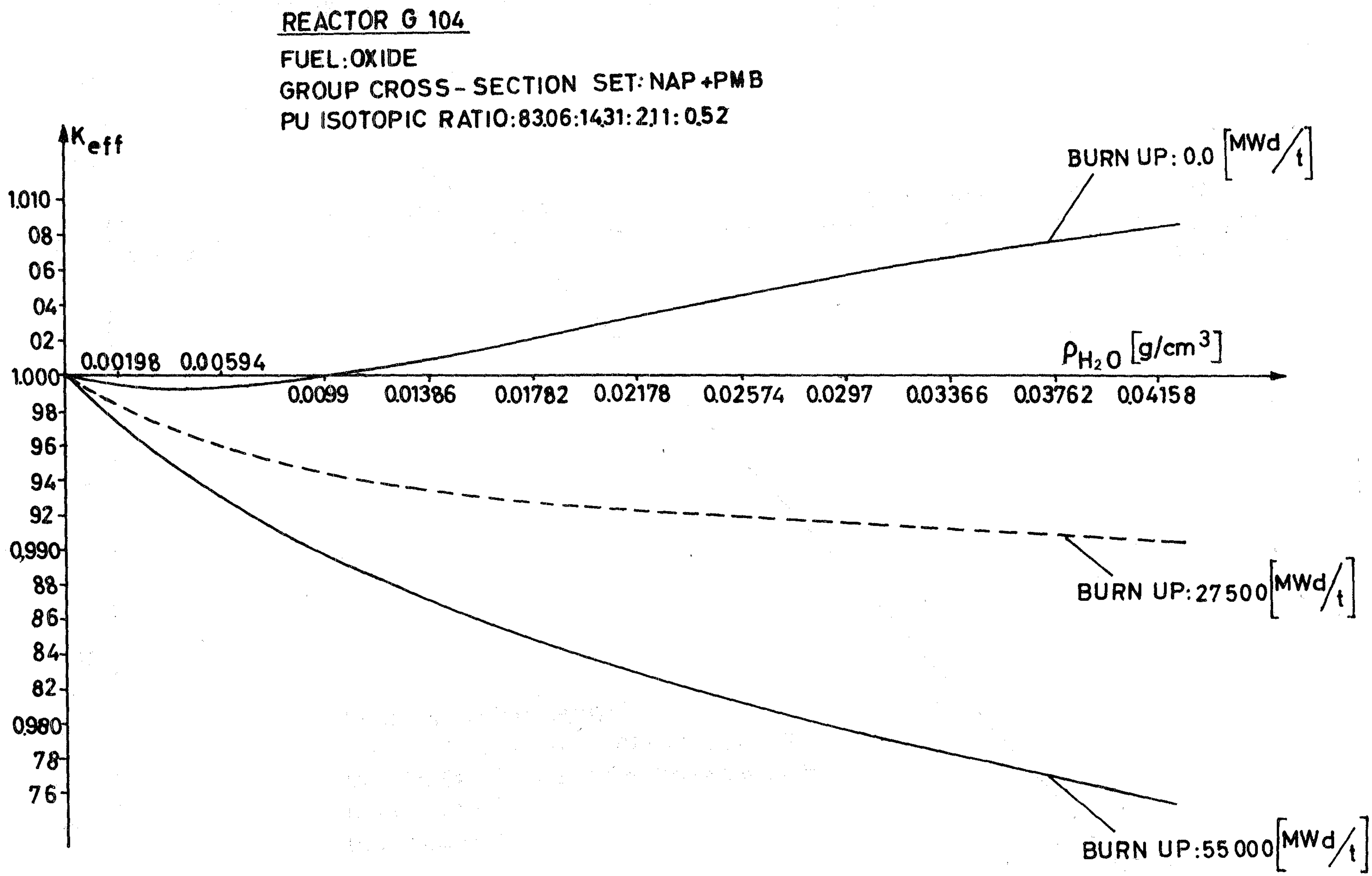

FIG. 2 EFFECTIVE MULTIPLICATION FACTOR AS A FUNCTION OF STEAM DENSITY

REACTOR G104
FUEL: OXIDE
GROUP CROSS SECTION SET: NAP+PMB+α(PU)
PU ISOTOPIC RATIO: 77.87:18.63:2.78:0.72

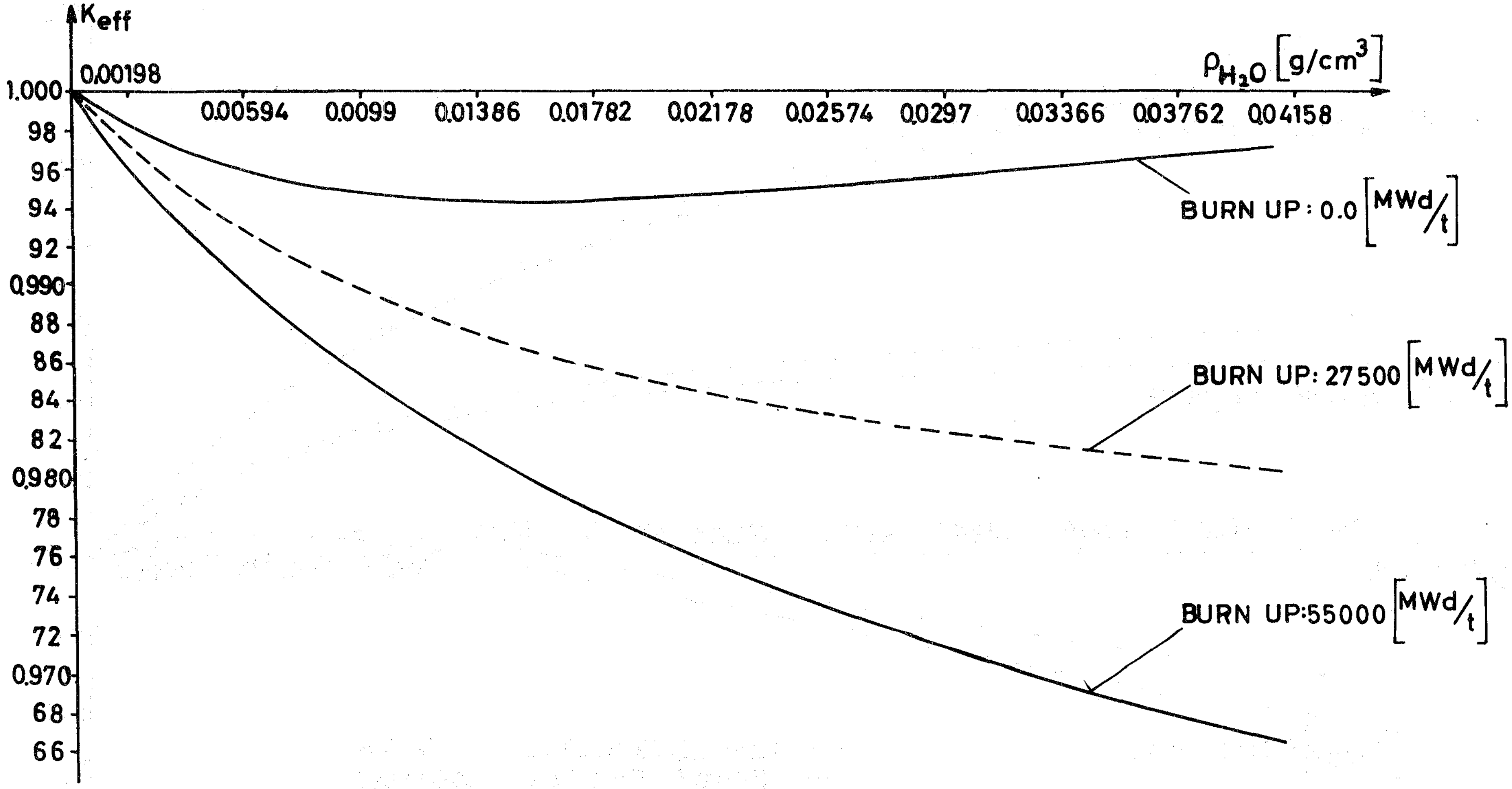

