OVERVIEW OF THE DESIGN OF CORE RESTRAINT SYSTEMS

DeBeNe Review Paper

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1. INTRODUCTION

This paper deals with the three Fast Breeder Reactors KNK II, SNR 300 and SNR 2. They differ mainly in three characteristics, namely size (Fig. 1), plant-type and status: KNK II is a loop reactor with a thermal power of 58 MW, it is running since 1977, just now the second core load has reached about 150 EFDP,
SNR 300 is also a loop reactor with a thermal power of 762 MW, it is currently in the final phase of construction, first criticality is scheduled for the begin of 1986,
SNR 2 will be a pool type reactor with a thermal power of 3420 MW, the negotiations between utility and manufacturer are in full swing, a corresponding engineering contract, which will cover a four years work, is expected in the next months.

2. CORE RESTRAINT SYSTEMS

The core restraint system of KNK II is shown in Fig. 2. It is a passive system with three pad levels and one restraint ring, which limits the deflections of the outermost reflector subassemblies at their tops. There is one peculiarity, namely an elastic hinge formed by a spring assembly in the heads of these reflectors. The purpose of this hinge is to limit the forces between adjacent subassemblies.

The core restraint system of SNR 300 is shown in Fig. 3. It is a passive system with two pad levels and two restraint rings. There are no hinges in the reflectors, the desired limitation of the forces is reached by adequate choice of the radial gap to the upper restraint ring. As in KNK II there is no transfer of bending moment between the subassembly and its grid plate insert.

The core restraint system of SNR 2 is not yet fixed, but the system shown in Fig. 4 is likely to come. It is a passive system with one pad level in the fuel region, two pad levels in the reflector region but without restraint rings. The bending stiffness of the reflector subassemblies, which are affixed to the diagrid as rigidly as practicably possible, serves as flexible restraint. Alternative solutions are under consideration: a second pad level below the core in order to reduce residual bowing, restraint rings in order to limit definitively fuel movements and corresponding reactivity effects under seismic incidents. In contrast to KNK II and SNR 300 the SNR 2 is a pool type reactor, which requires an axial shielding (long head ends of the subassembly) and a radial shielding (additional radial shielding subassemblies). Both penalize the core restraint: long head ends lead to large head deflections; due to the presence of the shielding subassemblies restraint rings, if desired or necessary, are difficult to place.

3. DESIGN CRITERIA

There is a certain number of design criteria for the design of a core restraint system. These criteria are related to

a) deformations
  - incore subassembly head displacement
  - incore subassembly bending
  - permanent subassembly bowing

b) forces on
  - pads
  - gridplate insert
  - rings

c) reactivity effects
  - jumps
  - power to flow coefficient
  - power coefficient

The allowed values differ from one reactor to the other, corresponding to the design of the subassemblies, the handling device and the reactivity requirements. Some typical values are listed below:

Design criteria for KNK II/SNR 300

. maximum incore subassembly head displacement	10 /17 mm
. maximum permanent subassembly bowing	8.3/25 mm
. maximum force on pads	3600/3600 N
. maximum extraction force	20000/20000 N

. the power to flow coefficient should not lead to a positive power coefficient

. reactivity jumps due to subassembly movements must be less than 1 $.

The values for SNR 2 are not yet defined. But concerning the reactivity effects there is already a request for a negative power to flow coefficient in order to ensure a satisfactory core behaviour during unprotected accidents.

4. CALCULATIONAL METHODS

The codes used for the core restraint analysis are shown in Fig. 5. The main tool is the code FIAT, which stems from the code NUBOW developed at Argonne National Laboratory (ANL). FIAT is a 2-dimensional code, which calculates the mechanical equilibrium configuration for a spoke through the core. Bowing, dilatations and forces are calculated taking into account the following effects:

- thermal effects
  - expansion
  - bowing caused by differential expansion
- neutron induced effects
  - expansion caused by swelling
  - bowing caused by differential swelling
  - bulging caused by creep under internal pressure
  - bowing caused by creep relaxing the bending stresses
- elastic bending
- local flexibilities in the pad levels
- clearances at the support and between adjacent subassemblies
- operating conditions
  - shut-down state
  - raising to full power
  - different power to flow ratios
- subassembly management
  - replacement of irradiated subassemblies by fresh subassemblies
  - rotation of irradiated subassemblies
  - exchange of irradiated subassemblies

FIAT uses as input temperature fields, calculated by the subchannel code IACOB and neutron flux fields calculated by the neutronic codes MOCA or KASYS. Reactivity effects are determined by means of the 2-dimensional code BIER, which processes the deflections from FIAT and the local reactivity coefficient from the code DIXYBOWP, a 2-dimensional perturbation code.

FIAT has been used extensively for the design of KNK II and SNR 300, its method and the results were accepted by the licensing authorities. FIAT is also used currently for studies on SNR 2.

