Nuclear Theory - Course 227

CHANGE OF REACTOR POWER WITH REACTIVITY CHANGE

In this lesson, we will consider how neutron density, neutron flux and reactor power change when the multiplication factor, k, or the reactivity, δk, change. For the moment, we will ignore the effects of the accumulation of fission products in the fuel and the effects of using up the U-235 in the fuel. We are only concerned with how the reactor power changes immediately following a change in reactivity. This will enable us to decide, later, how changes in power can be achieved safely, ie, it will help us to determine how reactor power can be regulated.

Effect of Reactivity on Neutron Multiplication

In the previous lesson, we saw how neutrons multiplied at a fantastic rate when the multiplication factor was equal to 2 or the reactivity was 1000 milli-k. This is, of course, an extreme case for two reasons: -

(1) A multiplication factor of 2 would be impossible to achieve in practice because neutron losses could not be cut down to this extent.

(2) Even if such a value of k was possible, the neutrons multiply so fast that the power would increase 1000 times in one-hundredth of a second. This type of power increase would be impossible to control and is, in fact, an explosive rate of increase.

Let us now look at more practical values of k and compare the neutron multiplications for various values of k.

Fig. 1 shows how the neutrons multiply for values of k from 1.0005 to 1.003 or for reactivity values from 0.5 milli-k to 3 milli-k.

When δk = 0.5 mk, the neutron population or neutron density is doubled in 1400 neutron generations.

When δk = 1 mk, the neutron population or density is doubled in 700 neutron generations, trebled in 1100 generations and is increased by a factor of 4 in 1400 generations.

When δk = 2 mk, the neutron density is doubled in 350 generations and has to increase 15 times its original value in 1350 generations.