FIG.3 EFFECTIVE MULTIPLICATION FACTOR AS A FUNCTION OF STEAM DENSITY

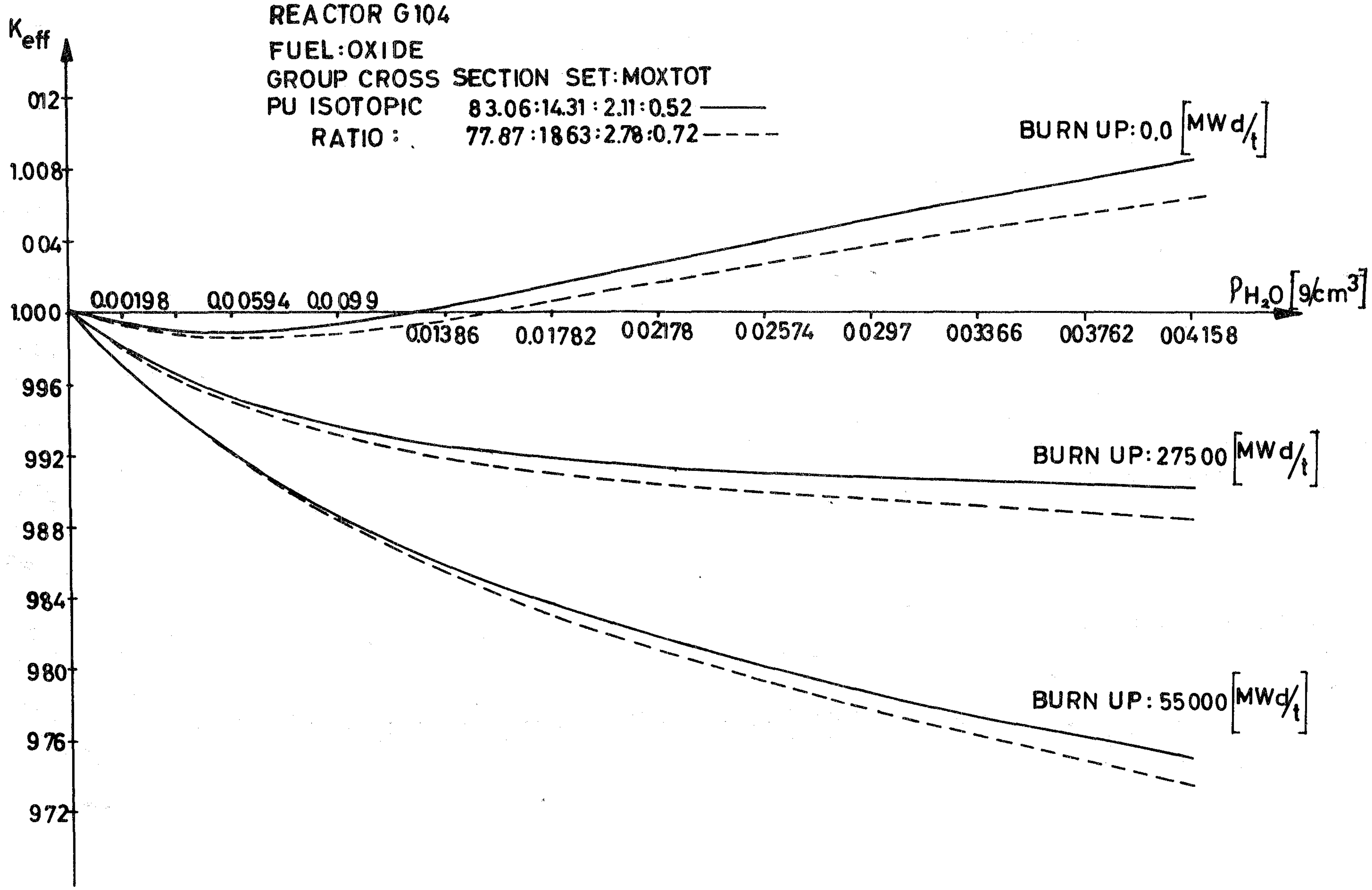

FIG.4 EFFECTIVE MULTIPLICATION FACTOR AS A FUNCTION OF STEAM DENSITY

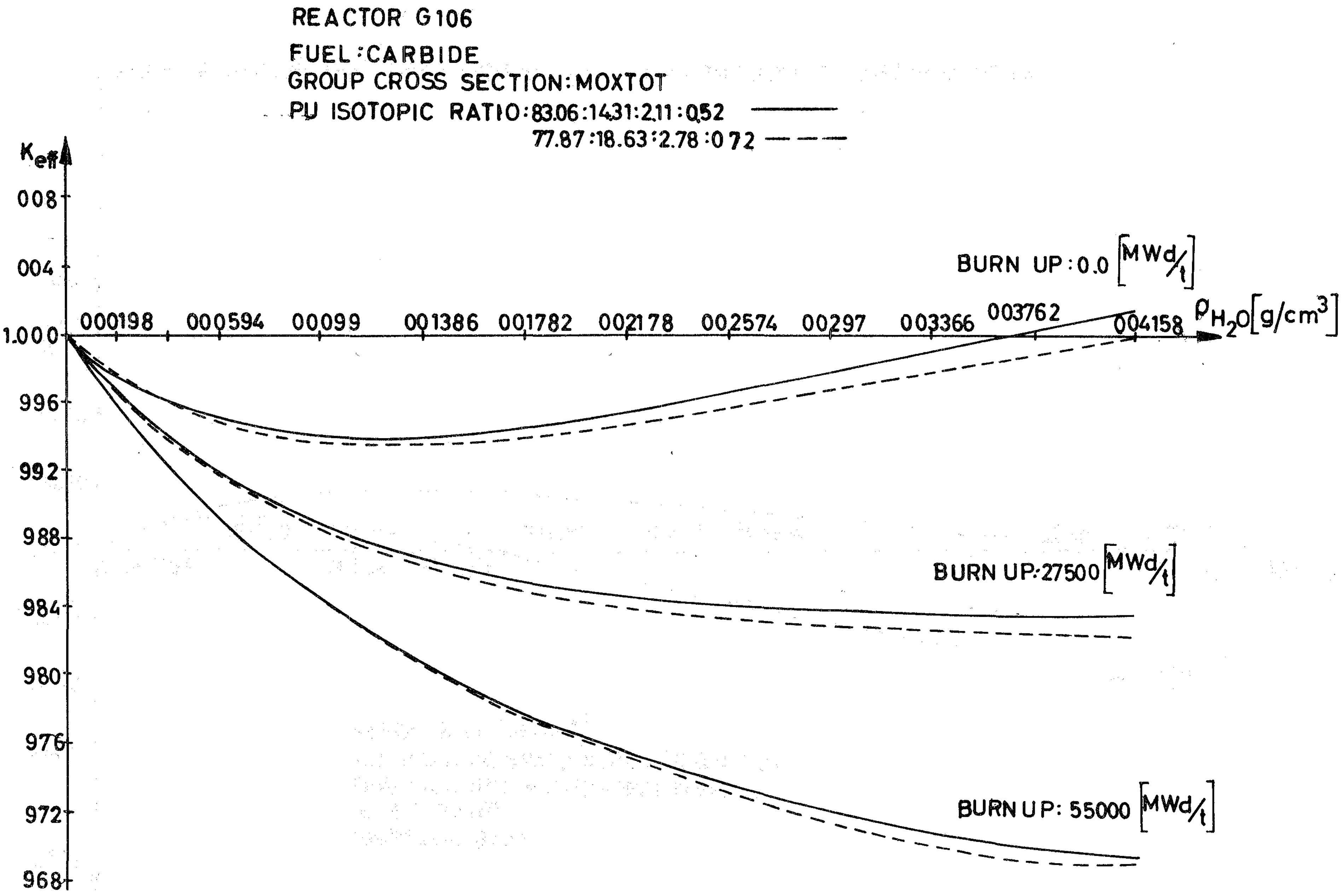

FIG. 5 EFFECTIVE MULTIPLICATION FACTOR AS A FUNCTION OF STEAM DENSITY