In addition to the 2-dimensional codes we have developped a set of 3-dimensional codes, DDT and DDTAB for the mechanics and D3BIER and KASBA for the reactivity effect. But up to now these codes have not been used for parametric studies not to mention project calculations. Concerning the verification of DDT a set of benchmark-calculations has been performed, which lead to an excellent agreement between the results of DDT and the results of two other 3d-codes.

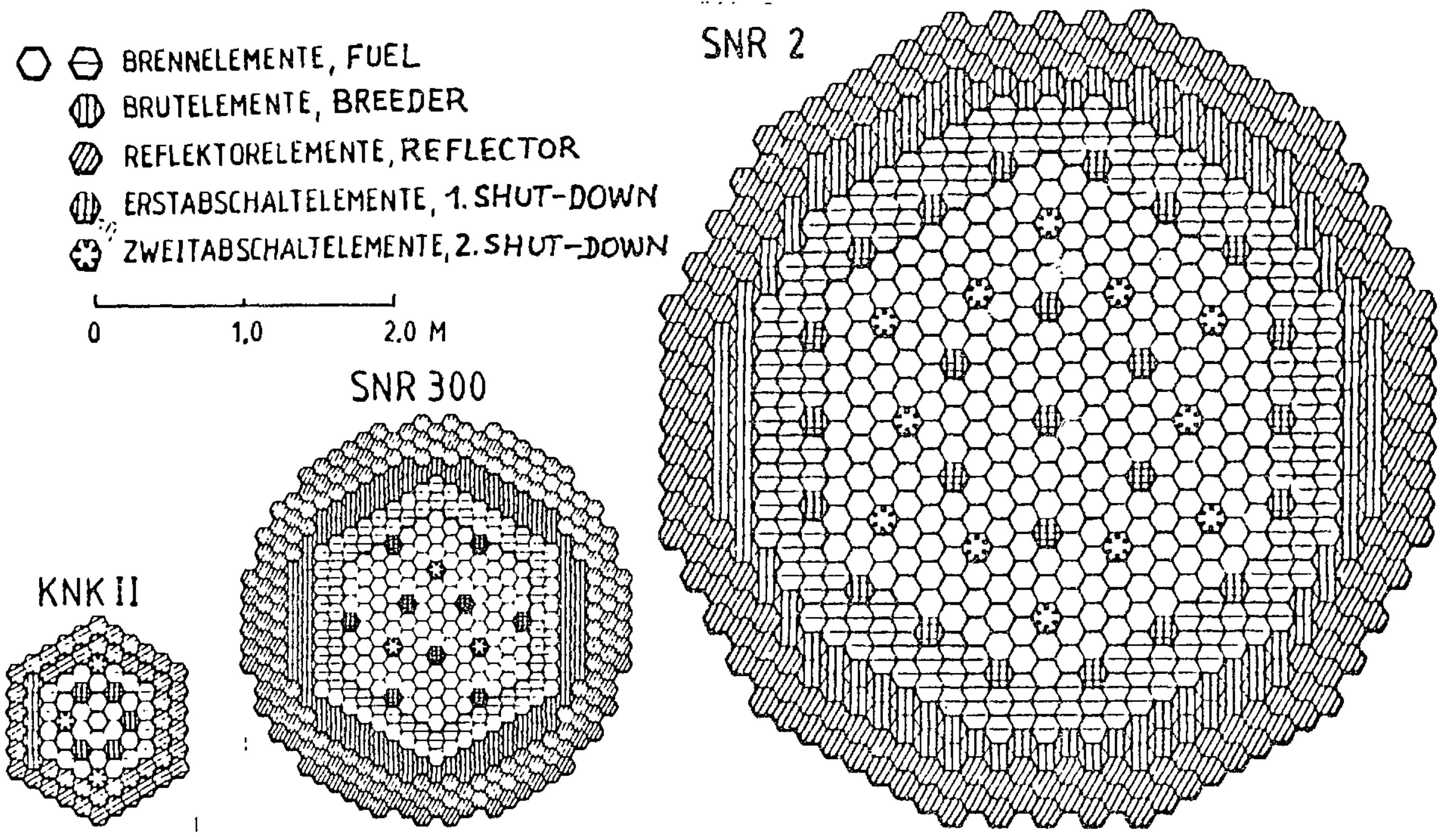
4. TYPICAL RESULTS

Some typical results of the core restraint calculations are presented in Fig. 6, 7 and 8. Fig. 6 shows the bowing lines and the load pad forces for KNK II/2 at end of life. Deflections and dilatations are rather small compared to the available gaps. This is due to the small irradiation dose in this small reactor. Fig. 7 shows the corresponding result for SNR 300. Deflections and dilatations are large. In order to avoid the additional contacts outside the pad levels, a certain management of some subassemblies is foreseen, depending on the results of intermediate measurements of the deformation of some subassemblies after one and two thirds of the residence time of the subassemblies.

