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APPENDIX E-1

NEUTRON STUDIES ON THE CONVERSION OF THE RA-3 REACTOR TO LEU FUEL

performed by

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ABSTRACT

Results of preliminary neutronic studies for conversion of the RA-3 reactor to LEU fuel are described.

1. THE RA-3 MAIN CHARACTERISTICS

The 7 MW*RA-3 reactor is operating in Buenos Aires, Argentina, since 1967. It is mainly used in the production of radioisotopes for applications.

The RA-3 utilizes standard MTR-type fuel elements (Fig. 1) containing 90 wt% enriched uranium. The fuel elements are composed of 19 plates of Al-U-Alloy with an uranium concentration of 18.7 wt%, being the corresponding uranium density of 0.59 g/cm^3.

The 0.52 mm meat plates are protected by an 0.39 mm Al cladding.

Normal cores consist of 25 standard fuel elements and 4 fuel fuel elements with control rods.

Typical final burn-ups are of about 40% consumed U-235 with a cycle length of around 20 days at 3 MW. At the end of each cycle one fuel element is replaced.

The medium thermal flux at 3 MW is of about 1.5 x 10^{13} neutrons/. cm^2 sec.

The thermohydraulic system allows a coolant flow of 900 m^3/hr, being the coolant temperature 45°C.

2. THE CONVERSION OF THE RA-3 TO LEU FUEL

The above mentioned coolant flow means heavy economical penalties, i.e. important changes in the primary circuit, if fuel elements have to suffer important geometry changes, i.e. diminution in the number of plates.

In this situation we must rely upon only two kinds of changes:

a) the increase of the uranium density in the meat,

b) minor geometric changes in the fuel elements, as changes in thickness and width in the meat or the cladding.

3. NEUTRONIC CALCULATIONS

We will now show some results of scoping neutronic calculations we have made in order to evaluate the effects on the RA-3 reactivity and burn-up of several kinds of geometric and composition changes.

In this first stage we have limited ourselves to cell calculations.

3.1 Calculation Methods

The calculations were performed using the WIMS-D cell code in the pin cell option with condensations from its 69 group library and the S4 option

*Operating at power level 3.5 MW

for the main transport calculation performed with the following four group structure.

1^{st} group	10 Mev	-	0.821 Mev
2^{nd} group	0,821 Mev	-	5.53 keV
3^{rd} group	5.55 KeV	-	0.625 eV
4^{th} group	0.62 eV	-	0. eV

In order to adapt the actual. cell geometry to the WIMS code, the cell was assumed composed of three kinds of infinite layers (Fig. 2).

Fuel (Al + U)
Clad + lateral support material (Al)
Coolant (H_2O)

so that the following conditions are fulfilled:

a) the fuel plate thickness is conserved

b) the volume ratios of the different materials are conserved.

3.2 Results

3.2.1. Reference case

Evaluation was performed for the current geometry and composition of the fuel elements and also for a fuel element with the same geometry and a 20% enriched meat with uranium concentration of 60 wt% and uranium density of 2.8 g/cm^3.

As a reference in the next sections we will compare two parameters:

a) the reactivity of a typical cold and clean water reflected configuration ($B^2 = 0.0078\ cm^{-2}$)

b) the average burn-up corresponding to zero reactivity.

Looking at Fig. 3 we can point out as a first remark that, in this case, the reactivity (parameter a) decreases from 13600 pcm to 9900 pcm and that the burn-up (parameter b) decreases from 30% to 22%.

3.2.2 Uranium concentration changes

In Fig. 4 the variations of reactivity and burn-up with the uranium concentration for the present geometry are shown. As it can be seen these parameters suddenly get apart from the present values while lowering the uranium concentration.

In order to obtain the present reactivity a concentration of 65 wt% is required ($\rho_u = 3.32\ g/cm^3$). As a reference we can point out that an increase in the porosity factor from 0.84 to 0.95 means increases in reactivity that ranges from 1000 pcm to 3500 for 80 wt% concentration and 40 wt% concentration respectively.