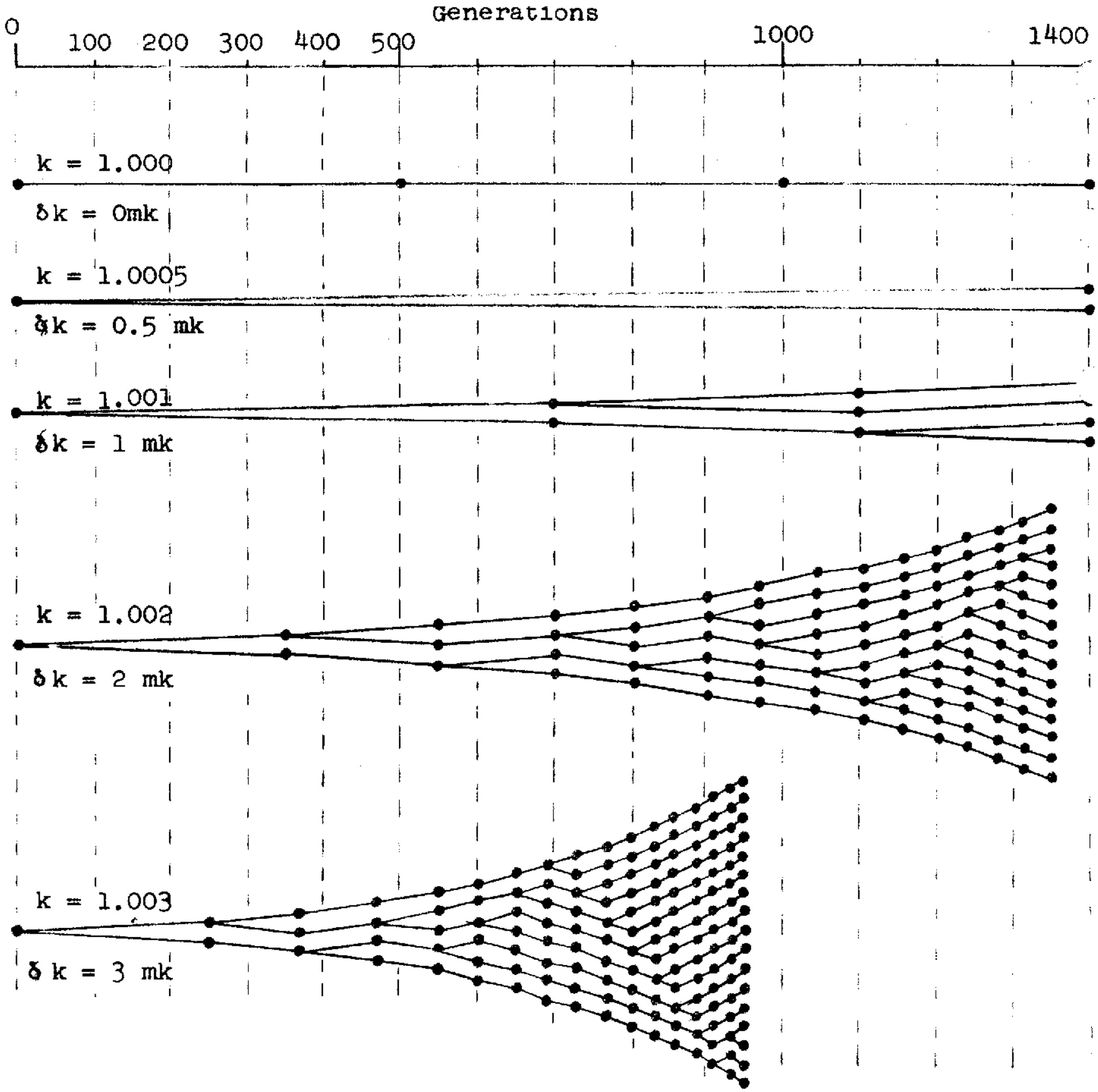

Fig. 1

Finally, when $\delta k = 3$ mk, the neutron density is doubled in only 250 generations and, in 950 generations, the neutron density would be 17 times its original value.

So, as k, and the reactivity increase in value, the number of neutrons grows progressively faster and faster. Also for any one value of the reactivity, the number of neutrons produced in successive equal numbers of generations, gradually increases.

eg, when $\delta k = 3$ mk.

New additional neutrons produced in first 250 generations is 1.12
New additional neutrons produced in second 250 generations is 2.36
New additional neutrons produced in third 250 generations is 5.02
New additional neutrons produced in fourth 250 generations is 10.5

In comparison, when $\delta k = 2$ mk,

New additional neutrons produced in first 250 generations is 0.65
New additional neutrons produced in second 250 generations is 1.07
New additional neutrons produced in third 250 generations is 1.76
New additional neutrons produced in fourth 250 generations is 2.9

Figure 2 shows, graphically, how the neutron density increases for various values of reactivities.