In Fig. 8 the influence of the loadpad stiffness on the reactivity behaviour for SNR 2 is shown. With increasing power to flow ratio an increase or decrease of the reactivity is achievable, depending on the value of the stiffness. Extensive studies have shown, that the loadpad stiffness is one of the key parameters for sign and magnitude of the bowing coefficient.

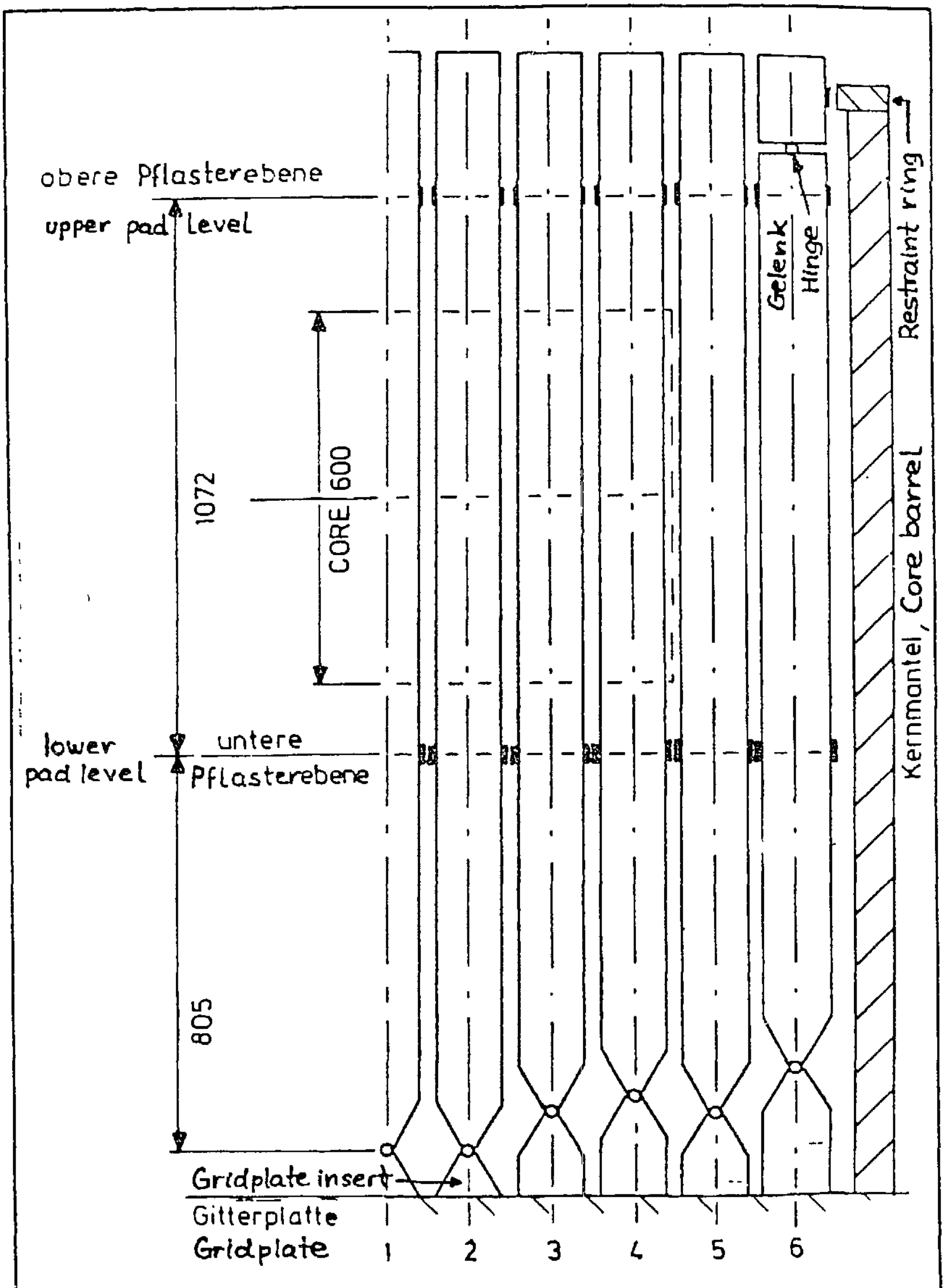
5. OUTLOOK

The optimization of the core restraint system is an important condition for the safe and reliable operation of a fast breeder reactor. For KNK II which is under successful operation and SNR 300 all requirements from safety and operation have been met with help of a ring type system. For SNR 2 the decision between the ring type system and the free standing core has to be done in the next future. Within these considerations the advantages of a ring type restraint system of limiting deflections during operation and limiting of possible movements under seismic conditions have to be balanced against the somewhat more complicated structure of the ring type restraint system.