3.2.3 Geometrical changes

In the following sections we will consider the effect on reactivity and burn-up of different geometrical changes in the 20% enriched fuel with uranium concentration of 60 wt%. Uranium loadings are always shown.

3.2.3.1 Variation of fuel thickness with constant can thickness.

Fig. 5 shows the incidence on reactivity and burn-up of the substitution of fuel volumes by moderator volumes. As it can be expected there is an optimal relation between fuel and moderator that, in our case, occurs for a fuel thickness of 0.72 mm.

Anyway, neither present reactivity nor burn-up are reached with this optimal thickness, a difference of 2200 pcm and 2.5% respectively being found.

3.2.3.2 Variations of the can thickness with constant moderator thickness.

In this case fuel is added at the expense of a lowering of the clad aluminum. This change is always positive from the neutronic point of view as it can be seen in Fig. 6.

It can also be observed that the present burn-up is reached decreasing the clad thickness in only 0.06 mm, while the present reactivity is achieved decreasing that thickness in 0.1 mm.

It must be pointed out, however, that the resulting clad thicknesses, remarkably in the second case, are not acceptable from the safety point of view.

3.2.3.3 Variations of the can thickness with constant fuel thickness (Fig. 7).

In this case, the clad thickness is diminished thanks to the moderator thickness, keeping the U-235 loading in 204 g. In this case too low values of clad thickness are necessary in order to reach the current reactivity and burn-up.

3.2.3.4 Variation of the plate number.

a) An alternative way of obtaining a similar result to that of the section 3.2.3.3 is to decrease the number of plates keeping the clad thickness, as well as the total fuel amount, constant.

   The effect produced by this modification is shown in Fig. 8. It may be observed that the present burn-up is achieved with 12 plates while the present reactivity is obtained with less than 10 plates.

   However it must be pointed out that, although the clad thickness is kept constant, a decrease in the number of plates leads to serious problems from the thermohydraulic point of view.

b) Finally, we studied the effects of geometrical variations, as changes in the volumes of materials in the cell. Such kind of changes normally imply changes in the fuel thickness and in the cell pitch.

As it is shown in Fig. 9 the effects of that kind of changes are negligible. We can conclude that reactivity and burn-up variations observed in the case a) of this section are mainly due to the interchange between aluminium and not to spatial disadvantage factors and the geometrical parameters used in the resonance calculations.

4. SUMMARY AND CONCLUSIONS

From the point of view of the conversion possibilities of RA-3 to 20% enriched fuel it is possible to define three regions for the parameter concentration of uranium in the meat:

1) High concentration region

$$65 \text{ wt\%} \leqslant C_u \leqslant 69 \text{ wt\%}$$

$$3.32 \text{ g/cm}^3 \leqslant \rho_u \leqslant 3.82 \text{ g/cm}^3$$

With this concentration the conversion without penalties would be direct with no modification in the gometry of the current fuel element.

2) Intermediate concentrations

$$C_u \approx 60 \text{ wt\%}$$

$$\rho_u \approx 2.8 \text{ g/cm}^3$$

in this region, and adequate combination of geometric modifications as described in section 3 make the conversion to 20% enrichment feasible without heavy penalties.

3) Low concentration region

$$C_u \approx 50\%$$

$$\rho u < 2 \text{ g/cm}^3$$

in this region the conversion would imply severe penalties on reactivity and burnup.