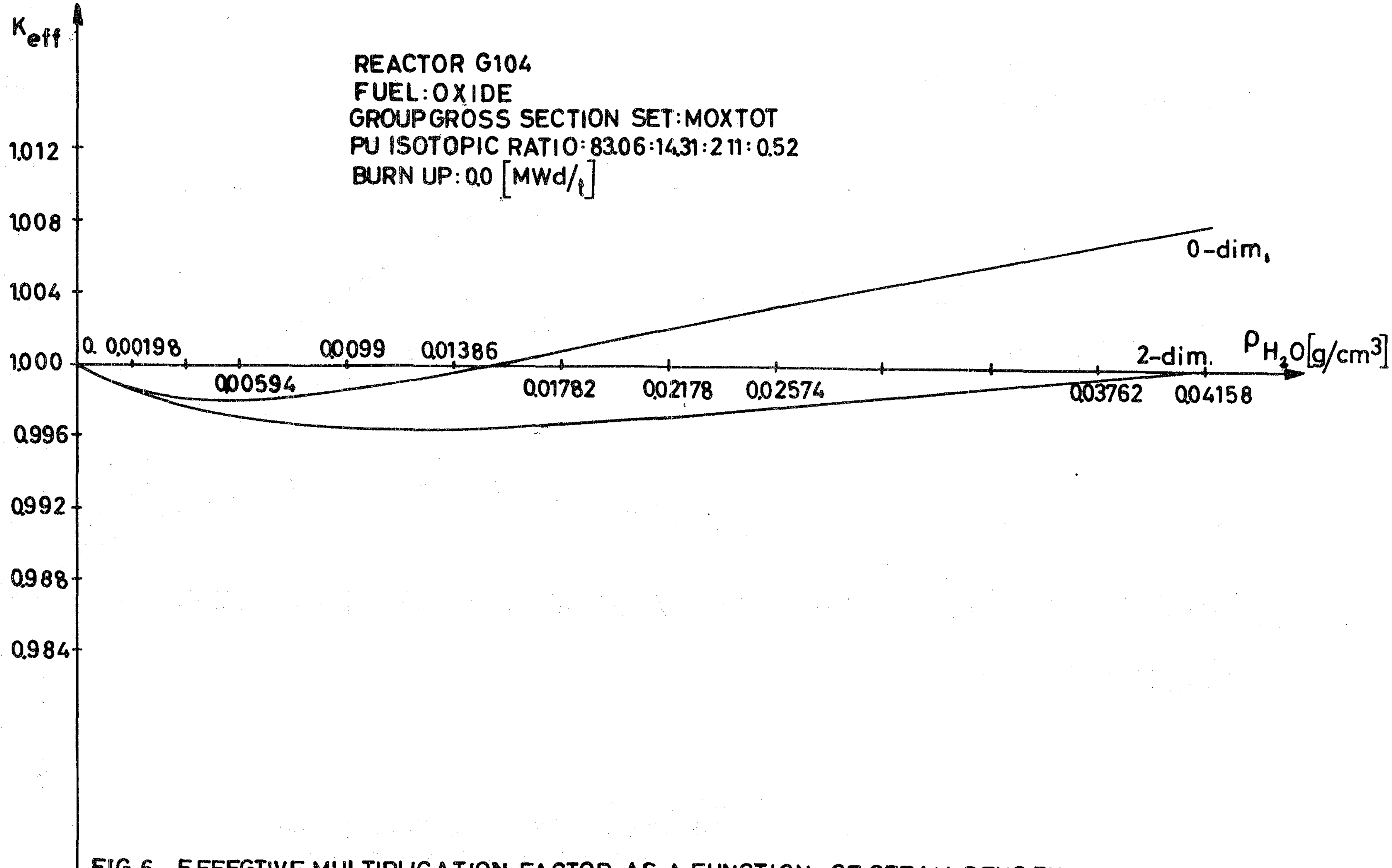

FIG. 6 EFFEGTIVE MULTIPLICATION FACTOR AS A FUNCTION OF STEAM DENSITY

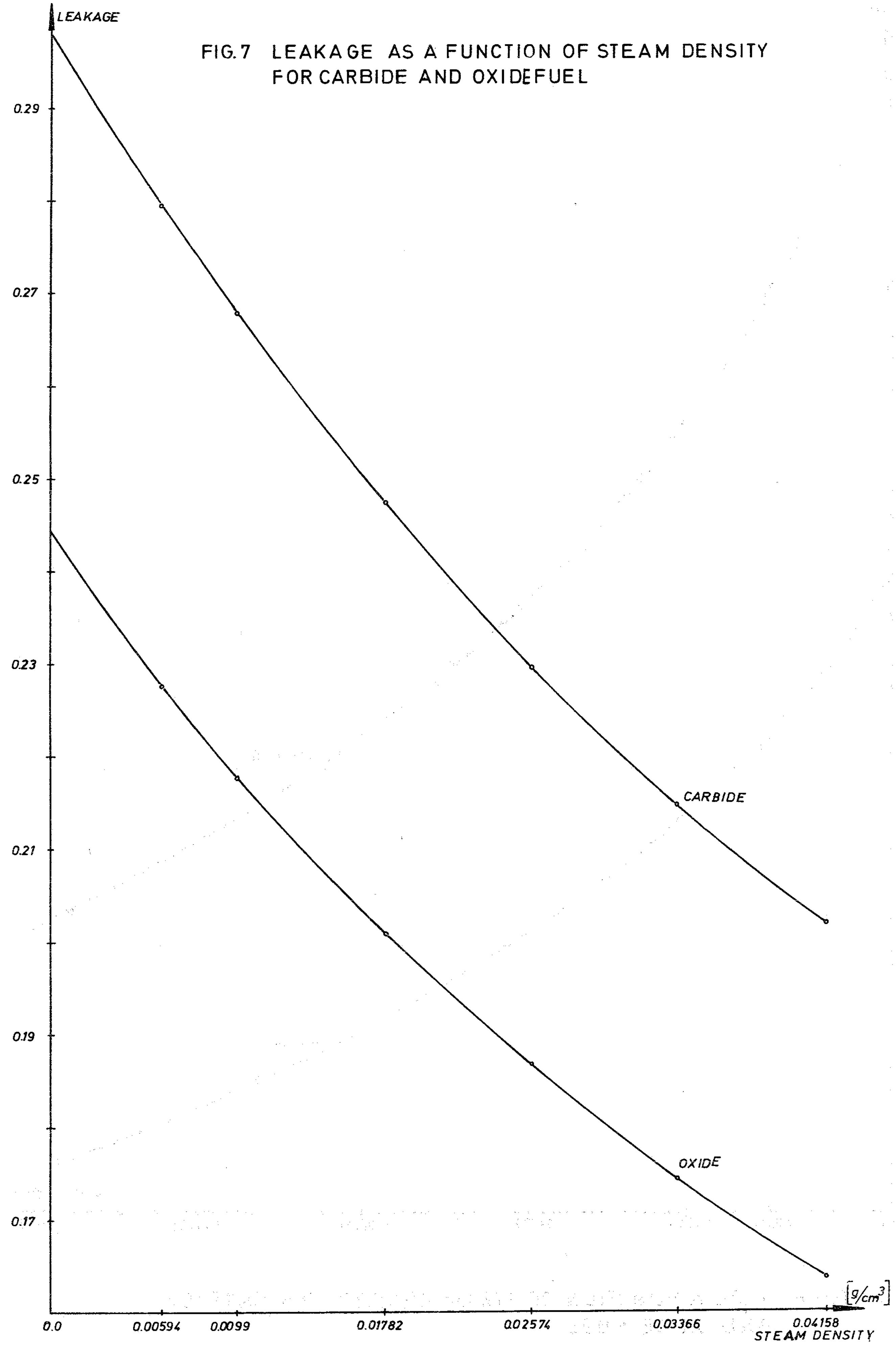

FIG. 7 LEAKAGE AS A FUNCTION OF STEAM DENSITY FOR CARBIDE AND OXIDEFUEL

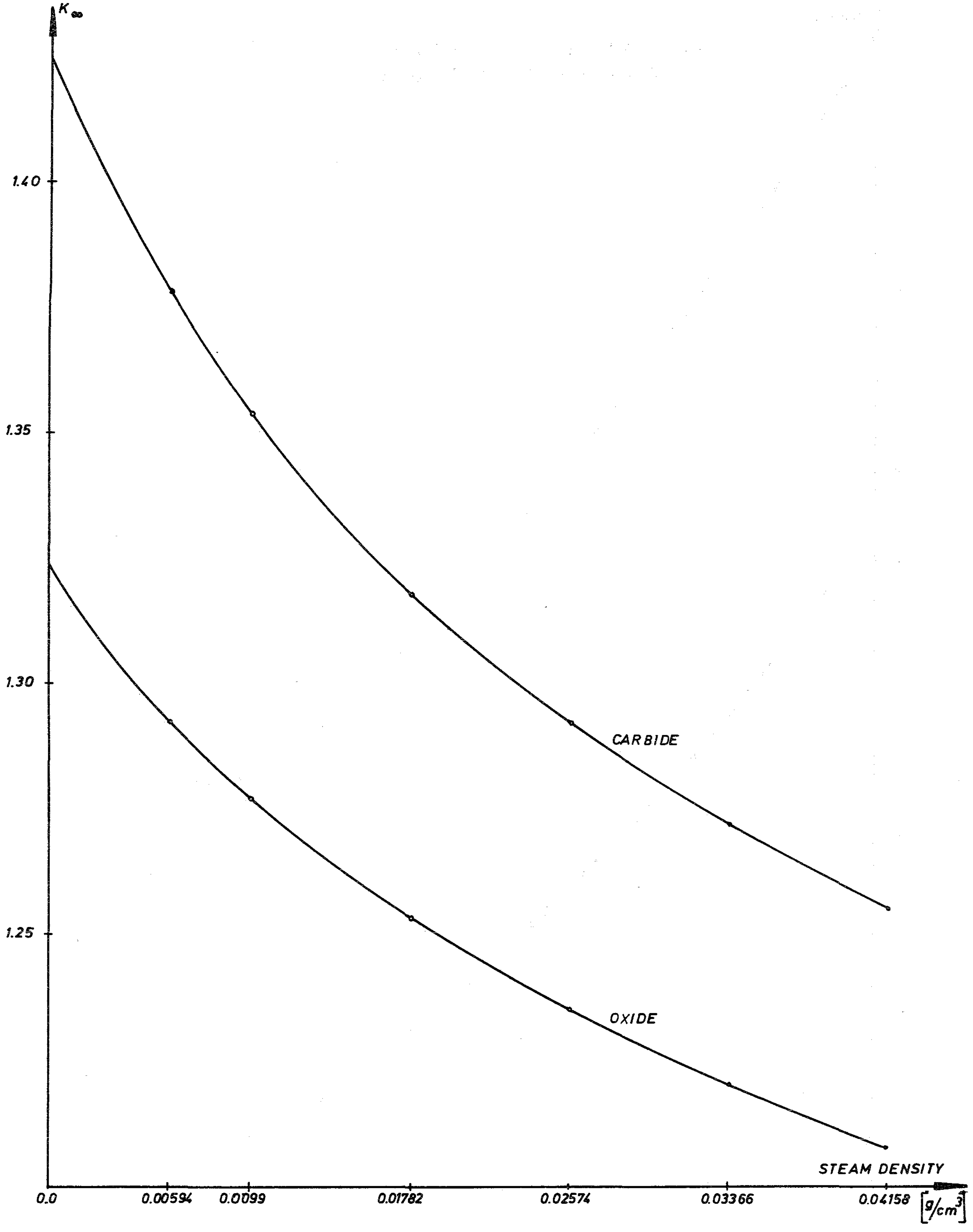

