CONTROLS

Various ways of controlling the chain reaction are illustrated in the following figures. Fig. 50 and 50a show a cylindrical graphite structure (1) of about equal diameter and height. The core (2) of this pile, as defined by the dotted line, may weigh about 500 tons and contains the uranium lattice. The graphite layer (3) outside this core serves the purpose of reflecting neutrons and absorbing the radiations which are generated in the chain reaction. Iron or other radiation absorbing elements can be contained in the center part of this peripheral graphite layer which is outside the uranium lattice core (2). A number of thin walled steel tubes, 4, 5, 6, of about 1 cm. diameter and .2 mm. go through the core of the graphite pile and rods 7, 8, 9 built of slow neutron absorbing material, for instance steel or cobalt or an iron-cobalt alloy of high cobalt content, or nickel or a nickel cobalt alloy can be moved up and down within these steel tubes. The thin walled steel tubes are satisfactory from the point of view of having a low absorbtion, provided that the diameter of the tube is small compared to mean free path of the thermal in graphite since this is about 2.5 cm tubes of 1 cm diameter fulfill this condition. These neutron absorbing rods may be hollow tubes and may be cooled by having a flow of a cooling gas, for instance air, maintained through the tubes 4, 5 and 6 as indicated by the arrows in the figure. All these rods may be rigidly held together and moved jointly up or down, the movement being controlled by the radiation emanating from the chain reaction, by means of an ionization chamber. If the radiation increases the current through the ionization increases and by means of a suitable amplifier and relay a motor may be set into motion which moves the control rods inward in the chain reacting pile. If the radiation decreases

~~decreases~~ the current in the ionization chamber decreases and by means of a suitable gadget the motor may be reversed and the rods may be moved in the upward direction out of the interior of the pile. If the system is damped it is adapted to stabilize the chain reaction if above a certain radiation intensity the motor is set into motion moving the rods in the downward direction and below a certain radiation intensity the motor is set into motion pulling the control rod upward out of the interior of the pile.

In a water cooled power unit aluminum tubes can be used in place of the steel tubes running through the pile.

Fig. 41 shows another way of controlling the pile. In Fig. 41 (1) is a thin-walled steel tube of about 1 cm. diameter and .2 mm. wall. It goes vertically through the pile and forms together with a tank (4) which is outside the chain reacting unit, a communicating system. This system contains a bismuth, lead, cadmium alloy which is a liquid ~~at~~ down to low temperatures and an electrodynamic pump (3) is so ~~arranged~~ connected as to pump this absorbing liquid out of the pile and into the tank (4) if a sufficient electric potential is applied to the stator of the pump. If the pump is switched off the ~~bismuth~~ cadmium alloy flows from the tank into the pile and stops the chain reaction. An ionization chamber which is exposed to the radiation of the pile controls the potential on the stator of the pump in the following manner: if the current through the ionization chamber is low the potential applied to the pump is high and accordingly the equilibrium position of the ~~bismuth~~ liquid cadmium alloy column in the pile towards which the ~~bismuth~~ liquid alloy meniscus moves is comparatively low. Accordingly the ~~bismuth~~ cadmium alloy moves in toward the tank 4 and thereby increases the intensity of the chain reaction and increases the current through the controlling ionization chamber. Accordingly, the potential applied to the electromagnetic pump is decreased and the equilibrium position of the meniscus in the steel tube (1) is raised, so that the Bi alloy may now be pumped out at the tank 4. In this manner the chain reaction can be controlled.in a satisfactory manner if the controlling system ~~has enough dampening~~. If this type of control is used we may have several independent controlling units as indicated in the view shown in Fig. 41b.

The steel tube (1) is cooled by a cooling agent, for instance liquid bismuth, which flows in an anular gap between steel tube (1) and the surface of a circular bore in the graphite column which contains the steel tube (1). The electrodynamic pump (3) is cooled by a flow of ~~bismuth~~ through a cooler (5)which is connected to the entrance and exit tubes to the electrodynamic pump (3). A valve (6) controls the flow through the cooler (5) in such a manner that this flow should be small compared to the pumping capacity of the pump (3).