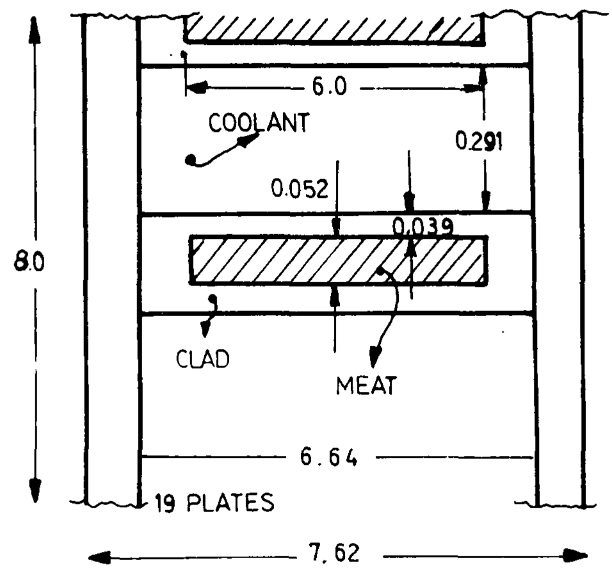
Finally, we can mention that calculations made for 45% enriched fuel show that almost direct conversion can be made with 38 wt% concentrations and uranium densities around 1.35 g/cm^3.

5. NEXT STEPS IN NEUTRONIC CALCULATION FOR THE RA-3 CONVERSION

Presently, we have finished a first draft containing the calculations made with our methods of the benchmark proposed by the Consultants Meeting held June 1975 in Vienna.

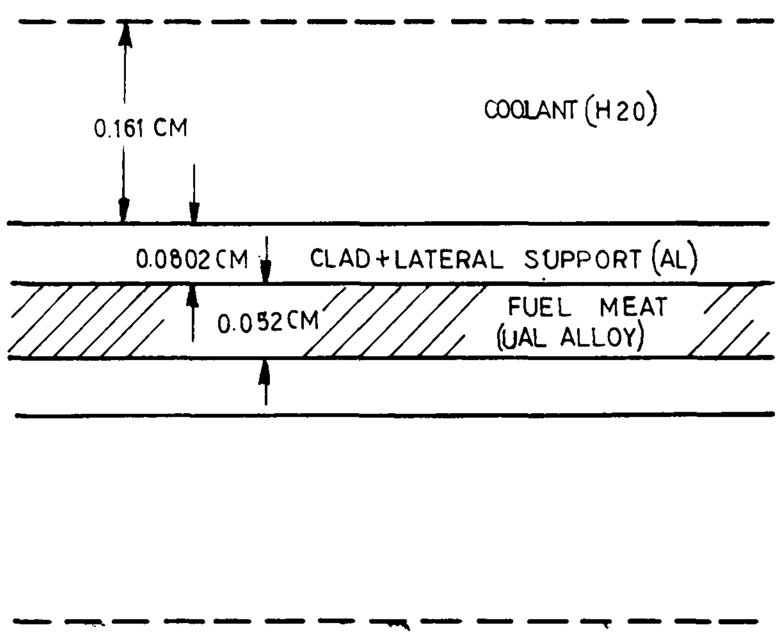
First comparisons show that our results are in good agreement with those obtained by other groups of work.

Soon we will perform shuffling calculations for different LEU fuel elements in order to obtain more accurate results than those we have outlined in this report.