FIG. 8 K_∞ AS A FUNCTION OF STEAM DENSITY FOR CARBIDE AND OXIDE FUEL

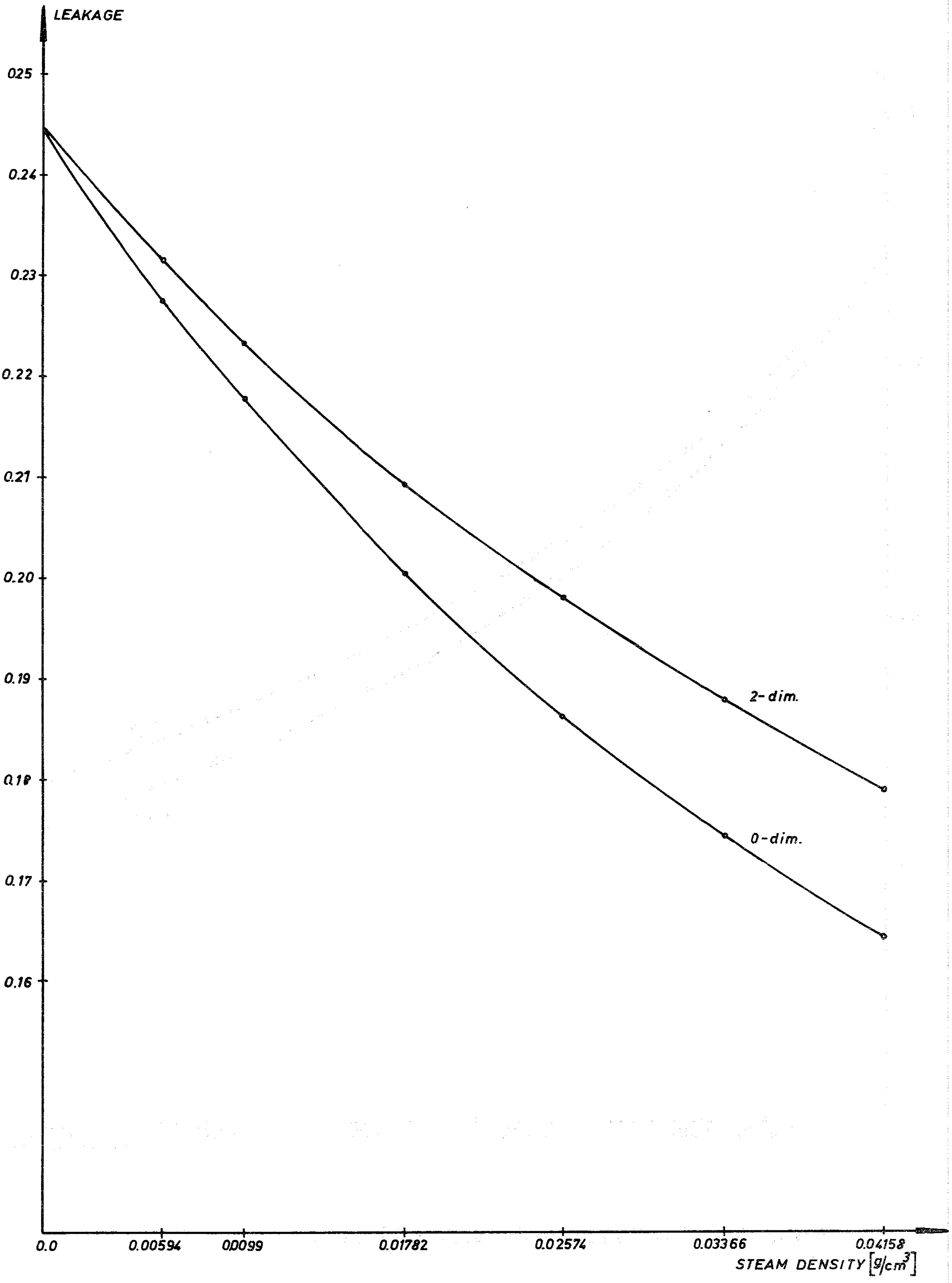

FIG. 9 LEAKAGE AS A FUNCTION OF STEAM DENSITY

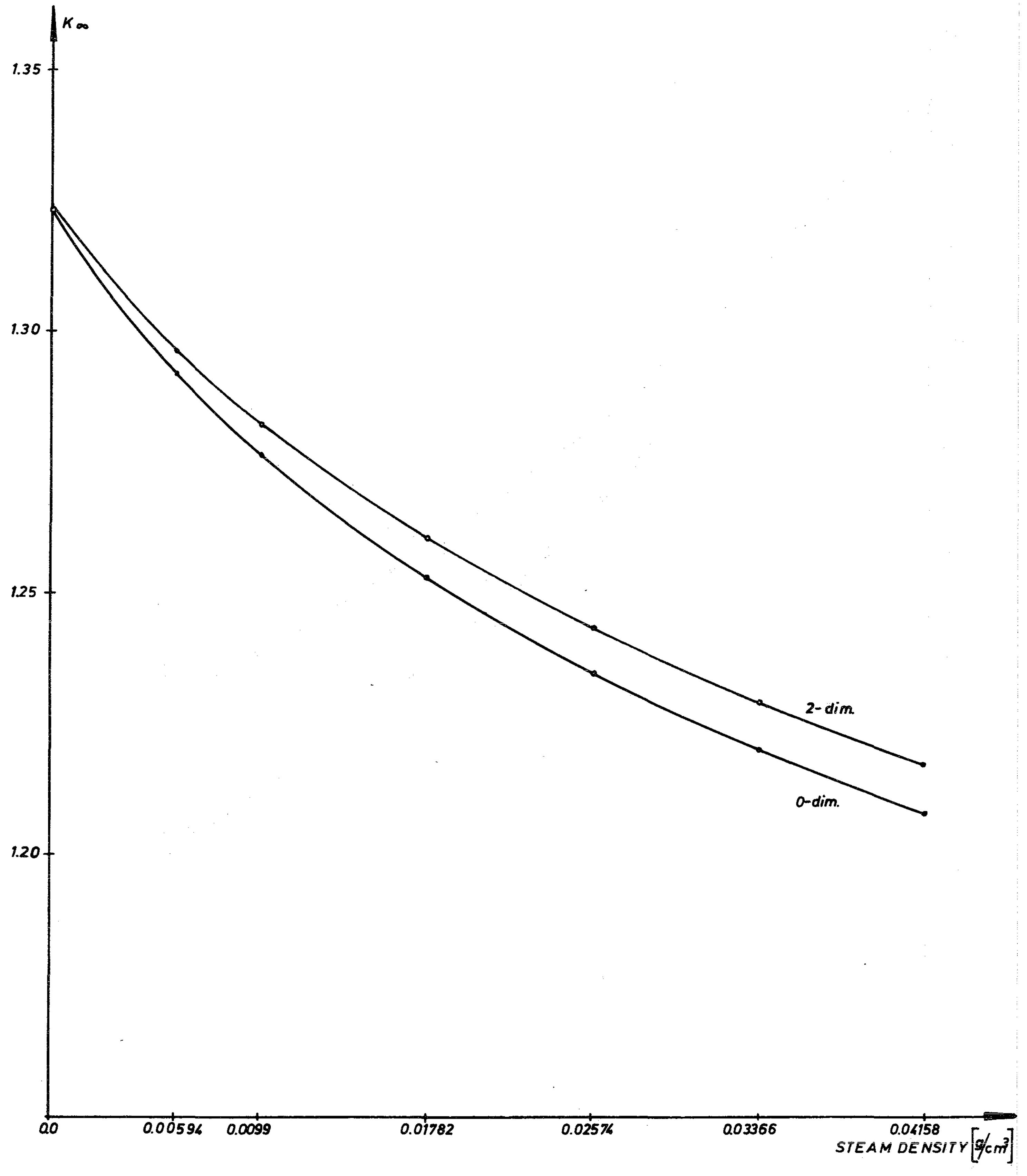

FIG. 10 K_∞ AS A FUNCTION OF STEAM DENSITY

Appendix

