This investigation concerns a potentially chain reacting system which comprises a quantity of an element like uranium which undergoes fission under the action of fast neutrons but does not undergo fission under the action of slow neutrons. (This element will be called the element of the first category,) and a quantity of an element like U^{235} or element 94^{239} or U^{233} which is capable of undergoing fission under the action of slow neutrons. If a chain reaction is maintained in a system which contains a suitable quantity of such elements, an element of the second category is produced from the element of the first category by the capture of neutrons which have been slowed down below the fission threshold of the element of the first category. As the chain reaction progresses, a larger quantity of an element of the second category may be formed from the element of the first category than is lost through fission of the elements of the second category.

According to this invention a chain reaction can be maintained, stabilized, and controlled in a system containing such a reactive mixture and it is not necessary to slow down the neutrons which form the links of the chain reaction by means of some lighter element. The presence of considerable quantities of light elements within the system would on the contrary defeat the purpose of this invention, since it would impede the participation of the element of the first category in the reaction. The participation of the element of the first category in the reaction is, however, essential for the production of a sufficient quantitiy of element of the second category in the course of the chain reaction.

For instance, if we use a mixture of U^{238} and element 94^{239} we are faced with the following situation: About two neutrons, perhaps slightly more, are emitted if an atom of 94 undergoes fission under the action of a slow or fast neutron. Of these neutrons one neutron is needed to carry on the chain reaction. A fraction of a neutron leaks out of a chain reacting system whereas the remaining fraction of the originally emitted neutrons will be captured by U^{238} and lead to the production of a certain quantity of 94^{239}. If we have a system in which the fast neutron emitted in the fission process of the element 94 cannot cause much fission in U^{238} because they are quickly slowed down below the fission threshold of U^{238}, the amount of 94 produced from U^{238} would at best just about slightly overcompensate the element 94 which disappears by fission. Thus a larger quantity of light elements, if present, would slow down the neutrons below the fission threshold of U^{238} and therefy reduce the neutron contribution of U^{238} to the chain reaction and impede the growth of the quantity of the element 94 in the system. In the absence of such light elements there is a considerable contribution of neutrons due to fission of U^{238} and, therefore, the amount of 94 produced from U^{238} may considerably exceed the amount of 94 which disappears by fission of 94, so that as a chain reaction proceeds the amount of 94 rapidly increases in the system.

Large quantities of heat liberated in the chain reaction can be dissipated according to this invention in such a chain reaction by using as a cooling medium He at high pressure or a low melting heavy metal or alloys of low melting heavy metals. Lead or bismuth and alloys of lead and bismuth may serve according to this invention as a cooling medium and may also serve as a stabilizing agent. Large quantities of radioactive elements are produced both from the uranium and from the bismuth contained in the cooling liquid if bismuth or bismuth alloy is used as a cooling medium. One of these radioactive elements produced from uranium is element 94^{239} and as chain reaction continues the quantity of this element present increases as the chain reaction is being allowed to run. After a certain length of operation the chain can be shut off and the circulation of the cooling medium can be maintained for a further period of time.

In the absence of light elements interacting with the chain reacting mass the neutrons which form the links of the chain in the chain reaction are not slowed down to thermal energies. Consequently, the time (   ) which elapses between two successive generations of neutrons is very small, practically zero. For this reason, it has been thought that it is not possible to stabilize a chain reaction of this type. This has been thought for the following reason: In order to maintain a chain reaction in a potentially chain reacting mass, one has to set up conditions so as to be very close to the critical dimensions in order to have the chain reaction going at an appreciable rate. A small deviation from these critical dimensions in the sense of exceeding the critical dimensions would lead, it has been thought, to an exceedingly rapid rise of the intensity of the chain reaction, making it impossible to have mechanical controls which would respond sufficiently fast to stabilize such a fast neutron chain reaction. According to this invention such a stabilization of the fast neutron reaction is possible and methods for stabilizing the reaction will be described further below.

In order to understand this, one ~~has to point out that there~~ are two different kinds of critical dimensions. A smaller one at which the total neutron emission including the delayed neutron emission becomes divergent, and a larger one at which the spontaneous neutron emission alone is sufficient to make the action divergent. If one operates the pile slightly above the smaller of these two values but considerably below the larger of these two values then the intensity of the chain reaction rises exponentially with time at the rate which is practically independent of life time (   ) of the fast neutrons in the chain reacting mass and is determined by the time constant of the delayed neutron emission