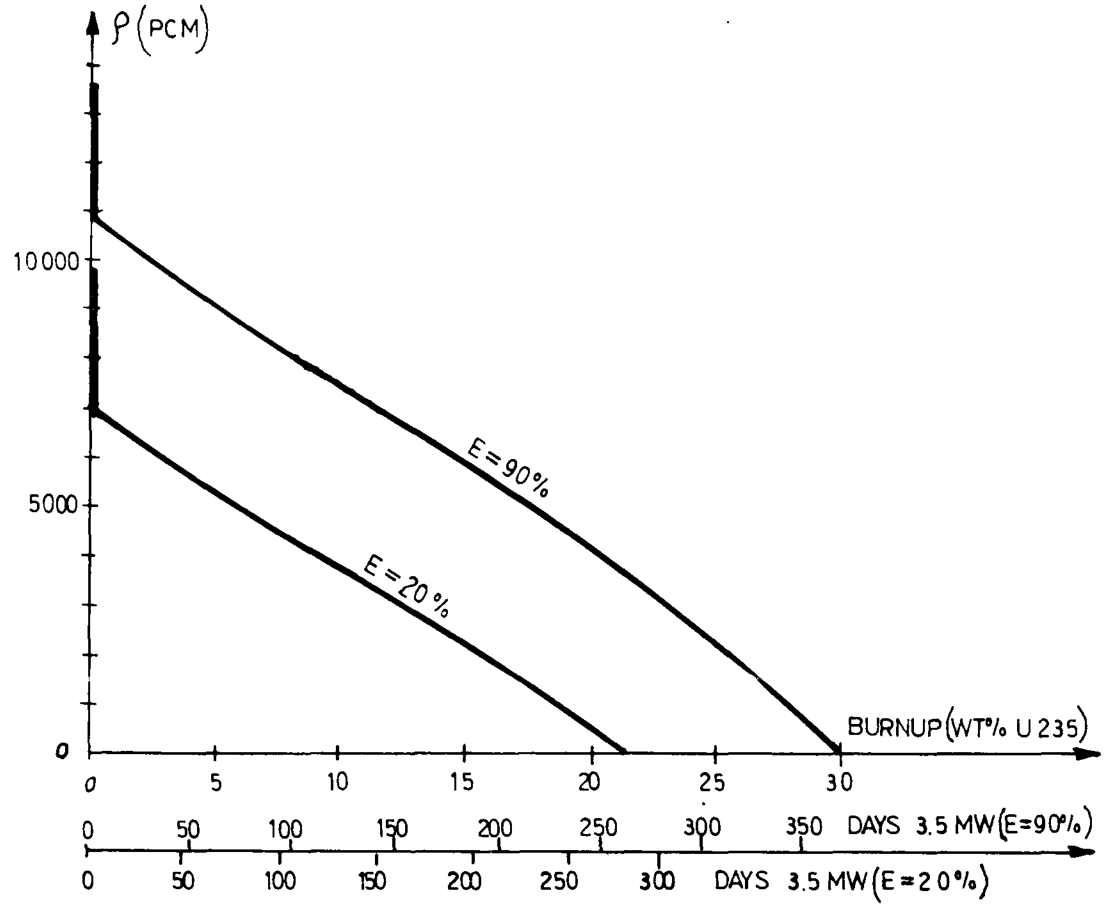
CURRENT FUEL ELEMENT

FIGURE 1



CURRENT FUEL ELEMENT REPRESENTATION IN WIMS

FIGURE 2



ρ (PCM)
10000
5000
0
E=90%
E=20%
BURNUP (WT% U 235)
0
5
10
15
20
25
30
0
50
100
150
200
250
300
350
DAYS 3.5 MW (E=90%)
0
50
100
150
200
250
300
DAYS 3.5 MW (E=20%)

