(5)

Of the various lattices which can be used, there are two classes which are of particular interest. To the first class belong lattices, the elements of which are spheres of uranium or short cylinders of uranium of about equal height and diameter or other such forms which more or less resemble spheres. To the second class belong lattices which are composed of rods of uranium, for instance, cylinders or square shaped rods. Of the lattices belonging to the first class, there are two types of lattices which are particularly simple, namely the three possible close-packed lattices on the one hand, and the simple cubic lattice on the other. Of the lattices belonging to the second class, there are again two types which are particularly simple, one which had trigonal and one which had hexagonal geometry.

Figure 16 shows a graphite column 161 , containing a string of short cylinders of uranium carbide, 162, , 163 , 164 , 166 . By placing a number of such graphite columns side by side, standing in a vertical position, one obtains a cubic lattice of uranium carbide cylinders. The square shaped graphite rod 161 has a circular bore in its center and cylindrical graphite rods 167 , 168 , 169 , 170 , and 171 alternate with the above-mentioned short uranium carbide cylinders in this bore. A cooling agent, for instance liquid bismuth, flows through the graphite column in the duct 172 and a certain fraction of this flow enters through the duct 173 , the graphite rod 169 . About half of this quantity flows through the uranium carbide cylinders 164 and 166 and the channel 174 to the duct 175 which passes downward through the graphite column 161 . The rest flows through the uranium carbide cylinders 163 and 162 and enters through the channel 176 into the duct 175 .

This type of flow we shall call parallel flow and in the particular sections of the lattice which are shown in the drawing, two lattice elements are in series. The number of lattice elements which are in series may be different in different parts of the lattice. Near the center of the graphite where the neutron density is largest, we may have only few lattice elements in series or perhaps all lattice elements in parallel. Towards the periphery of the graphite structure, however, where the neutron density is lowest, a larger number of lattice elements may be connected in series. In this manner we may, if we wish, have approximately the same rise in temperature in the cooling agent which passes from one duct 172 to the other duct 175 , in spite of the fact that the neutron density, and accordingly the heat production, differs greatly between the center of the graphite structure and the periphery.

Figure 15 shows how a vertical graphite column is built from several sections. In Figure 15, 161 is the square shaped graphite rod shown in Figure 17 and 177 is another square shaped graphite rod which is joined to the former in the manner shown in the figure. A ground surface of conical shape forms the seal for the cooling agent which flows through the ducts 172 and 175 .

Figure 16a shows in what manner a cubic lattice is built from such square shaped rods, which, like 161 , have equal ________ (?)

Figure 16b shows in what manner a close-packed lattice may be built up from graphite rods for which the ratio of the two sides is $\sqrt{3}$: 2. These two figures, 16a and 16b, may be understood without further explanation if viewed in conjunction with Figure 16.

Figure 16c shows a cross-section and a side view of the uranium carbide plugs number in Figure 16. Section AA' in Figure 16c shows the slits in which the liquid cooling agent can flow through the uranium carbide plug.

Carbide Rods--Bi Cooling.--Figure 17 shows a square shaped graphite rod 178 which forms part of the vertical graphite column that goes through the whole graphite power unit. A circular bore in the center of the square graphite rod contains cylindrical rods of uranium carbide 179 , 180, , 181 182 and 183 , etc. These pieces of uranium carbide are piled up one on top of the other and aggregate into a long cylindrical rod of uranium carbide going through the whole length of the graphite structure. Each of the sections 179 , 180 , etc., has a shape similar to the (cross) section AA' in Figure 16c. The sections 179 and 180 are separated by a ring of uranium carbide 184 and similarly, sections 182 and 183 are separated by such a ring 185 . The cooling agent flowing downwards in duct 186 passes through the channel 187 into the interior of the ring 184 and about half of the amount entering into the ring 184 passes through the slits in 180 , 181 and 182 into the interior of the ring 185. From here the cooling agent goes through the channel 188 into the duct 189. .