One way of stabilizing the chain reaction is to introduce into the chain reacting mass near the center of that mass a certain quantity of liquid bismuth or lead or a lead bismuth alloy whenever the intensity of the chain reaction increases and to withdraw liquid when the intensity of the chain reaction decreases. We call about 1/8 of the volume of the chain reactingmass, which is closest to the center of the chain reacting mass, the core of the chain reacting mass. Stabilization can be effected by varying the amount of liquid bismuth in the core of the chain reacting mass in such a manner that a quantity of bismuth or lead up to 1/5 of the mass of the core can be pushed in or withdrawn according to whether the intensity of the reaction is too high or too low. Fig. 4 illustrates this way of regulating the chain reaction. In Fig. 4, 41 indicates the chain reacting mass which has a shape of a cylinder of about equal diameter and height. 42, 43, etc., are steel tubes which form with the tank 44 a communicating system. An electrodynamic pump 45 is installed between the tank 44 and the tubes, 42, 43. If this pump is out of action the level of the liquid metal in tank 44 and in the communicating steel tubes is at equal height at about the upper boundary of the core of the chain reactin unit. In order to start the chain reaction, the electrodynamic pump is put into action and the liquid bismuth is partially withdrawn from the core of the chain reaction unit. Equipment to the gamma or neutron radiation or both which emanate from the pile is used to control the voltage applied to the electrodynamic pump in such a manner that when the radiation is increased, the pumping time is decreased and the bismuth flows from the tank under the action of gravity into the core of the chain reacting unit and when the radiation decreases the voltage on the electrodynamic pump is so changed as to increase the pumping time so that the liquid metal flows out of the core of the chain reaction unit into the tank 44. The liquid 45 towards the tank 44, a small fraction flows back through the cooler 46, to the low pressure and of the electrodynamic pump. Thus, even if the miscibility of the liquid in the tank is stationary, there is a constant flow of the liquid through the pump 45 and the cooler 46 which provides for the cooling of the pump 45.

In the following, the word uranium will be used for alloys, the main component of which is U^{238}.

In Fig. 1, 1 is auranium rod of about 1 cm. diamter and about 2 or 3 meters long. 2 is a thin-walled steel tube which covers the uranium rod 1 (not in He cooling). 3 is a steel plug at the end of the uranium rod. These two steel plugs seal the uranium rod in such a way to prevent access of the cooling medium to the uranium. 5 is a steel rod about 25 cm long which supports the weight of the long uranium rod. Uranium rods of the type shown in Fig. 1 are arranged in the form of a lattice shown in Fig. 2a and 2b. As indicated by Fig. 2a, a certain amount of space is left free between the uranium rods which, in the operating chain reaction unit, is filled with He or a liquid metal.

Fig. 3a and 3b show cylindrical tank 10 of about equal diameter and height. The cylindrical space 11 inside the tank is filled by a lattice of uranium rods of the type shown in Fig. 2. Three uranium rods, 12, 13, and 14, are only actually shown in Fig. 3. Through the tube 15 He or liquid bismuth flows into a space between the upper cover of the tank and the steel plate 17. The cooling agent flows as indicated by the arrows radially towards the periphery of the tank and enters the lattice of uranium rods at the top. Here the cooling agent flows towards the axis of the arrangement and flows downward into space left free by the uranium rods. At the bottom the cooling agent flows again towards the periphery where it flows through a number of channels like channel 18 in the steel cylinder 19 into the space between the steel plate 20 and the bottom of the tank 21.

Finally the cooling agent leaves the tank through tube 22.

The steel plate 17 holds the uranium rods in place by means of steel rods like the steel rod 23, which fits into the bore 24 in Fig. 1. Steel plate 17 is supported by a steel column 25 and other similar steel columns which are shown in Fig. 3b.

This ~~investigation~~ invention concerns a potentially chain reacting system which comprises a quantity of an element like uranium which undergoes fission under the action of fast neutrons but does not undergo fission under the action of slow neutrons, (~~This~~ Such an element will be called ~~the~~ an element of the first category,) and a quantity of an element like U^{235} or element 94^{239} or U^{233} which is capable of undergoing fission under the action of slow neutrons. (such an element will be called an element of the second category) If a chain reaction is maintained in a system which contains ~~a~~ ~~suffic.~~ ~~suitable~~ a proper quantity of such elements, an element of the second category is produced from the element of the first category by the capture of neutrons which have been slowed down below the fission threshold of the element of the first category. As the chain reaction progresses, a larger quantity of an element of the second category may be formed from the element of the first category than is lost through fission of the elements of the second category.