In case of a water cooled power unit we may use mercury in place of the bismuth-lead-cadmium alloy. The steel tubes which run through the pile may be water cooled and protected from the chemical action ~~by~~ water by an aluminum tube. This is indicated in Fig. 60. In Fig. 60 (1) is mercury inside a steel tube (2). (3) is an aluminum tube in thermal contact with the steel tube (2). (4) is another aluminum tube. (5) is water flowing through the anular gap between the steel tube (2) and the aluminum tube (4).

Another way in which the chain reaction may be controlled is shown in Fig. 142. In this figure (1) is a uranium sphere, (2) is a rod composed of a thermal neutron absorber moving in a vertical tube. Section (2) of the control rod (5), which is composed of an element that strongly absorbs thermal neutrons, is near the center sphere and is shielded by the uranium from thermal neutrons so that it is in a position where the thermal neutron density is comparatively low. This absorbing section of the control rod can move within a tube in the vertical direction and its position may be controlled by the intensity of the neutron radiation emitted by the chain reaction. If the intensity of this radiation increases the absorbing section of the rod may be automatically moved away from the center of the uranium sphere and ultimately, if required, may be moved entirely out of the uranium sphere. It will then absorb larger and larger numbers of thermal neutrons thereby reducing the fraction of the neutrons which are absorbed in the thermal region by uranium, thus stabilizing the chain reaction.

Apart from the control rods or liquid containing control tubes we may have safety devices of a similar nature as the control devices which however operate only in case of an emergency and have the purpose of stopping the chain reaction if the radiation emitted in the chain reaction becomes too intense. Since these devices stop the reaction in a very short time it is not necessary to have them cooled. We may have, for instance, a number of rods similar to those shown in Fig. 50 which are entirely moved out of the pile and are suspended by an electromagnet. If the radiation becomes too intense the magnet is switched off and the rods fall under the action of gravity into the pile.

Replacement in Section V under: Cooling; lattice elements

Fig. 3 shows an example for the lattice element. In Fig. 3 (1) is a cylindrical uranium rod covered by a thin steel tube (2). An anular gap (4) is left free for the flow of the cooling agent inside the steel tube (3) which is embedded in a mass of graphite (5). Liquid bismuth or a liquid bismuth lead alloy may be used as a cooling agent in this arrangement.

Fig. 4 shows another example for the lattice element. In Fig. 4 (1) is a cylindrical uranium tube; (2) is a thin walled tube inside of the said uranium tube. Liquid bismuth or a bismuth lead alloy flows through the tube (2); (4) is a thin protecting coating covering the uranium tube (1); (5) is a mass of graphite into which the uranium tube is embedded. There is a small gap between the uranium tube (1) and the mass of graphite (5).

Fig. 5 shows another example for the lattice element. In Fig. 5, (1) is a cylindrical uranium rod; (2) is a thin walled steel tube; a cooling agent is flowing through the steel tube (2) in the axis of the uranium rod (1). (4) is a tube on the outside of the uranium rod (1); (5) is a gap between the uranium rod and a tube (6); (7) is the slowing agent.

This arrangement can be used if a bismuth-lead eutectic alloy is used as a cooling agent and heavy water is used as a slowing agent. Tube (6) can be of aluminum and the gap (5) may be filled with helium which in this particular case serves as a heat insulator.

Fig. 80 shows another example for the lattice element. In Fig. 80 (1) is a uranium rod surrounded by a thick-walled beryllium tube (2). The uranium rod is covered by a thin-steel tube (3). Liquid bismuth lead alloy flows through the gap (4) between the uranium rod (1) and the beryllium tube (2). The beryllium tube may be surrounded by a thin aluminum tube (5) leaving a gap (6) for purposes of heat insulation. (7) is a slowing down agent into which this lattice element is embedded.