This arrangement represents again parallel flow. The length of the uranium carbide rod between 2 adjacent rings 187 and 188 will be smaller towards the center of the graphite structure and larger towards the periphery of the power unit as discussed above in conjunction with Figure 16.

A number of square-shaped graphite bricks 178 placed side by side in the manner shown in Figure 16a will gorm a tetragonal lattice of uranium carbide rods. If a graphite brick of a sligntly different shape is used and placed side by side in the manner illustrated in Figure 16b, we obtain a trigonal lattice of cylindrical uranium carbide rods.

Metal, Series Flow.--Figure 40 shows an example in which the lattice is built of uranium metal rods. An element of thelattice is shown in the Figure. 401 is part of a graphite column which contains a cylindrical rod 402 of uranium metal which is surrounded by a thin steel tube 403, contained in a cylindrical bore in the graphite column 401 , leaving an annular gap 404 between the graphite and the steel tube. This cylindrical uranium rod is hollow but no cooling agent is passed through the hollow space in the axis of the rod. The cooling agent flows in the downward direction through the whole length of the entire graphite structure in the annular gap 404. Figure 14 shows in what manner two adjacent sections of the graphite column are joined together. In Figure 14, 401 is the lower graphite brick and 405 is the adjacent brick, which are joined together to form part of the vertical graphite column which goes through the entire graphite structure.

Figure 41 shows an example where the lattice element is formed by an aggregate of 3 uranium metal rods. This aggregate forms an approximately triangularly-shaped rod which represents the lattice element. The 3 uranium rods 406 , 407 and 408 are covered by thin steel tubes, one of which is designated by 409 . The cooling agent passes downward in the space 410 inside the circular bore in the graphite brick 401 . Figure 42 shows another example for an aggregate in which 7 uranium rods together form one lattice element. In Figure 42 we have 7 such rods placed in a cylindrical bore of the graphite brick 401 . The cooling liquid passes along this uranium aggregate in the space which is left free within the cylindrical bore in the vertical graphite column.

Figure 43 shows another example in which there are 4 uranium rods, (each within a thin steel tube) placed within a cylindrical bore in the graphite brick 401 . 411 is a steel plate which serves to hold the 4 uranium rods shown in Figure 43 in position. That fraction of the cooling agent which flows within the uranium rod aggregate proper is deflected by the steel plate 411 and united with the main flow of the cooling agent which passes between the steel plate 411 and the surface of the cylindrical bore in the graphite column.

Uranium metal rod arrangement--parallel flow.--In Fig. 33, 331 is a square shaped graphite brick with a cylindrical bore in the center. A uranium rod 333 covered by a thin-walled steel tube, 334 goes through the bore in the center of the graphite brick 331 leaving an annular space 335 free for the flow of the cooling agent. 332 is another square shaped graphite brick which forms together with 331 part of a vertical graphite column which goes through the entire pile structure. The cooling agent moves in the downward direction in the duct to 336. It enters the annular space 335 through the channel 337 from where about half flows upward and half flows downward in the annular gap surrounding the cylindrical uranium rod 333 . The cooling agent which has been in thermal contact with the uranium rod 333 is collected in the duct 338 in which it passes through the pile in the downward direction.

Another similar arrangement in which the uranium rod is composed of a number of sections which are joined together in the same place in which the sections of the graphite column are joined together is shown in Fig. 30. 301 and 302 are adjacent graphite bricks in the vertical graphite column. 305 is the annular gap surrounding the uranium rod 303. 304 is a thin steel tube which covers the uranium rod 303. The cooling agent enters from the duct 306 into the annular space surrounding the two sections of the uranium rod which are shown in the figure through the channels 307 and 308. 309 and 310 are steel disks which center the uranium rods in the bore in the graphite column. Channels in these steel disks, like for instance the channel 311, permits a drainage of the cooling agent in case a liquid cooling agent is used. Otherwise, the same applies to the construction shown in Fig. 30 as applies to the construction in Fig. 33.

