Nuclear Theory - Course 127

EXAMPLES OF PRACTICAL REACTOR BEHAVIOUR

The effects of poison buildup, temperature changes and fuel burnup have been considered, in previous lessons, as separate effects. However, since fission product poisons, temperature and burnup of fissile material change with changes in reactor power, considerations of practical reactor behaviour must involve all of these effects. The manner in which a reactor responds to power changes will also be determined by all these factors. The examples of reactor behaviour, given in this lesson, will illustrate how these factors affect the reactor behaviour.

Some examples of reactor behaviour, given in the Level 2 Nuclear Theory course will be reviewed in order to present a complete picture and maintain continuity.

Effect of Xenon Delay on the Approach to Full Power

On reactor startup, following a shutdown, the xenon load is zero or very small. If absorber rods are used as the only control elements, the calandria will always be full of moderator and the increase in reactivity will be compensated for by insertion of absorber rods. No restriction is thus placed on the maximum permissible power.

However, if moderator level is used as a control element, the critical moderator level is much lower than when equilibrium poison has been established. The resulting thermal neutron flux distribution and the fact that only a part of the normal reactor core is being used, limits the power to a value well below full power. The variation of permissible power with moderator level, in NPD, is shown in Fig. 1. This delay in reaching full power is known as XENON DELAY. It can only be avoided by introducing neutron absorbing material into the core in order to operate the reactor with a higher critical moderator level. Liquid poison, in the form of boric acid injected into the moderator, is proposed for Douglas Point.

If xenon delay does limit the operating power, as at NPD, the manner in which the reactor power is increased and the changes in moderator level that occur are shown in Fig. 2.

At A, reactor power is increased to a nominal 5% of full power to B, to warm up the heat transport system and to raise steam pressure. The reactor power remains constant from B to C until the turbine is up to speed and the generator synchronized to the system.