FIGURE 3

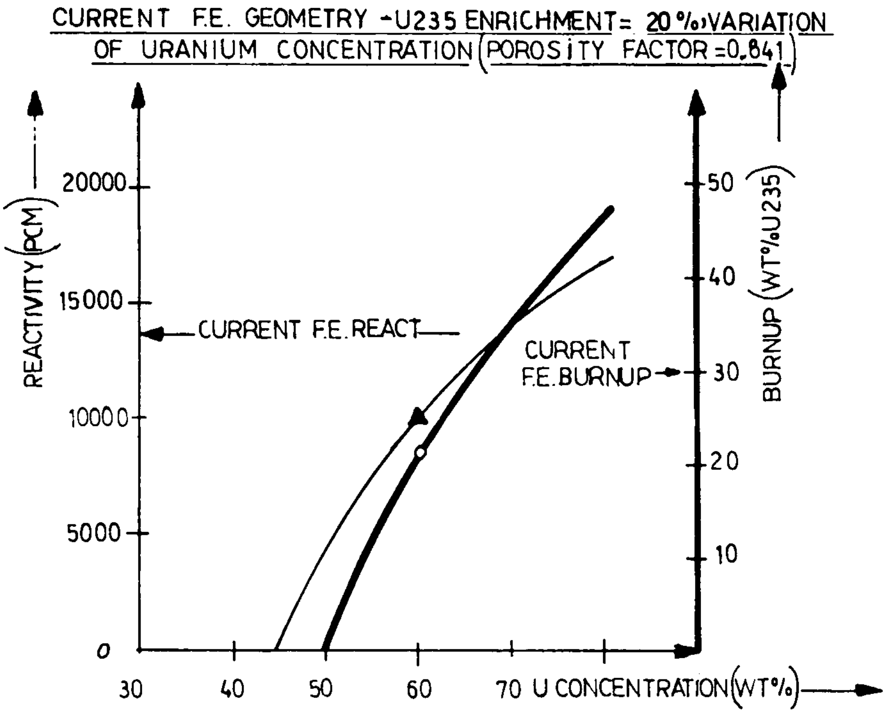


FIGURE 4

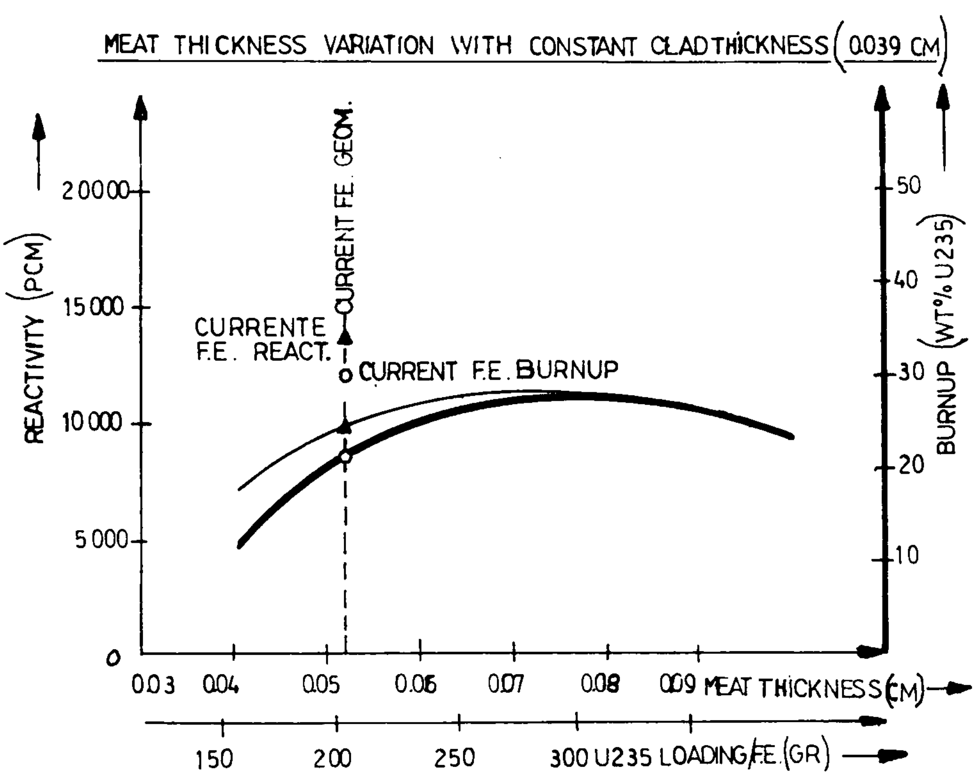