The construction shown in Fig. 32 is very similar to the construction shown in Fig. 30, the only difference being that instead of a solid uranium rod, we have here a hollow uranium rod, the inner wall of which is covered by a thin-walled steel tube, and the cooling agent flows both through the annular gap outside and the steel tube inside the uranium rod.

Fig. 31 differs from the previous figures 32 and 33 only in as much as we have here an aggregate of uranium rod inside thin steel tubes and these aggregates which have the contour of a cylindrical rod form the lattice element in place of a single massive uranium rod shown in the previous figures.

5

1

Of the various lattices which can be used, there are two classes which are of particular interest. ~~One class is~~ To the first class belongs lattices, the elements of which are spheres of uranium or short cylinders of uranium of about equal height and diameter or other such forms which more or less resemble spheres. To the second class belong lattices which are ... ~~Of the lattices built of such elements~~ belonging to the first class, there are ~~again~~ two types of lattices which are particularly simple, namely the three possible close-packed lattices on the one hand, and the simple cubic lattice on the other. ~~To the second class~~ Of the lattices belonging to the second class there are again two types,

Figure 16 shows a graphite column 161, containing a string of short cylinders of uranium carbide, 162, 163, 164, 166. By placing a number of such graphite columns side by side, standing in a vertical position, one obtains a cubic lattice of uranium carbide cylinders. The square shaped graphite rod 161 has a circular bore in its center and ~~circular~~ cylindrical graphite rods 167, 168, 169, 170 and 171 alternate~~ly~~ with the above-mentioned short uranium carbide cylinders in this bore. ~~The~~ A cooling agent, for instance liquid bismuth, flows through the graphite column ~~through~~ on the duct 172 and a certain fraction of this flow enters through the duct 173, the graphite rod 169. About half of this quantity flows through the uranium carbide cylinders 164 and 166 and the channel 174 ~~through~~ to the duct 175 which passes downward through the graphite column 161. ~~Another half~~ The rest flows through the uranium carbide cylinders 163 and 162 and enters through the channel 176 into the duct 175. This type of flow we shall call parallel flow and in the particular sections shown in the drawing, two lattice elements are in series. The number of lattice elements which are in series may be

which are particularly simple one ~~corresponding to the closed pack lattices which of the first~~ which has hexagonal and one which has tetragonal symmetry different in different parts of the lattice.

Near the center of the graphite where the neutron density is largest, we may have only few lattice elements in series or perhaps all lattice elements in parallel. Towards the periphery of the graphite structure, however, where neutron density is lowest, a larger number of lattice elements may be connected in series. In this manner we may, if we wish, have approximately the same rise in temperature in the cooling agent which passes from one duct 172 to the other duct 175, in spite of the fact that the neutron density, and accordingly the heat production, varies greatly between the center of the graphite structure and the periphery.

Figure 15 shows how a vertical graphite column is built together from several sections. In Figure 15, 161 is the square-shaped graphite rod shown in figure 17 and 177 is another square-shaped graphite rod which is joined to the former in the manner shown in the figure. A ground surface of conical shape seal the cooling agent which flows through the ducts 172 and 175.

Figure 16a shows in what manner a cubic lattice is built up of square-shaped rods.

Figure 16b shows in what manner a close-packed lattice may be built up from graphite rods for which the ratio of the two sides is $\sqrt{3} : 2$. These two figures, 16a and 16b, may be understood without further explanation if viewed in conjunction with figure 16.