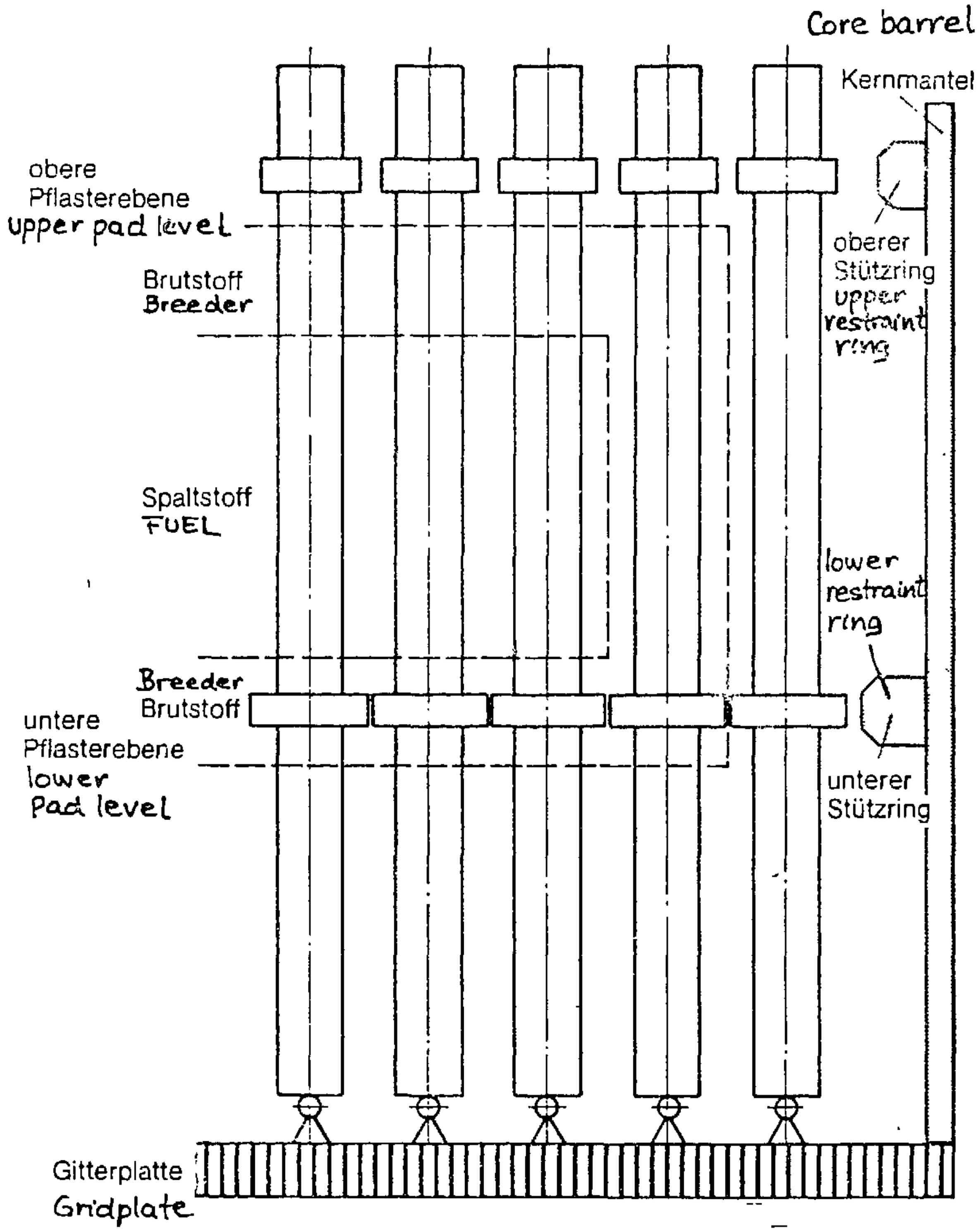


LAYOUT OF KNKII, SNR300 UND SNR2

Fig. 1



KNK II CORE RESTRAINT SYSTEM Fig. 2