FIGURE 5

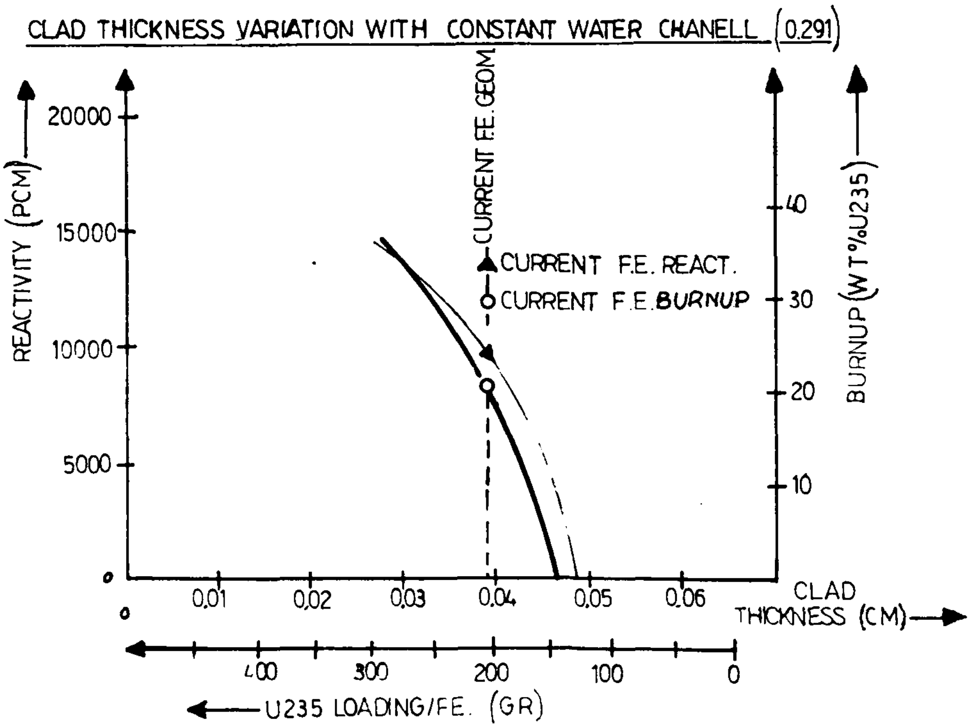


FIGURE 6

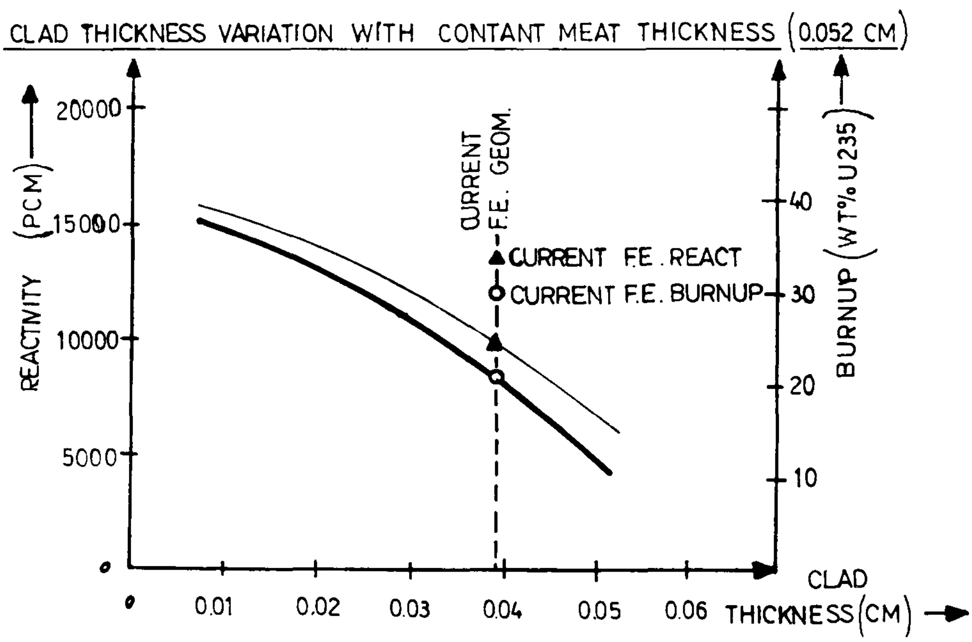


FIGURE 7