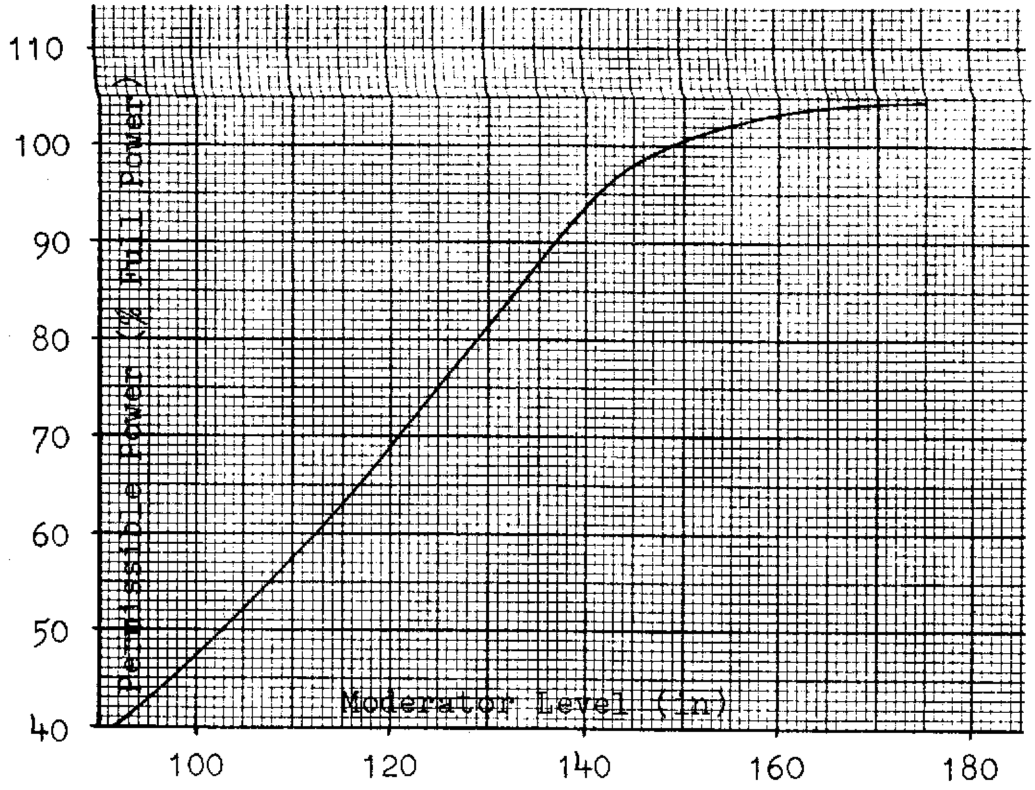

Permissible Power (% Full Power)
110
100
90
80
70
60
50
40
Moderator Level (in)
100
120
140
160
180