Specifications of the Karlsruhe design of a gas cooled fast breeder reactor of 1000 MWe power with oxide and carbide fuel respectively.

	Oxide Fuel	Carbide Fuel
Geometry		
Core vol. [m^3]	8.47	4.181
Core height [cm]	120	110
Core diameter [cm]	300	220
ax. blanket thickness [cm]	60	60
rad. blanket thickness [cm]	50	50
Volume of Corezone 1 / Volume of Corezone 2	1	1
Core and axial blankets		
Volume fractions		
coolant	0.5524	0.5697
structure	0.0730	0.0700
cladding	0.0766	0.0758
fuel	0.2980	0.2845
Structural material	16/13 SS	
density [g/cm^3]	7.76	
composition	Cr16; Fe67.8; Mo1.3;Nb1.2; Ni13, V0.7	
Cladding material	Vanadin alloy	
density [g/cm^3]	5.96	
composition	V96; Ti3; Si1	

	Oxide Fuel	Carbide Fuel
Coolant density [g/cm^3]	$0.5389 \cdot 10^{-2}$	$0.6587 \cdot 10^{-2}$
Smear density of the fuel in the core	0.83	0.80
fertile mat. in ax.blanket	oxide	carbide
Smear density	0.90	0.90
<u>Radial blanket</u>		
Vol. fractions		
coolant	0.241	0.241
structure and cladding	0.183	0.183
fuel	0.576	0.576
Structural and cladding material	Incoloy 800	
density	8.0	
compositon	Cr21; Fe46.5; Ni32.5	
fuel	Oxide	
smear density	0.87	