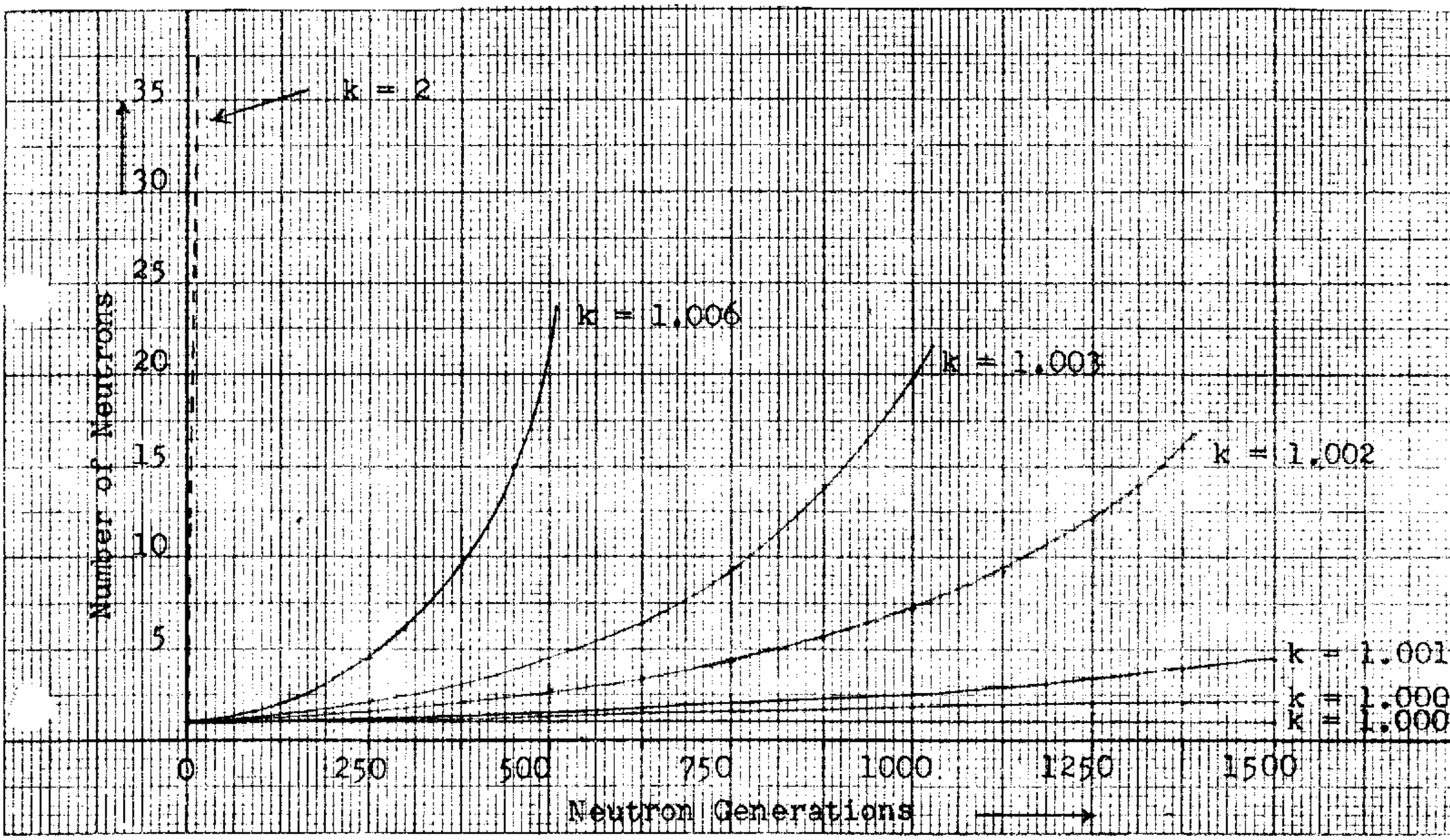

Fig. 2

The shape of each curve is the same as the shape of the envelope of the corresponding neutron diagram in Fig. 1 Such curves are known as EXPONENTIAL curves. Thus we can say that the neutrons population in a reactor increases exponentially.

If we had started with a neutron density n_o, in a reactor, instead of just one neutron, then the same would apply to every neutron we had initially. Therefore, the neutron density also increases exponentially.

Thus if the neutron density is n, then after N neutron generations: -

$$n = n_o e^{aN}$$

where "e" is the "exponential e" (e = 2.718) and a is some factor depending on the reactivity or the value of k. In fact, $a = \delta k$.

That is,

$$n = n_o e^{N.\delta k}$$

If $\delta k = 0.5$ mk = 0.0005 and N = 1400 $\quad n = n_o e^{0.7} = 2.01\, n_o$

If $\delta k = 3$ mk = 0.003 and N = 240 $\quad n = n_o e^{0.72} = 2.05\, n_o$

As can be seen, these are more accurate figures than those used in Fig. 1.

Effect of Reactivity on Neutron Flux and Reactor Power

We have seen that both the neutron flux and the power level, in a reactor, are proportional to the neutron density. Therefore, reactor power and the neutron flux follow the same exponential law as neutron density. So we can write: -

$$P = P_o\, e^{N.\delta k} \quad \text{for the power}$$

and

$$\phi = \phi_o\, e^{N.\delta k} \quad \text{for the flux}$$

On plotting either power or flux against the number of neutron generations, N, we get the same shape curves as in Fig. 2.

In words, what happens is that, if δk is positive, more fissions take place than is just required to maintain the chain reaction. The neutron density, therefore, increases and still more neutrons become available to cause further fissions. Thus, the neutron density increases, the rate of fissioning therefore increases and consequently, the power increases. All these increases are exponential.

Effect of Negative Reactivity Changes

Suppose that a reactor was operating at steady power so that it was just critical (ie, $k = 1$, $\delta k = 0$). Now suppose that k was suddenly reduced below 1, say to $k = 0.999$. The reactivity, δk, is now -0.001, or -1 mk. What happens?

Obviously, the chain reaction can no longer be sustained so that the neutron density starts to decrease. We no longer have one neutron from each fission causing a further fission. So the reactor power decreases and the flux increases.

The neutron population decreases and we go from **right** left, in Fig. 1, instead of from left to right. The neutron density, neutron flux and reactor power again change exponentially except that δk is now negative.

ie, $n = n_o e^{N.\delta k}$ $\quad \phi = \phi_o e^{N.\delta k}$ $\quad$ and $P = P_o e^{N.\delta k}$

eg, if $\delta k = -1 \text{ mk} = -0.001$ and $N = 1000$ $\quad P = P_o e^{-1} = 0.037\, P_o$

So the power decreases to 37% of P_o in 1000 neutron generations if $\delta k = -5 \text{ mk} = 0.005$ and $N = 1000$ $P = P_o e^{-5} = 0.007\, P_o$ or 0.7% P_o

The more negative reactivity is introduced (ie, the lower **k** is made) the faster the power decreases.

ASSIGNMENT

1. How is reactor power affected by: -

   (a) increasing the positive reactivity in a reactor?

   (b) increasing the negative reactivity in a reactor?

2. (a) The reactivity is +3 mk. The number of neutrons produced in the first 250 neutron generations is 2.12, the number produced in the second 250 generations is 4.48, in the third 250 generations, 9.5 and in the fourth 250 generations, 20. What do these figures illustrate?

2. (b) If the reactivity is reduced to zero at the end of these 1000 neutron generations, what would be the number of neutrons produced during the next 250 generations?

   (c) If the multiplication factor, k, is made equal to 0.997, at the end of these 1250 generations, what would be the number of neutrons at the end of the next 500 generations?

3. Write down the exponential equations connecting the neutron density, neutron flux and neutron power with reactivity.

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