Fig. 1

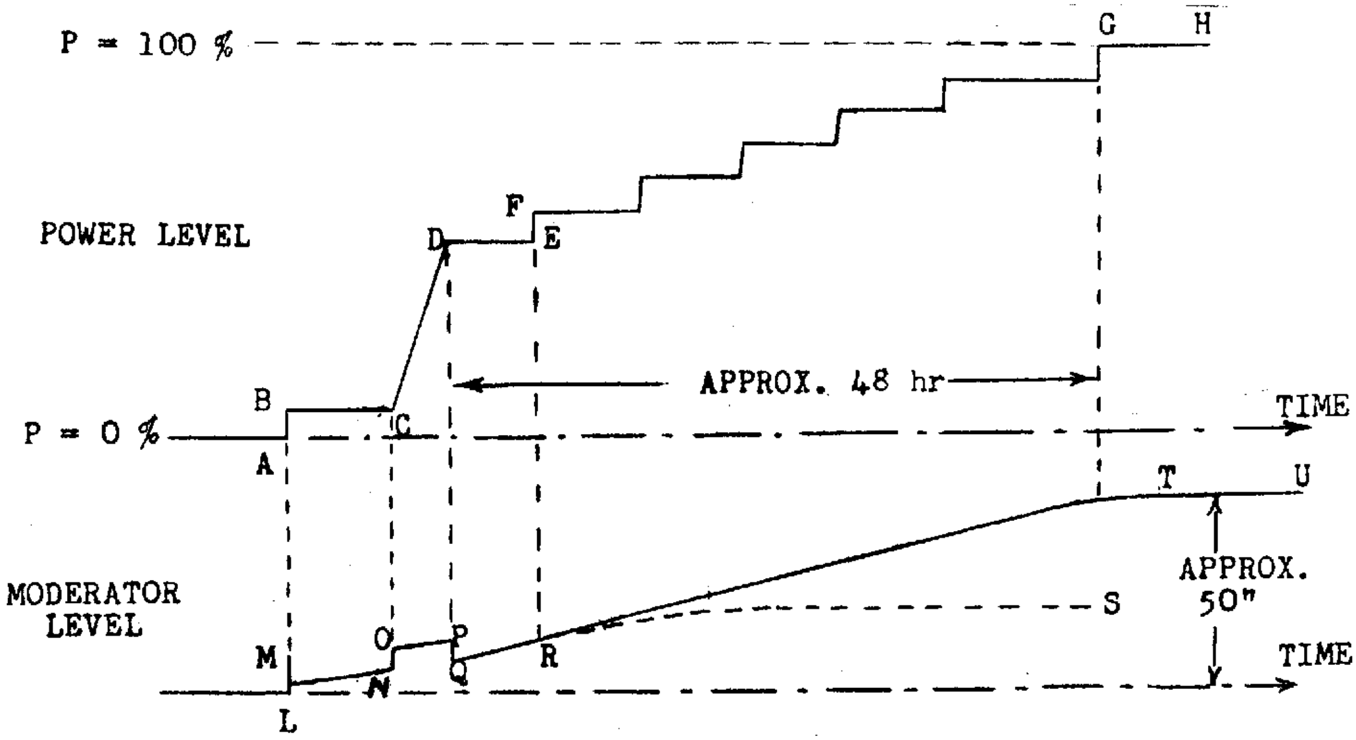

P = 100 %
G
H
POWER LEVEL
F
D
E
APPROX. 48 hr
B
C
P = 0 %
A
TIME
T
U
APPROX. 50"
MODERATOR LEVEL
S
O
P
M
R
Q
N
L
TIME

Fig. 2

At L the moderator level rises to M long enough for the power increase AB to take place. The level then drops back to maintain the reactor just critical. The new critical level is slightly above the initial critical level because of the power coefficient. It then rises to N due to the loss of reactivity associated with the heat transport system negative temperature coefficient.

The load is increased at C and the reactor power rises to about 50% of full power. The moderator level rises and remains above critical along OP during the power increase. When the power is levelled off at D the moderator level drops back to the critical level at Q. If the power remained at D the moderator would follow the curve QRS as the xenon built up to equilibrium.

In order to reach full power as quickly as possible, the power is raised in steps such as EF whenever the moderator level, and hence the permissible power, is high enough to allow it. This keeps the xenon buildup continuing until it reaches its equilibrium TU slightly after the power reaches 100% at GH. The fine structure on the moderator curve associated with each individual power step has been ignored for simplicity.

Moderator Level Response to Load Changes

Although moderator level response to load changes is considered here and, therefore, a moderator level control element is assumed, the response of absorber rods would follow similar patterns. Where the moderator level is shown to rise, absorber rods would move out of the reactor. A fall in moderator level corresponds to a movement of absorber rods into the reactor. Five types of load changes are considered:

(a) Minor Load Changes

A minor change in load may occur due to some change in setting in the regulating system which changes the steam pressure by a few psi.

Fig. 3 (a) shows reactor changes following such a minor load change and restoration of full load. Fig. 3 (b) shows the response of the moderator level when fuel burnup is ignored and Fig. 3 (c) shows the moderator level response when the effect of fuel burnup is not to be ignored.

The reactor power remains steady up to A, when a small decrease in power, AB, occurs due to a load change. Ignoring fuel burnup the level remains constant along EF when a temporary drop occurs to G to provide the necessary negative reactivity. When fuel burnup is taken into account the level rises from M to N and then drops to O. In both cases a rise will then occur due