SNR 300 CORE RESTRAINT SYSTEM

Fig. 3

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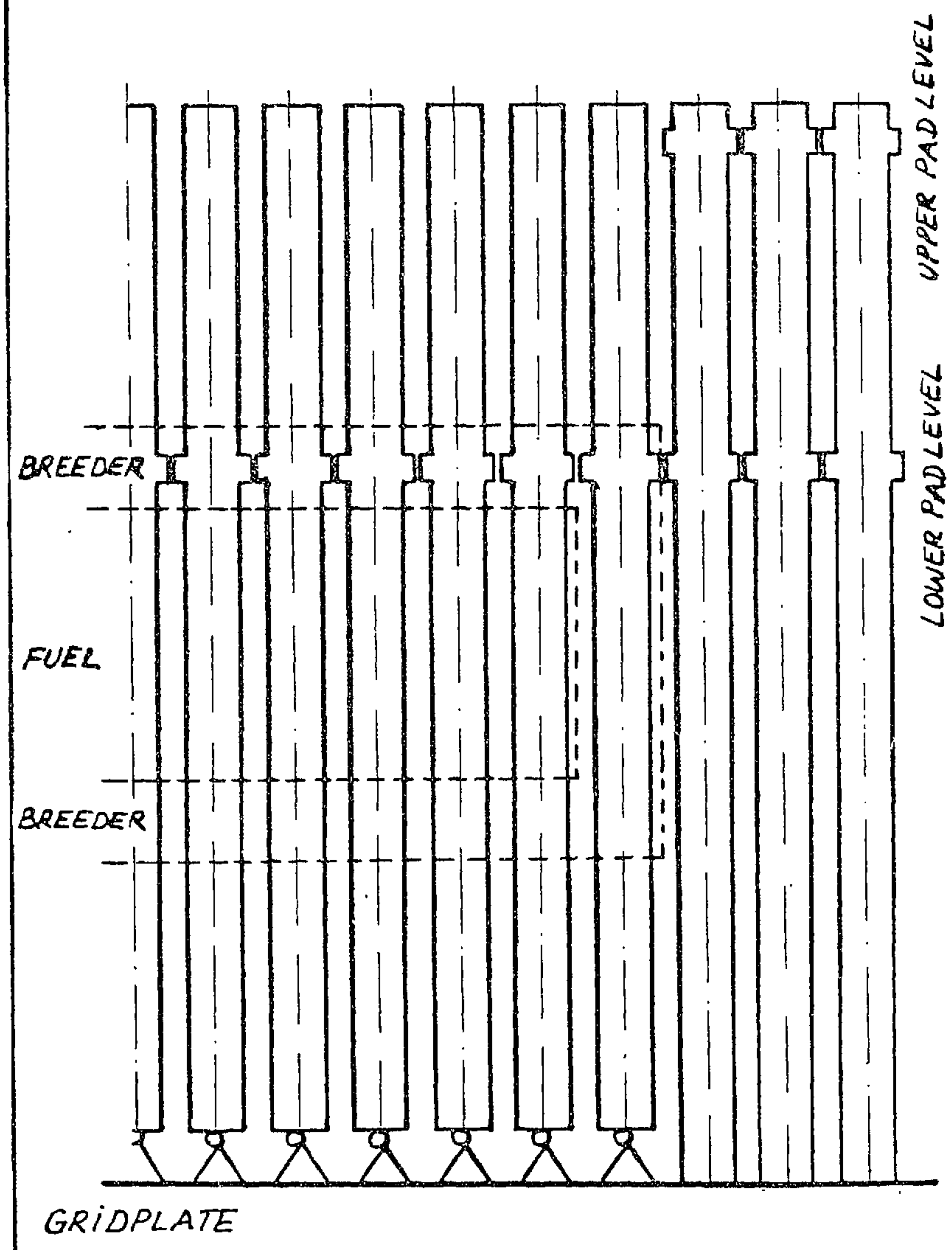