Ad Pdg 17 (3)

Figure 16c shows a cross-section and a side view of the uranium carbide plugs in Figure 16. Section AA' in Figure 16c shows the slits in which the liquid cooling agent can flow through the uranium carbide plug. Figure 17 shows a square shaped graphite rod 178 which forms part of the vertical graphite column that goes through the whole graphite structure which forms the chain-reacting pile. A circular bore in the center of the square graphite rod contains cylindrical rods of uranium carbide 179, 180, 181, 182 and 183, etc. These pieces of uranium carbide are piled up one on top of the other and aggregate into a long cylindrical rod of uranium carbide going through the whole length of the graphite structure. Each of the sections 179, 180, etc., has a shape similar to the cross section AA' in Figure 16c. The sections 179 and 180 are separated by a ring of uranium carbide 184 and similarly, sections 182 and 183 are separated by a ring 185. The liquid cooling agent flowing downwards in duct 186 passes through the channel 187 into the interior of the ring 184 and about half of the amount entering into the ring 184 passes through the slits in 180, 181 and 182 into the interior of the ring 185. From here the cooling agent goes through the channel 188 into the duct 189.

This arrangement represents again parallel flow. The length of the uranium carbide rod between 2 adjacent rings 187 and 188 will be smaller towards the center of the graphite structure and larger towards the peripheral structure as discussed in conjunction with Figure 16.

A number of square-shaped graphite rods placed side by side as shown in Figure 16a will give a tetragonal lattice of uranium carbide rods. If a graphite ~~rod~~ block of a slightly different shape is used and placed side by side ~~as~~ in the manner illustrated in Figure 16b, we obtain a trigonal lattice of cylindrical uranium carbide rods.

Metal, ~~Bismuth~~ Series Flow

Figure 40 shows ~~an element of a~~ lattice ~~which may~~ be built of uranium metal rods. 401 is part of a graphite column which contains a cylindrical rod 402 of uranium metal which is surrounded by a thin steel tube 403, contained in a cylindrical bore in the graphite column 401, leaving an annular gap 404 between the graphite and the steel tube. This cylindrical uranium rod is hollow but no cooling agent is passed through the hollow space in the axis of the rod. The cooling agent flows in the downward direction through the whole length of the entire graphite structure in the annular gap 404. Figure ~~40~~ 14 shows in what manner two adjacent sections of the graphite column are joined together. In Figure ~~40~~ 14, 401 is the lower graphite brick and 405 is the adjacent brick, which are joined together to form part of the vertical graphite column which goes through the entire graphite structure.

Figure 41 shows an example where the lattice element is formed by an aggregate of 3 uranium metal rods. This aggregate forms an approximately triangularly-shaped rod which represents the lattice element. The 3 uranium rods 406, 407 and 408 are covered by thin steel tubes, one of which is designated by 409. The cooling agent passes downward in the space 410 inside the circular bore in the graphite brick 401. Figure 42 shows another example for an aggregate ~~of~~ 7 uranium rods which form one lattice element. In Figure 42 we have 7 such rods placed in a cylindrical bore of the graphite brick 401. The cooling liquid passes along this uranium aggregate in the space which is left free within the cylindrical bore in the vertical graphite column.

Figure 43 shows another example in which there are 4 uranium rods, (each within a thin steel tube) placed within a cylinrdical bore in the graphite brick 401. 411 is a ~~thin~~ steel plate which serves to hold the 4 uranium rods shown in Figure 43 in position. That fraction of the cooling agent which flows within the uranium rod aggregate proper is deflected by the steel plate 411 and united with the main flow of the cooling agent which passes between the steel plate 411 and the surface of the cylindrical bore in the graphite column.

Fig. 30, the only difference being that instead of a solid uranium rod, we have here a hollow uranium rod, the inner wall of which is covered by a thin-walled steel tube, and the cooling agent flows both through the annular gap outside and the steel tube inside the uranium rod. Fig. 31 differs from the previous figures 32 and 33 only in as much as we have here an aggregate of uranium rod inside thin steel tubes and these aggregates which have the contour of a cylindrical rod form the lattice element in place of a single massive uranium rod shown in the previous figures.