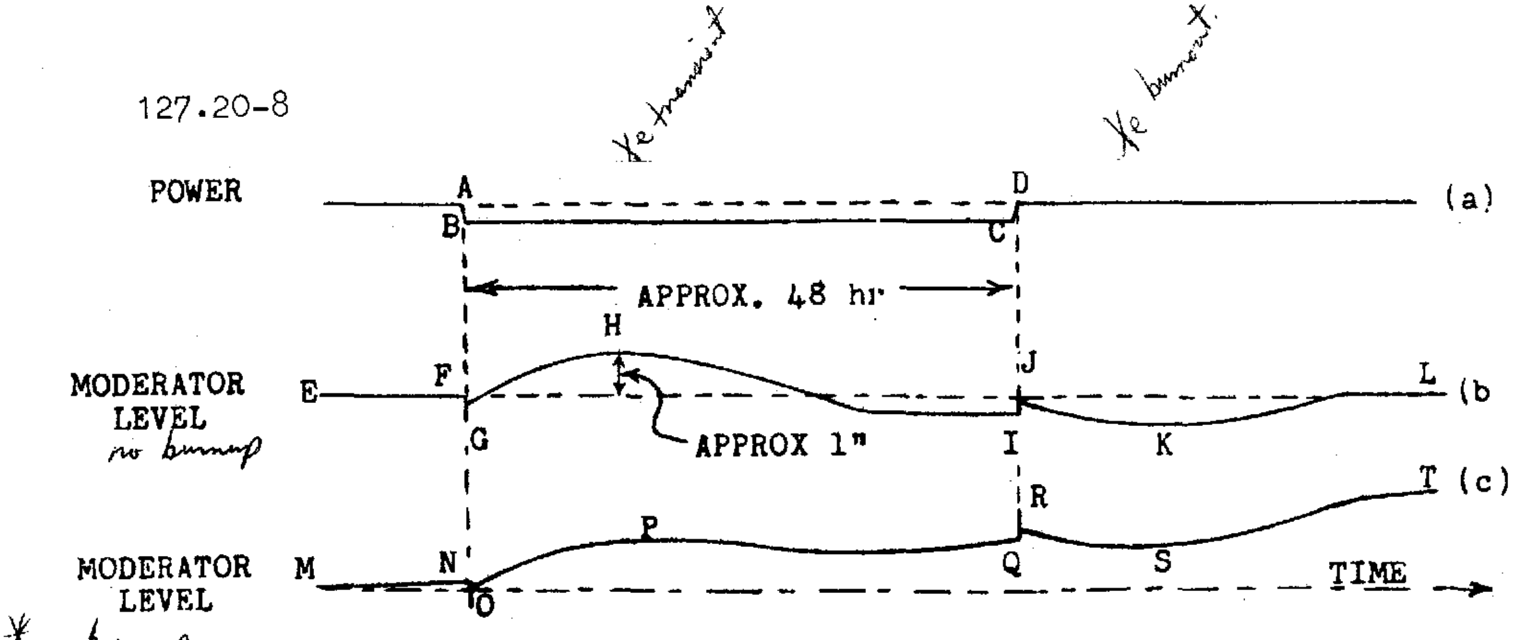


Fig. 3

* burnup allowed for.

to the xenon transient. The xenon will eventually come to an equilibrium which is lower than the original amount and the moderator level is steady at I. In curve (c) the fuel burnup effect may be large enough so that there is no decrease in level from P to Q.

When the power is restored from C to D there is a transient rise in moderator level to J (or R) to supply the necessary positive reactivity during the power change. The level then drops back to critical and a downward xenon transient starts. This transient is caused by an increase in xenon burnout which temporarily makes xenon destruction (burnout and decay) greater than xenon production. The production rate builds up however and the level eventually returns to L, the original critical level, if burnup is ignored. If fuel burnup is allowed for, the final moderator level will be at T (curve (c)).

(b) Larger Load Changes

weekly test? protective system equipment?

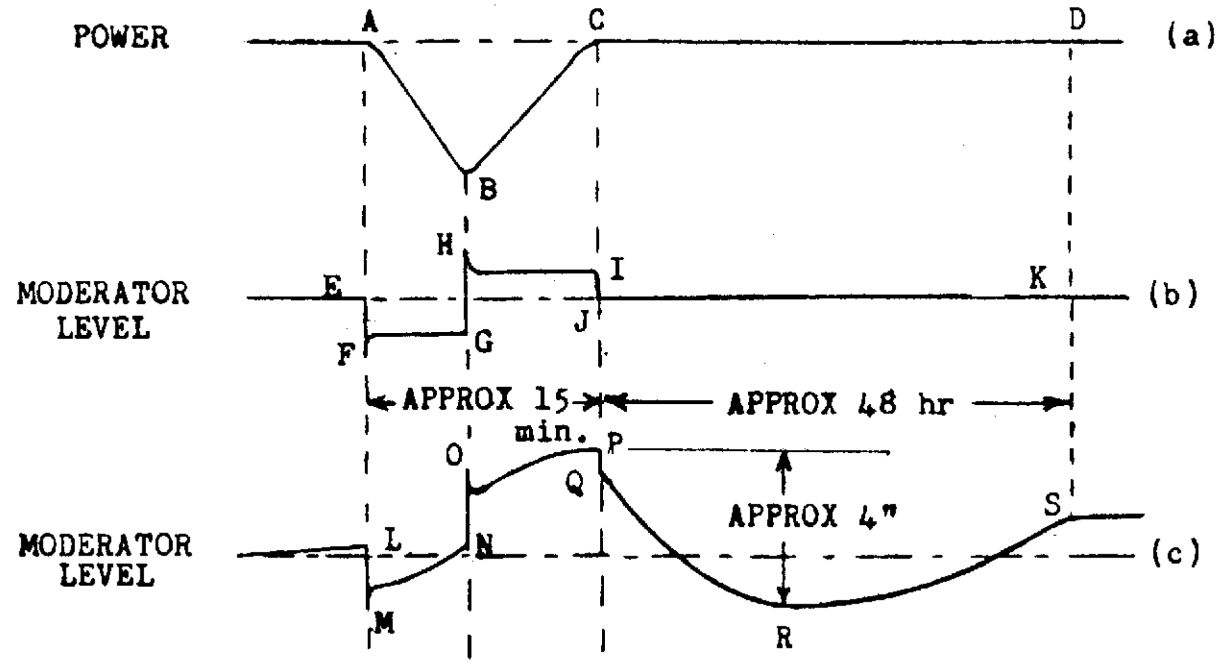
This is the load change that takes place when, for instance, a turbine emergency stop valve is tested by closing it. The reactor power change that occurs may be as much as 15% and the resulting xenon change is, therefore, much harsher than in case (a).