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VI

CONTROLS

Various ways of controlling the chain reaction are illustrated in the following figures. Figures 50 and 50b show a cylindrical graphite structure (1) of about equal diameter and height. The core (2) of this pile, as defined by the dotted line, may weigh about 500 tons and contains the uranium lattice. The graphite layer (10) (between two dotted lines) serves as a reflector for the neutrons and a layer (11) on the periphery of the structure which is built of alternate layers of graphite and iron serves as a radiation shield. A number of thin-walled steel tubes, 4, 5, 6, of about 1 cm diameter and .2 mm wall thickness go through the core of the graphite pile and rods, 7, 8, 9, built of slow neutron absorbing material, for instance steel or cobalt or an iron-cobalt alloy of high cobalt content, or nickel or a nickel-cobalt alloy can be moved up and down within these steel tubes. The thin-walled steel tubes are satisfactory from the point of view of having a low absorption, provided that the diameter of the tube is small compared to the mean free path of the thermal neutrons in graphite. Since this is about 2.5 cm, tubes of 1 cm diameter fulfill this condition. These neutron absorbing rods may be hollow tubes, and may be cooled by having a flow of a suitable cooling gas, maintained through the tubes 4, 5 and 6, as indicated by the arrows in the figure. All these rods may be rigidly held together and moved jointly up and down, the movement be controlled by the radiation emanating from the chain reaction, by means of an ionization chamber. If the radiation increases the current through the ionization increases and by means of a suitable amplifier and relay a motor may be set into motion which moves the control rods inward in the chain reacting pile. If the radiation decreases the current in the ionization chamber decreases and by means of a suitable gadget the motor may be reversed and the rods may be moved in the upward direction out of the interior of the pile. If the system is damped it is adapted to stabilize the chain reaction if above a certain radiation intensity the motor is set into motion moving the rods in the downward direction and below a certain radiation intensity the motor is set into motion pulling the control rod upward out of the interior of the pile.

Figure 41 shows another way of controlling the pile. In Figure 41 (1) is a thin-walled steel tube of about 1 cm diameter and .2 mm wall. It goes vertically through the pile and forms together with a tank (4) which is outside the chain reacting unit, a communicating system. This system contains a bismuth-lead-cadmium alloy which is a liquid down to low temperatures and an electrodynamic pump (3) is so connected as to pump this absorbing liquid out of the pile and into the tank (4) if a sufficient electric potential is applied to the stator of the pump. If the pump is switched off the cadmium alloy flows from the tank into the pile and stops the chain reaction. An ionization chamber which is exposed to the radiation of the pile controls the potential on the stator of the pump in the following manner: if the current through the ionization chamber is low the potential applied to the pump is high and accordingly the equilibrium position of the liquid cadmium alloy column in the pile towards which the liquid alloy meniscus moves is comparatively low. Accordingly, the cadmium alloy moves in the system towards the tank (4) and thereby increases the intensity of the chain reaction and increases the current through the controlling ionization chamber. Thereby, the potential applied to the electromagnetic pump is decreased and the equilibrium position of the meniscus in the steel tube (1) is raised, so that the cadmium alloy may now be pumped out of the tank 4. In this manner the chain reaction can be controlled in a satisfactory manner if the controlling system is sufficiently strongly damped. If this type of control is used we may have several <u>independent</u> controlling units as indicated in the view shown in Figure 41b.

The steel tube (1) is cooled by a cooling agent, for instance liquid bismuth or a liquid bismuth-lead alloy which flows in an annular gap between steel tube (1) and the surface of a circular bore in the graphite column which contains the steel tube (1). The electrodynamic pump (3) is cooled by a flow of the cadmium alloy through a cooler (5) which is connected to the entrance and exit tubes to the electrodynamic pump (3). A valve (6) controls the flow through the cooler (5) in such a manner that this flow should be small compared to the pumping capacity of the pump (3).