Uranium metal rod arrangement - parallel flow

33 In Fig. 33, 331 is a square shaped graphite brick with a cylindrical bole in the ~~center,~~ [a] uranium rod 333 ~~within~~ [covered by] a thin-walled steel tube, 334 goes through the bole in the center of the graphite brick 331 leaving an annular space 335 free for the flow of the cooling agent. 332 is another square shaped graphite brick which forms together with 331 part of a vertical graphite column which goes through the entire pile structure. The cooling agent moved in the downward direction in the duct to 336. It enters the annular space 335 through the channel 337 from where about half flows upward and half flows downward in the annular gap surrounding the cylindrical uranium rod 333. The cooling agent which ~~has no heat transfer~~ [has been in thermal contact] with the uranium rod 333 is ~~cooled~~ [collected] in the duct 338 in which it passes through the pile in the downward direction.

30 Another similar arrangement in which the uranium rod is composed of a ~~form~~ [number] of sections which are joined ~~directly~~ together in the same place in which the sections of the graphite column are joined together as shown in Fig. 30. 301 and 302 are adjacent graphite bricks in the vertical graphite column. 305 is the annular gap surrounding the uranium rod 303. 304 is a thin steel tube which covers the uranium rod 303. The cooling agent enters from the duct 306 into the annular space surrounding the two sections of the uranium rod which are shown in the ~~Fig.~~ [figure] through the channels 307 and 308. 309 and 310 are steel disks which center the uranium rods in the ~~central~~ bole ~~of the~~ [in the] graphite column. Channels in these steel disks, like, for instance, the channel 311, permits a drainage of the cooling agent in case a liquid cooling agent is used. Otherwise, the same applies to the construction shown in Fig. 30 as applies to the construction shown in Fig. 33.

32 The construction shown in Fig. 32 is very similar to the construction shown in

the annular gap between the Al tubes (3) and the Al-covered uranium rod (1). In order to have a potentially chain reacting system, it is necessary to have the gap which is filled with water rather small, but if the uranium rod has a diameter of about 3 cm and if the gap is about 1 mm and if water is flowing through the gap, we still have a potentially chain reacting lattice.

Figure 4 shows a somewhat different cooling system. In figure 4, (1) is a cylindrical uranium rod which forms the lattice element. An Al tube (2) is in thermal contact with the uranium, and water flows through this Al tube. (3), is an Al coating which covers the outside of the cylindrical uranium rod and (4) is the graphite into which a lattice of such uranium rods is embedded.

If liquid Bi is used as a cooling agent in a system described by figure 3 or figure 4, steel coatings or steel tubes have to be used in place of Al coatings or Al tubes. The steel coatings or steel tubes will not prevent the chain reaction, but in order to keep the losses sufficiently low, it is advisable to cover the wall thickness of the steel tubes or steel coatings down to about 1% of the diameter of the uranium rod. In the examples given in figures

such steel coated uranium rods are drawn.

If liquid Bi is used as a cooling agent it may be allowed to be in direct touch with the graphite and need not have a closed circulation but may have a gravity flow of liquid Bi through the chain reaction pile. Uranium metal must not be used in direct contact with Bi but uranium carbide may be used in that manner.

V

Arrangement Class 1C alpha.

Metal, Series Flow, (gravity flow)--Figure 40 shows an example in which the lattice is built of uranium metal rods. An element of the lattice is shown in the Figure. 401 is part of a graphite column which contains a cylindrical rod 402 of uranium metal which is surrounded by a thin steel tube 403, contained in a cylindrical bore in the graphite column 401, leaving an annular gap 404 between the graphite and the steel tube. This cylindrical uranium rod is hollow but no cooling agent is passed through the hollow space in the axis of the rod. The cooling agent flows in the downward direction through the whole length of the entire graphite structure in the annular gap 404. Figure 14 shows in what manner two adjacent sections of the graphite column are joined together. In Figure 14, 401 is the lower graphite brick and 405 is the adjacent brick, which are joined together to form part of the vertical graphite column which goes through the entire graphite structure.