Fig. 4 shows how the moderator level would respond to such a reduction in power followed by a restoration of full power.

The load decrease starts at A and continues to B where one stop valve would be fully shut. The load then returns as the valve is opened from B to C. Fig. 4 (b) shows the moderator level if xenon and fuel burnup are ignored. The level decreases from E to F with some overshoot but remains subcritical until G. Positive reactivity is then required and the level rises to H (again with some overshoot) and remains high

Xe transient

Xe burnout



no burnup & poison

burnup & poison allowed for.

Fig. 4

enough to keep the reactor supercritical while the power is increasing. The level returns from I to J, the original critical level, when the power stops rising.

In Fig. 4 (c) the effects of fuel burnup and xenon have been included to show what actually happens. The shape of the curve from L to Q is modified from (b) mainly by xenon buildup which is most pronounced when the power is lowest (at B in (a)). The transient QRS is due to xenon burnout and is similar to the transient in Fig. 3. The final level S is higher than L due to fuel burnup.

(c) Substantial or Complete Load Rejection

This is the type of load rejection that occurs when a loss of line occurs and it is basically an exaggereated form of the load reduction in (b). A partial load rejection may occur very rpaidly or, in the extreme case, all the load except the station service may be rejected. The changes in moderator level, that would follow a sudden complete rejection of external load, are shown in Fig. 5. The load is rejected at A and the reactor power decreases to about 10% of full power at B. There is a sudden and substantial drop in moderator level, from D to E, to provide the necessary decrease in reactivity. If the load rejection continues, the moderator

