
NEUTRON POISONS

In some reactors, neutron-absorbing materials called poisons are intentionally designed into the reactor for specific purposes. Some of these poisons deplete as they absorb neutrons during reactor operation, and others remain relatively constant.

EO 3.1 **DEFINE** the following terms:

- a. **Burnable poison**
- b. **Non-burnable poison**
- c. **Chemical shim**

EO 3.2 **EXPLAIN** the use of burnable neutron poisons in a reactor core.

EO 3.3 **LIST** the advantages and disadvantages of chemical shim over fixed burnable poisons.

EO 3.4 **STATE** two reasons why fixed non-burnable neutron poisons are used in reactor cores.

EO 3.5 **STATE** an example of a material used as a fixed non-burnable neutron poison.

Fixed Burnable Poisons

During operation of a reactor the amount of fuel contained in the core constantly decreases. If the reactor is to operate for a long period of time, fuel in excess of that needed for exact criticality must be added when the reactor is built. The positive reactivity due to the excess fuel must be balanced with negative reactivity from neutron-absorbing material. Moveable control rods containing neutron-absorbing material are one method used to offset the excess fuel. Control rods will be discussed in detail in a later chapter. Using control rods alone to balance the excess reactivity may be undesirable or impractical for several reasons. One reason for a particular core design may be that there is physically insufficient room for the control rods and their large mechanisms.

To control large amounts of excess fuel without adding additional control rods, burnable poisons are loaded into the core. *Burnable poisons* are materials that have a high neutron absorption cross section that are converted into materials of relatively low absorption cross section as the result of neutron absorption. Due to the burnup of the poison material, the negative reactivity of the burnable poison decreases over core life. Ideally, these poisons should decrease their negative reactivity at the same rate the fuel's excess positive reactivity is depleted. Fixed burnable poisons are generally used in the form of compounds of boron or gadolinium that are shaped into separate lattice pins or plates, or introduced as additives to the fuel. Since they can usually be distributed more uniformly than control rods, these poisons are less disruptive to the core power distribution.

Soluble Poisons

Soluble poisons, also called *chemical shim*, produce a spatially uniform neutron absorption when dissolved in the water coolant. The most common soluble poison in commercial pressurized water reactors (PWR) is boric acid, which is often referred to as "soluble boron," or simply "solbor." The boric acid in the coolant decreases the thermal utilization factor, causing a decrease in reactivity. By varying the concentration of boric acid in the coolant (a process referred to as boration and dilution), the reactivity of the core can be easily varied. If the boron concentration is increased, the coolant/moderator absorbs more neutrons, adding negative reactivity. If the boron concentration is reduced (dilution), positive reactivity is added. The changing of boron concentration in a PWR is a slow process and is used primarily to compensate for fuel burnout or poison buildup. The variation in boron concentration allows control rod use to be minimized, which results in a flatter flux profile over the core than can be produced by rod insertion. The flatter flux profile is due to the fact that there are no regions of depressed flux like those that would be produced in the vicinity of inserted control rods.

DOE reactors typically do not use soluble neutron poisons during normal operation. Some DOE reactors do, however, include emergency shutdown systems that inject solutions containing neutron poisons into the system that circulates reactor coolant. Various solutions, including sodium polyborate and gadolinium nitrate, are used.

Fixed burnable poisons possess some advantages over chemical shim. Fixed burnable poisons may be discretely loaded in specific locations in order to shape or control flux profiles in the core. Also, fixed burnable poisons do not make the moderator temperature reactivity coefficient less negative as chemical shim does. With chemical shim, as temperature rises and the moderator expands, some moderator is pushed out of the active core area. Boron is also moved out, and this has a positive effect on reactivity. This property of chemical shim limits the allowable boron concentration because any greater concentration makes the moderator temperature coefficient of reactivity positive.

Non-Burnable Poisons

A *non-burnable poison* is one that maintains a constant negative reactivity worth over the life of the core. While no neutron poison is strictly non-burnable, certain materials can be treated as non-burnable poisons under certain conditions. One example is hafnium. The removal (by absorption of neutrons) of one isotope of hafnium leads to the production of another neutron absorber, and continues through a chain of five absorbers. This absorption chain results in a long-lived burnable poison which approximates non-burnable characteristics. Absorbers with low neutron absorption cross sections can also be treated as non-burnable under most conditions.

It is possible to make the reactivity of a poison material that is usually a burnable poison more uniform over core life through the use of self-shielding. In self-shielding, the poison material is thick enough that only the outer layer of the poison is exposed to the neutron flux. The absorptions that take place in the outer layers reduce the number of neutrons that penetrate to the inner material. As the outer layers of poison absorb neutrons and are converted to non-poison materials, the inner layers begin absorbing more neutrons, and the negative reactivity of the poison is fairly uniform.

The normal use of fixed non-burnable poisons is in power shaping, or to prevent excessive flux and power peaking near moderator regions of the reactor.

Summary

The important information in this chapter is summarized below.

Neutron Poisons Summary

- A burnable neutron poison is a material that has a high neutron absorption cross section that is converted into a material of relatively low absorption cross section as the result of neutron absorption.
- A non-burnable neutron poison is a material that has relatively constant neutron absorption characteristics over core life. The absorption of a neutron by one isotope in the material produces another isotope that also has a high absorption cross section.
- Chemical shim is a soluble neutron poison that is circulated in the coolant during normal operation.
- Burnable neutron poisons are used in reactor cores to compensate for the excess positive reactivity of the fuel when the reactor is initially started up.
- Chemical shim has several advantages over fixed burnable poisons.
 - Has a spatially uniform effect
 - Possible to increase or decrease amount of poison in the core during reactor operation
- Fixed burnable poisons have several advantages over chemical shim.
 - Can be used to shape flux profiles
 - Do not have an adverse effect on moderator temperature coefficient
- Two reasons for using non-burnable neutron poisons in reactor cores are to shape power and to prevent excessive flux and power peaking near moderator regions.
- An example of a material that is used as a fixed non-burnable neutron poison is hafnium.