SNR2 CORE RESTRAINT SYSTEM PRELIMINARY DESIGN

Fig. 4

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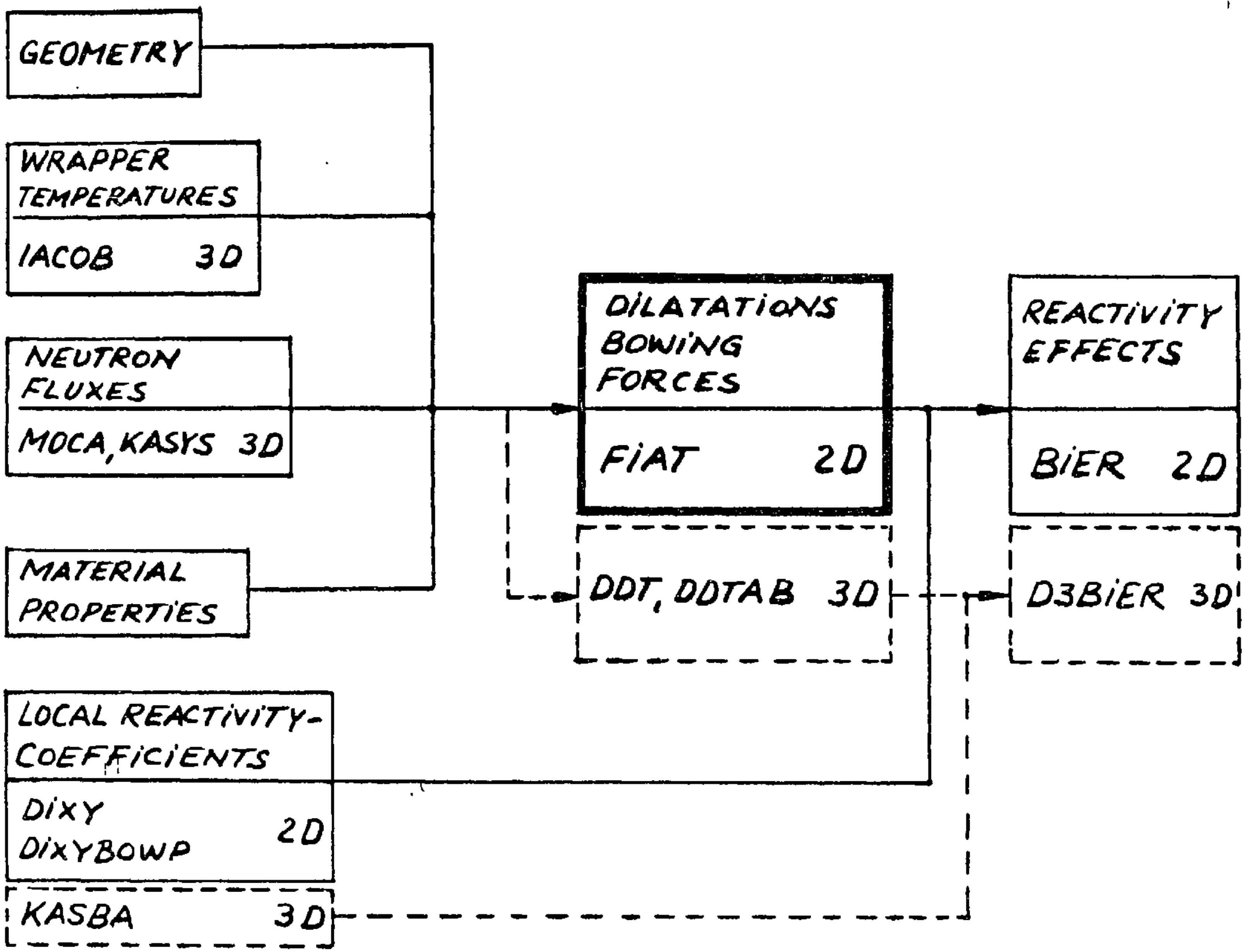