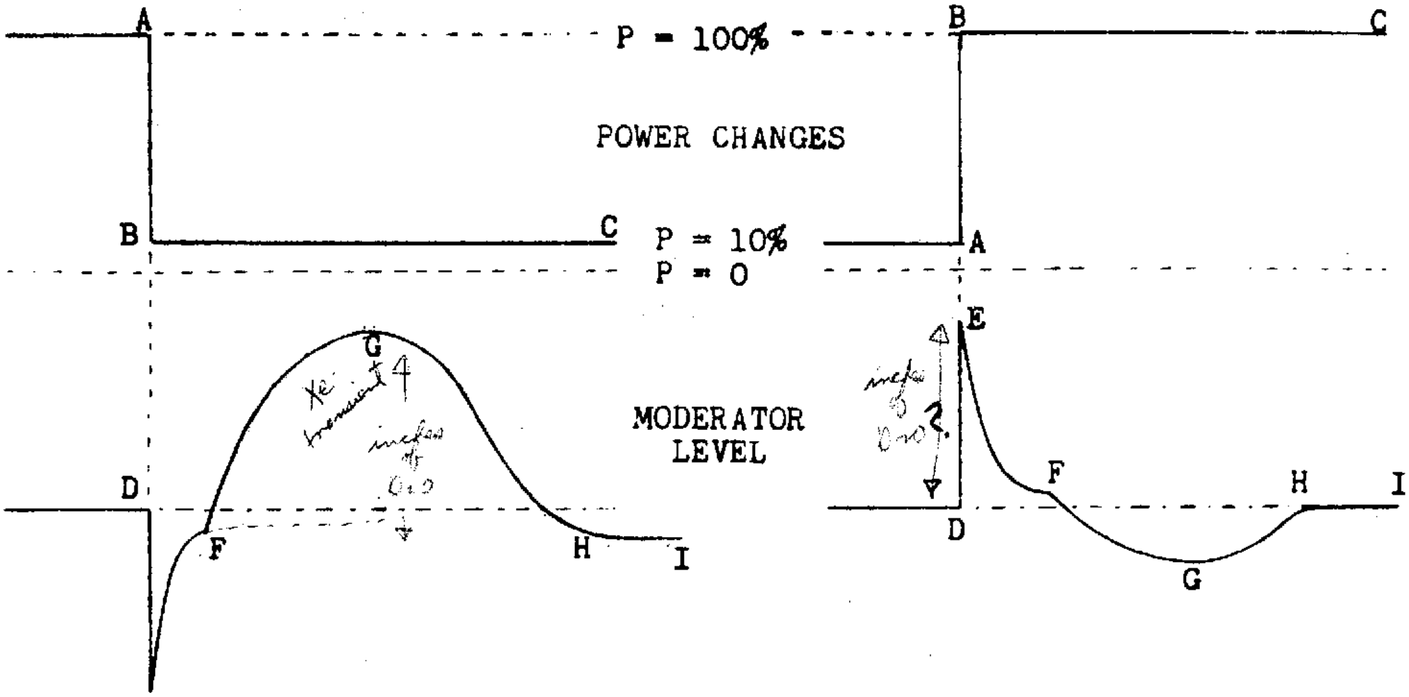


Fig. 5 (c)

Fig. 6 (d)

level would recover along EF, except for the xenon transient that occurs because of the reduction in power. Because of the xenon transient, the moderator level rises along FG and then decreases along GH, because of the subsequent xenon decay. The moderator level finally settles down at I, at a lower value than D, because of the smaller xenon load. The substantial increase in moderator level along FG will cause the reactor to poison out, unless load is restored quickly. ??

(d) Substantial Sudden Load Demand

In a base load generating station, already operating at or close to 100% power, sudden load demands do not normally occur. They only occur after a load rejection when the line is restored. Fig. 6 shows the moderator level changes that would occur following restoration of full load from, say 10% load. Again the reactor power changes rapidly from A to B and a sharp moderator rise from D to E occurs. The moderator level then recovers along EF. However, xenon is being burnt out faster than it is being produced, at the higher power, and so the moderator level continues to fall along FG. The rate of production of xenon eventually exceeds the rate at which it is removed and the moderator level rises along GH, and settles down at the previous level I.

(e) Load Rejection Quickly Followed by Load Restoration

As was suggested in (d), a load rejection due to loss of line may be followed quickly by a sudden load demand when the line is restored. Sudden changes are shown in Fig. 7.