In place of a cadmium, alloy, mercury can be used inside a thin-walled steel tube of about 1 cm diameter provided that the temperature at which the power unit operates is sufficiently low, otherwise the mercury pressure would disrupt the thin-walled steel tubes. Two concentric steel tubes may be used leaving an annular gap in which a liquid Bi-Pb alloy (eutectic) flows for the purpose of cooling the mercury inside the inner steel tube. If it is desired to use water in place of the liquid Bi-Pb alloy as a cooling agent, both steel tubes ought to be preferably stainless steel tubes in order to avoid corrosion by the water.

Another way in which the chain reaction may be controlled is shown in Figure 142. In this figure (1) is a uranium sphere, (2) is a rod composed of a thermal neutron absorber moving in a vertical tube (3). Section (2) of the control rod (5), which is composed of an element that strongly absorbs thermal neutrons, is near the center sphere and is shielded by the uranium from thermal neutrons so that it is in a position where the thermal neutron density is comparatively low. This absorbing section of the control rod can move within a tube in the vertical direction and its position may be controlled by the intensity of the neutron radiation emitted by the chain reaction. If the intensity of this radiation increases the absorbing section of the rod may be automatically moved away from the center of the uranium sphere and ultimately, if required, may be moved entirely out of the uranium sphere. It will then absorb larger and larger numbers of thermal neutrons thereby reducing the fraction of the neutrons which are absorbed in the thermal region by uranium, thus stabilizing the chain reaction. In Fig. 142 (6) is liquid bismuth or bismuth alloy which may serve as a cooling agent.

Apart from the control rods or liquid containing control tubes we may have safety devices of a similar structure as the control devices which operate only in case of an emergency and have the purpose of stopping the chain reaction if the radiation emitted in the chain reaction becomes too intense. Since these devices stop the reaction in a very short time it is not necessary to have them cooled. We may have, for instance, a number of rods similar to those shown in Figure 50 which are entirely moved out of the pile and are suspended by an electromagnet. If the radiation becomes too intense the magnet is switched off and the rods fall under the action of gravity into the pile.

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CONTROLS (REPLACEMENT)

Various ways of controlling the chain reaction are illustrated in the following figures. Figure 50 and 506 show a cylindrical graphite structure (1) of about equal diameter and height. The core (2) of this pile, as defined by the dotted line, may weigh about 500 tons and contains the uranium lattice. The graphite layer (3) outside this core serves the purpose of reflecting neutrons and absorbing the radiations which are generated in the chain reaction. Iron or other radiation absorbing elements can be contained in the outer part of this peripheral graphite layer which is outside the uranium lattice core (2). The graphite layer (10) (between two dotted lines) serves as a reflector for the neutrons and a layer (11) on the periphery of the structure which is built of alternate layers of graphite and iron serves as a radiation shield. A number of thin-walled steel tubes, 4, 5, 6, of about 1 cm diameter and .2 mm go through the core of the graphite pile and rods 7, 8, 9 built of slow neutron absorbing material, for instance steel or cobalt or an iron-cobalt alloy of high cobalt content, or nickel or a nickel-cobalt alloy can be moved up and down within these steel tubes. The thin-walled steel tubes are satisfactory from the point of view of having a low absorption, provided that the diameter of the tube is small compared to mean free path of the thermal in graphite since this is about 2.5 cm tubes of 1 cm diameter fulfill this condition. These neutron absorbing rods may be hollow tubes and may be cooled by having a flow of a cooling gas, for instance air, maintained through the tubes 4, 5 and 6 as indicated by the arrows in the figure. All these rods may be rigidly held together emanating from the chain reaction, by means of an ionization chamber. If the radiation increases the ~~chain~~ current through the ionization increases and by means of a suitable amplifier and relay a motor may be set into motion which moves the control rods inward in the chain reacting pile. If the radiation decreases the current in the ionization chamber decreases and by means fof a suitable gadget the motor may be reversed and the rods may be moved in the upward direction out of the interior of the pile. If the system is damped it is adapted to stabilize the chain reaction if above a certain radiation intensity the motor is set into motion moving the rods in the downward direction and below a certain radiation intensity the motor is set into motion pulling the control rod upward out of the interior of the pile.