CORE RESTRAINT ANALYSIS

Fig. 5

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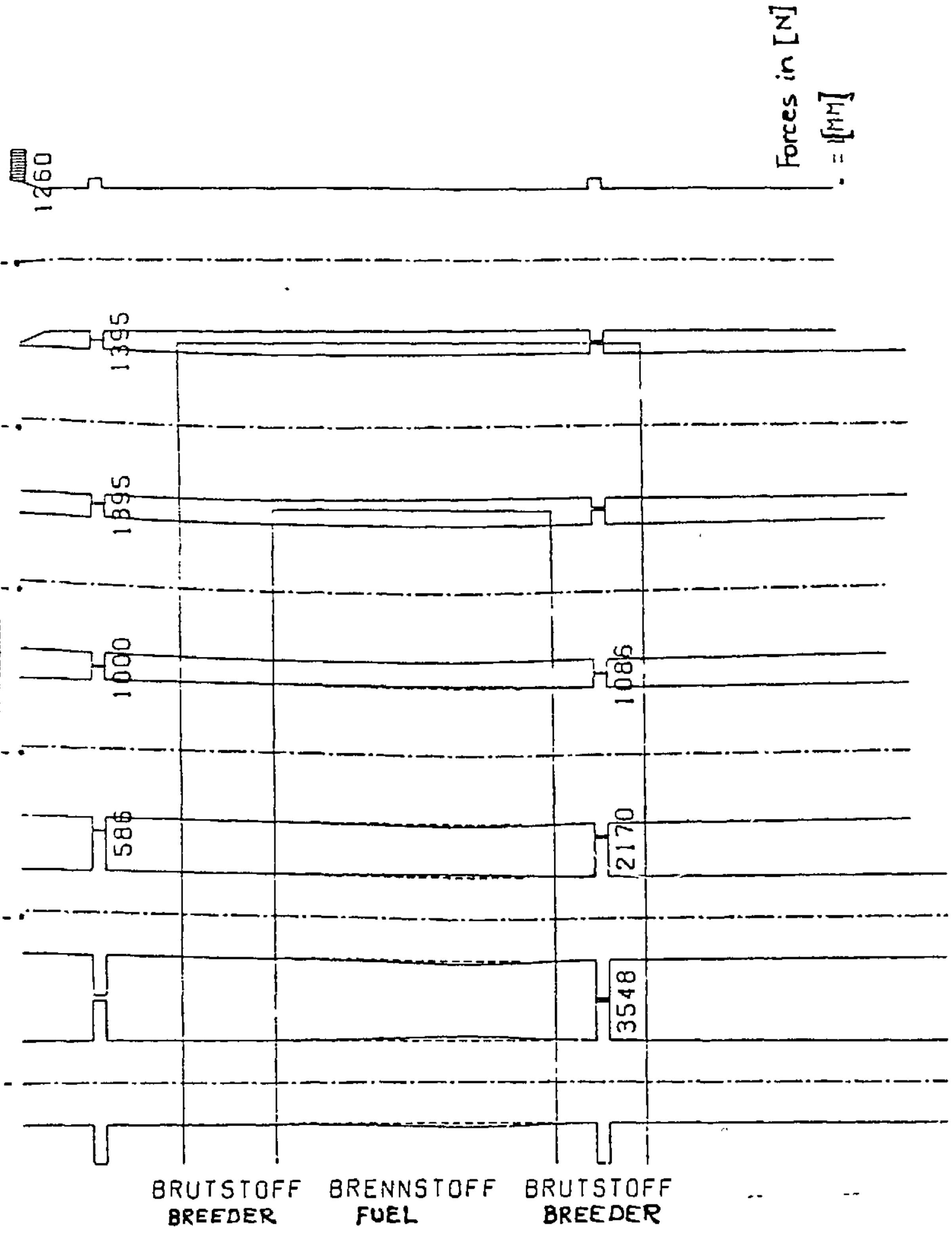
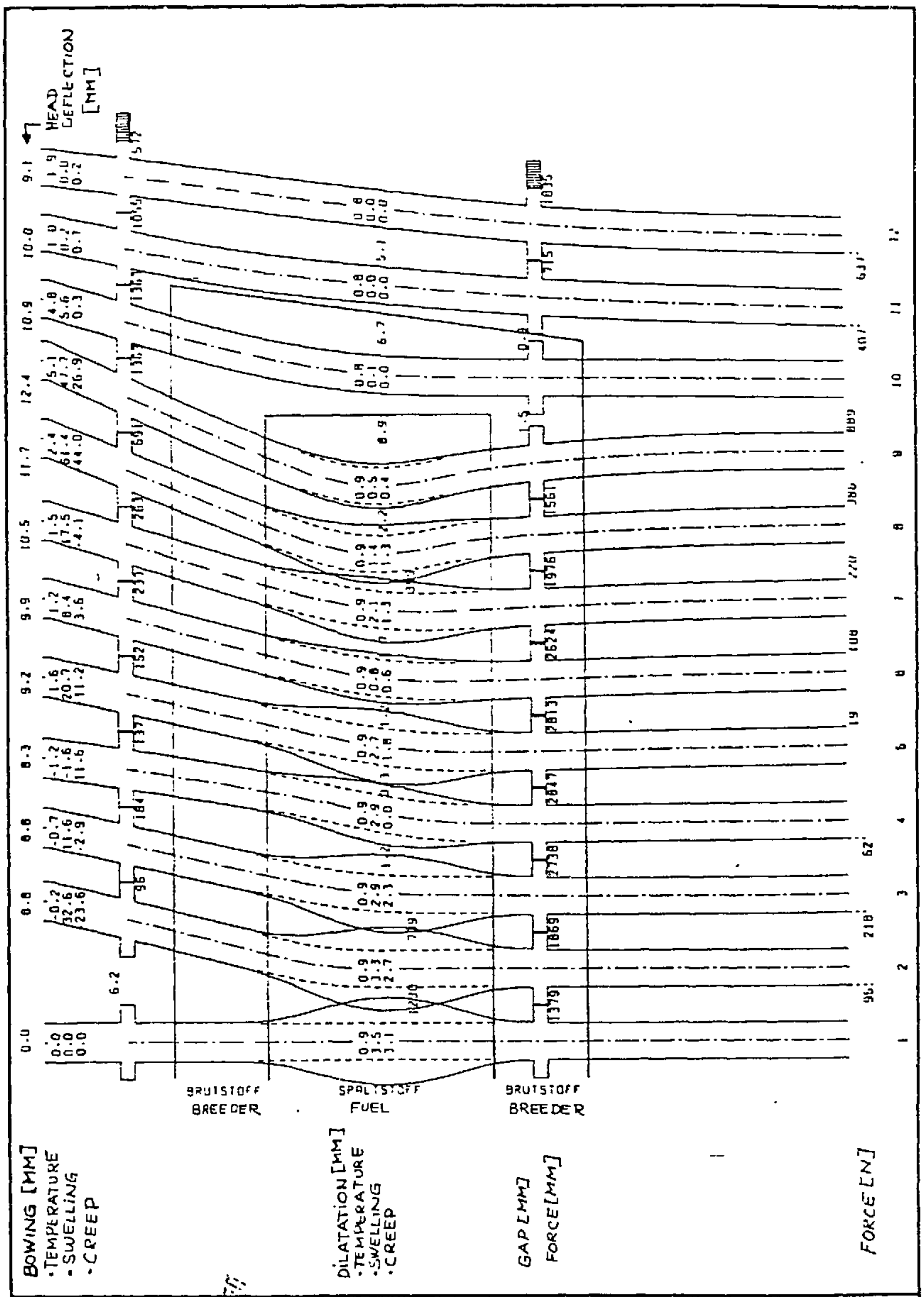