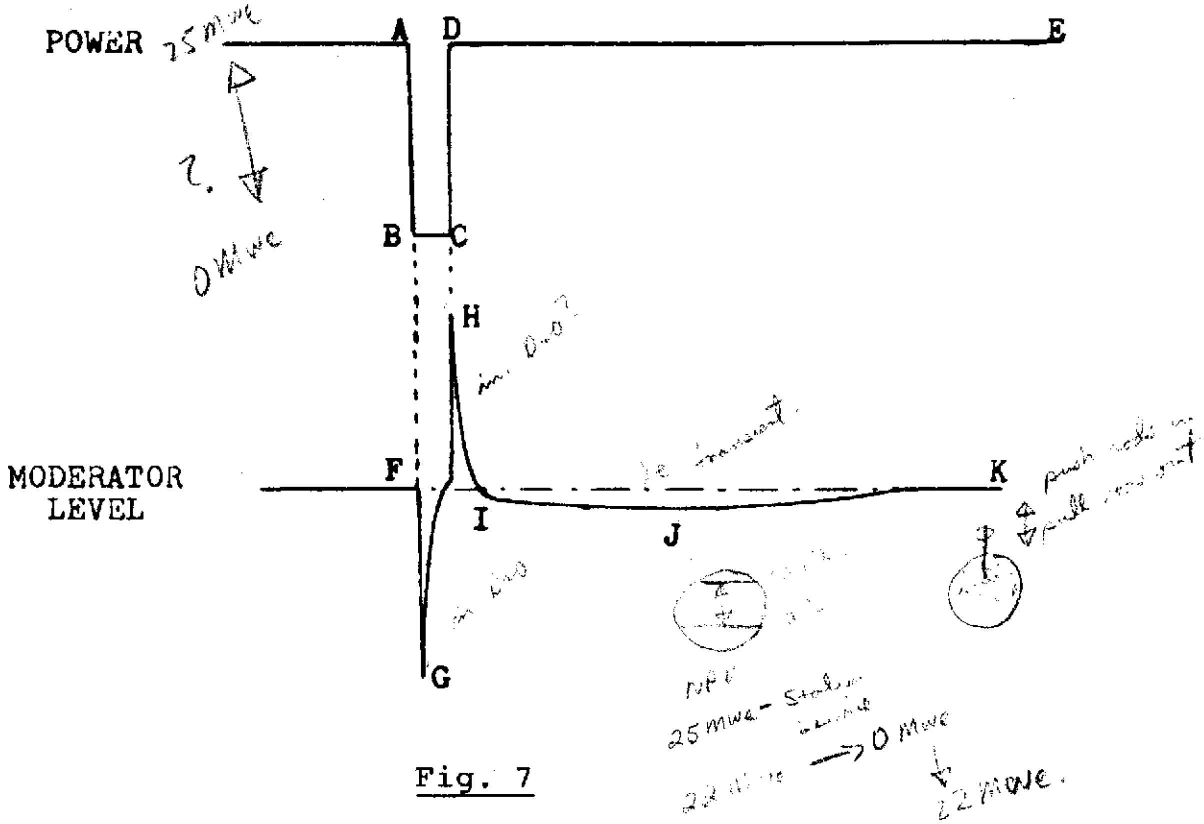


Fig. 7

A rapid decrease in power, from A to B, is caused by the load rejection and, as in (c), the moderator level drops from F to G. Very shortly after this the line is restored and the level rises above critical to H. When the power has been restored to 100% the moderator level returns to the critical value and goes through a xenon transient as in previous cases.

Note that the effects of fuel burnup have been ignored in (c) (d) and (e).

ASSIGNMENT

1. When reactor power is raised, the first increase in power is to nominal 5% of full power.

   (a) How long is reactor power kept at this value?

1. (b) What moderator level changes occur during this period and why?

2. Following this period at 5% full power, reactor power is further increased because of load demand.

   (a) What limit is there on this second increase in power?

   (b) Why should this limit on reactor power exist?

   (c) Why can this limit be exceeded later?

3. After the limit in 2 (a) can be exceeded, how is reactor full power achieved and what basic principle is involved in this method of achieving full power?

4. (a) How does the initial drop in moderator level, following a minor load reduction, differ from that following a major load decrease or rejection?

   (b) How does the subsequent rise in moderator level differ and how might this affect the reactor if the load is not restored quickly?

   (c) Why, in the case of load reduction, is the final moderator level lower than the initial level before the reduction?

5. (a) When is a sudden substantial load increase or demand most likely to occur?

   (b) In general, how does such a load increase modify the moderator level response in 4 (b), when it occurs as in 5 (a)?

   (c) How does the rate at which such a load increases affect moderator level response?

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