According to this invention a chain reaction can be maintained, stabilized, and controlled in a system containing such a reactive ~~mixture~~ composition of elements and it is not necessary to slow down the neutrons which form the links of the chain reaction by means of some lighter element. The presence of considerable quantities of light elements within the system would on the contrary defeat the purpose of this invention, since it would impede the participation of the element of the first category in the reaction. The participation of the element of the first category in the reaction is, ~~however~~, essential for the production of a sufficient quantitiy of element of the second category in the course of the chain reaction.

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4th floor
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Large quantities of heat liberated in the chain reaction can be dissipated according to this invention in such a chain reaction by using as a cooling medium He at high pressure or a low melting heavy metal or alloys of low melting heavy metals. Lead or bismuth and alloys of lead

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and bismuth may serve according to this invention as a cooling medium and may also serve as a stabilizing agent. Large quantities of radioactive elements are produced both from the uranium and from the bismuth contained in the cooling liquid if bismuth or bismuth alloy is used as a cooling medium. One of these radioactive elements produced from uranium is element 94^{239} and as the chain reaction continues the quantity of this element present increases as the chain reaction is being allowed to run. After a certain length of operation the chain reaction can be shut off and the circulation of the cooling medium can be maintained for a further period of time.

In the absence of light elements interacting with the chain reacting mass the neutrons which form the links of the chain in the chain reaction are not slowed down to thermal energies. Consequently, the time (τ) which elapses between two successive generations of neutrons is very small, practically zero. For this reason, it has been thought that it is not possible to stabilize a chain reaction of this type. This has been thought for the following reason: In order to maintain a chain reaction in a potentially chain reacting mass, one has to set up conditions so as to be very close to the critical dimensions in order to have the chain reaction going at an appreciable rate. A small deviation from these critical dimensions in the sense of exceeding the critical dimensions would lead, it has been thought, to an exceedingly rapid rise of the intensity of the chain reaction, making it impossible to have mechanical controls which would respond sufficiently fast to stabilize such a fast neutron chain reaction. According to this invention such a stabilization of the fast neutron reaction is possible and methods for stabilizing the reaction will be described further below.

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In order to understand this, one has to point out that there are two different kinds of critical dimensions. A smaller one at which the total neutron emission including the delayed neutron emission becomes divergent, and a larger one at which the ~~spontaneous~~ instantaneous neutron emission alone is sufficient to make the action divergent. If one operates the pile slightly above the smaller of these two values but considerably below the larger of these two values then the intensity of the chain reaction rises exponentially with time at the rate which is practically independent of life time (τ) of the fast neutrons in the chain reacting mass and is determined by the time constant of the delayed neutron emission .

One way of stabilizing the chain reaction is to introduce into the chain reacting mass near the center of that mass a certain quantity of liquid bismuth or lead or a lead bismuth alloy whenever the intensity of the chain reaction increases and to withdraw liquid when the intensity of the chain reaction decreases. We call about 1/8 of the volume of the chain reactingmass, which is closest to the center of the chain reacting mass, the core of the chain reacting mass. Stabilization can for instance be effected by varying the amount of liquid bismuth, lead alloy, in the core of the chain reacting mass in such a manner that a quantity of bismuth or lead up to 1/5 of the

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mass of the core can be pushed in or withdrawn according to whether the intensity of the reaction is too high or too low. Fig. 4 illustrates this way of regulating the chain reaction. In Fig. 4, 41 indicates the chain reacting mass which has a shape of a cylinder of about equal diameter and height. 42, 43, etc., are steel tubes which form with the tank 44 a communicating system. An electrodynamic pump 45 is installed between the tank 44 and the tubes, 42, 43. If this pump is out of action the level of the liquid metal in tank 44 and in the communicating steel tubes is at equal height at about the upper boundary of the core of the chain reacting unit. In order to start the chain reaction, the electrodynamic pump is put into action and the liquid bismuth lead alloy is partially withdrawn from the core of the chain reaction unit. Equipment sensitive to the gamma or neutron radiation or both which emanate from the ~~pile~~ unit is used to control the voltage applied to the electrodynamic pump in such a manner that when the radiation is increased, the pumping ~~time~~ ~~speed~~ action is decreased and the bismuth lead alloy flows from the tank under the action of gravity into the core of the chain reacting unit and when the radiation decreases the voltage on the electrodynamic pump is so changed as to increase the pumping ~~time~~ action so that the liquid metal flows out of the core of the chain reaction unit into the tank 44. ~~The~~ While the liquid is pumped by the pump 45 towards the tank 44, a small fraction flows back through the cooler 46, to the low pressure end of the electrodynamic pump 45. Thus, even if the ~~miscibility~~ level of the liquid in the tank is stationary, there is a constant flow of the liquid through the pump 45 and the cooler 46 which provides for the cooling of the pump 45.

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capable of maintaining a fast neutron chain reaction;

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