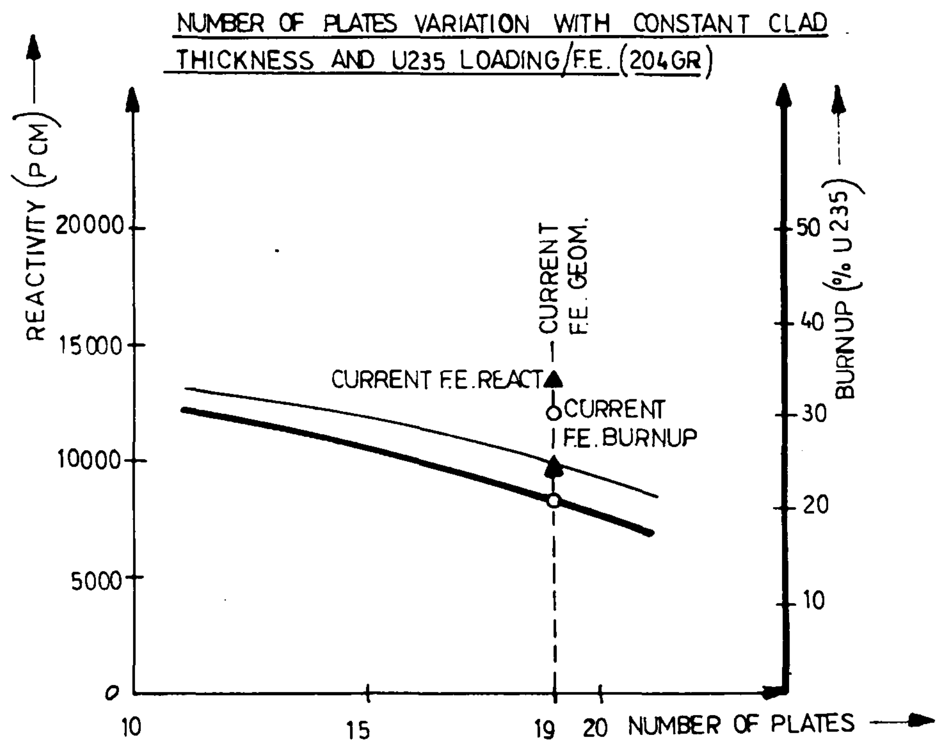


FIGURE 8

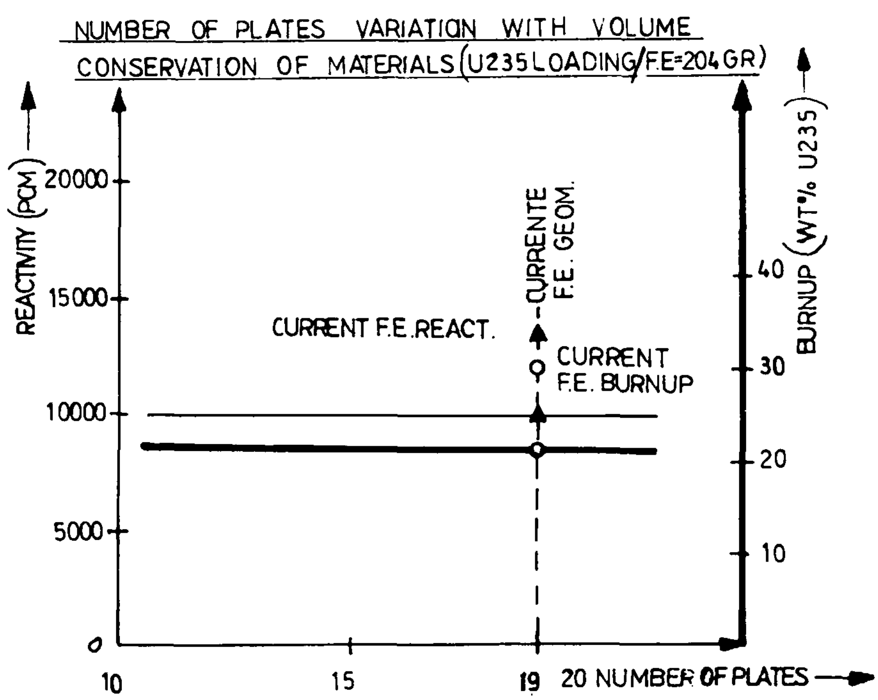


FIGURE 9