Figure 41 shows another way of controlling the pile. In Figure 41 (1) is a thin-walled steel tubes of about 1 cm diameter and .2 mm wall. It goes vertically through the pile and forms together with a tank (4) which is outside the chain reacting unit, a communicating system. This system contains a bismuth-lead-cadmium alloy which is a liquid down to low temperatures and an electrodynamic pump (3) is so connected as to pump this absorbing liquid out of the pile and into the tank (4) if a sufficient electric potential is applied to the stator of the pump. If the pump is switched off the cadmium alloy flows from the tank into the pile and stops the chain reaction. An ionization chamber which is exposed to the radiation of the pile controls the potential on the stator of the pump in the following manner: if the current through the ionization chamber is low the potential applied to the pump is high and accordingly the equilibrium position of the liquid cadmium alloy column in the pile towards which the liquid alloy meniscus moves is comparatively low. Accordingly the cadmium alloy moves in toward the tank (4) and thereby increases the intensity of the chain reaction and increases the current through the controlling ionization chamber. Accordingly, the potential applied to the electromagnetic pump is decreased and the equilibrium position of the meniscus in the steel tube (1) is raised, so that the Bi alloy may now be pumped out at the tank 4. In this manner the chain reaction can be controlled in a satisfactory manner if the controlling system is sufficiently strongly damped. If this type of control is used we may have several independent controlling units as indicated in the view shown in Figure 41b.

The steel tube (1) is cooled by a cooling agent, for instance liquid bismuth or a liquid bismuth-lead alloy which flows in an annular gap between steel tube (1) and the surface of a circular bore in the graphite column which contains the steel tube (1). The electrodynamic pump (3) is cooled by a flow of the cadmium alloy through a cooler (5) which is connected to the entrance and exit tubes to the electrodynamic pump (3). A valve (6) controls the flow through the cooler (5) in such a manner that this flow should be small compared to the pumping capcity of the pump (3).

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CONTROLS (REPLACEMENT)

Various ways of controlling the chain reaction are illustrated in the following figures. Figure 50 and 50b show a cylindrical graphite structure (1) of about equal diameter and height. The core (2) of this pile, as defined by the dotted line, may weigh about 500 tons and contains the uranium lattice. The graphite layer (3) outside this core serves the purpose of reflecting neutrons and absorbing the radiations which are generated in the chain reaction. Iron or other radiation absorbing elements can be contained in the outer part of this peripheral graphite layer which is outside the uranium lattice core (2). The graphite layer (10) (between two dotted lines) serves as a reflector for the neutrons and a layer (11) on the periphery of the structure which is built of alternate layers of graphite and iron serves as a radiation shield. A number of thin-walled steel tubes, 4, 5, 6, of about 1 cm diameter and .2 mm go through the core of the graphite pile and rods 7, 8, 9 built of slow neutron absorbing material, for instance steel or cobalt or an iron-cobalt alloy of high cobalt content, or nickel or a nickel-cobalt alloy can be moved up and down within these steel tubes. The thin-walled steel tubes are satisfactory from the point of view of having a low absorption, provided that the diameter of the tube is small compared to mean free path of the thermal in graphite since this is about 2.5 cm tubes of 1 cm diameter fulfill this condition. These neutron absorbing rods may be hollow tubes and may be cooled by having a flow of a cooling gas, for instance air, maintained through the tubes 4, 5 and 6 as indicated by the arrows in the figure. All these rods may be rigidly held together emanating from the chain reaction, by means of an ionization chamber. If the radiation increases the current through the ionization increases and by means of a suitable amplifier and relay a motor may be set into motion which moves the control rods inward in the chain reacting pile. If the radiation decreases the current in the ionization chamber decreases and by means fof a suitable gadget the motor may be reversed and the rods may be moved in the upward direction out of the interior of the pile. If the system is damped it is adapted to stabilize the chain reaction if above a certain radiation intensity the motor is set into motion moving the rods in the downward direction and below a certain radiation intensity the motor is set into motion pulling the control rod upward out of the interior of the pile.

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