KNK II/2, END OF LIFE

Fig. 6



SNR300 MarkIa EOL 100% POWER

Fig. 7

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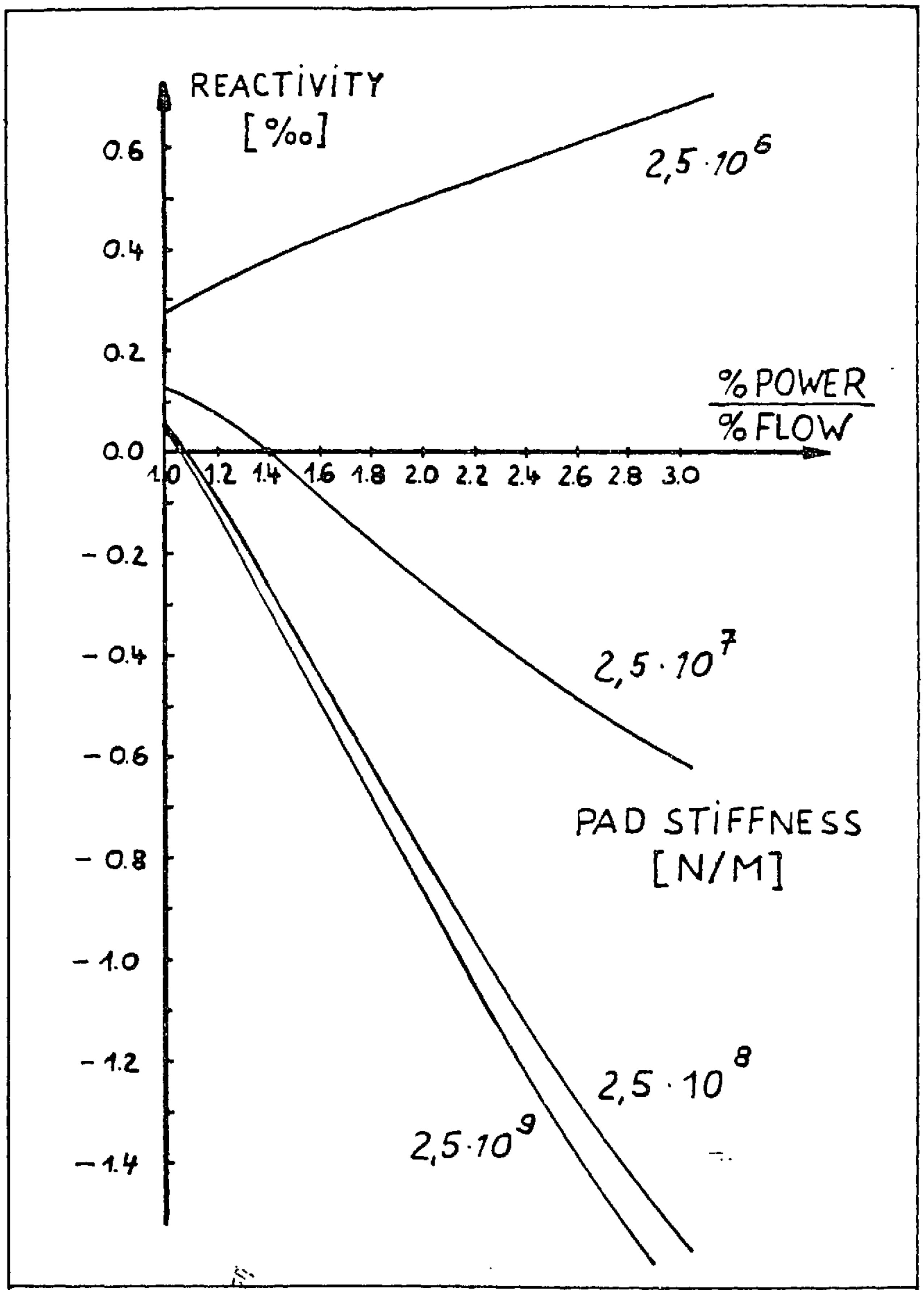

SNR 2 INFLUENCE OF PAD STIFFNESS Fig. 8

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