Figure 41 shows an example where the lattice element is formed by an aggregate of 3 uranium metal rods. This aggregate forms an approximately triangularly-shaped rod which represents the lattice element. The 3 uranium rods 406, 407, and 408 are covered by thin steel tubes, one of which is designated by 409. The cooling agent passes downward in the space 410 inside the circular bore in the graphite brick 401. Figure 42 shows another example for an aggregate in which 7 uranium rods together form one lattice element. In Figure 42 we have 7 such rods placed in a cylindrical bore of the graphite brick 401. The cooling liquid passes along this uranium aggregate in the space which is left free within the cylindrical bore in the vertical graphite column.

Figure 43 shows another example in which there are 4 uranium rods, (each within a thin steel tube) placed within a cylindrical bore in the graphite brick 401. 411 is a steel plate which serves to hold the 4 uranium rods shown in Figure 43 in position. That fraction of the cooling agent which flows within the uranium rod aggregate proper is deflected by the steel plate 411 and united with the main flow of the cooling agent which passes between the steel plate 411 and the surface of the cylindrical bore in the graphite column.

Figure 45 shows how one may assemble a lattice having lattice elements as those shown in Figure 40, in a manner which permits the removal of the uranium rod 402 of Figure 40 from the graphite structure. In Figure 45, (1), (2), (3), (4), and (5) are adjacent square graphite columns arranged in a vertical position. Uranium rods 402 form a lattice which has a tetragonal symmetry. A liquid Bi-Pb alloy flows from the pipe (10), (11), and (12) into the steel cylinders (13), (14) and (15) respectively. These steel cylinders communicate with the steel cylinders (16), (17) and (18) and the Bi-Pb alloy will have a certain level in the cylinders (13) to (18) and will flow under the action of gravity into the gaps 404 between the uranium rods 402 and the graphite. Bi-Pb alloy flows along the surface of the uranium rod through the whole structure and is collected in the bottom, goes through a heat exchanger and is pumped back to the top of the structure. The steel rods (19) are attached to the uranium rods 402 and the uranium rods can be pulled out of the structure by means of the steel rods.

Uranium metal rod arrangement -- parallel flow. In Figure 33, 331 is a square shaped graphite brick with a cylindrical bore in the center. A uranium rod 333 covered by a thinwalled steel tube, 334 goes through the bore in the center of the graphite brick, leaving an annular space 335 free for the flow of the cooling agent. 332 is another square shaped graphite brick which forms together with 331 part of a vertical graphite column which goes through the entire pile structure. The cooling agent moves in the downward direction in the duct to 336. It enters the annular space 335 through the channel 337 from where about half flows upward and half flows downward in the annular gap surrounding the cylindrical uranium rod 333. The cooling agent which has been in thermal contact with the uranium rod 333 is collected in the duct 338 in which it passes through the pile in the downward direction.

Another similar arrangement in which the uranium rod is composed of a number of sections which are joined together in the same place in which the sections of the graphite column are joined together is shown in Figure 30. 301 and 302 are adjacent graphite bricks in the vertical graphite column. 305 is the annular gap surrounding the uranium rod 303. 304 is a thin steel tube which covers the uranium rod 303. The cooling agent enters from the duct 306 into the annular space surrounding the two sections of the uranium rod which are shown in the figure through the channels 307 and 308. 309 and 310 are steel disks which center the uranium rods in the bore in the graphite column. Channels in these steel disks, like, for instance, the channel 311, permits a drainage of the cooling agent in case a liquid cooling agent is used. Otherwise, the same applies to the construction shown in Figure 30 as applies to the construction in Figure 33.

(Carbide Rods--Bi Cooling). Figure 17 shows a square shaped graphite rod 178 which forms part of the vertical graphite column that goes through the whole graphite power unit. A circular bore in the center of the square graphite rod contains cylindrical rods or uranium carbide 179, 180, 181, 182, and 183, etc.. These pieces of uranium carbide are piled up one on top of the other and aggregate into a long cylindrical rod of uranium carbide going through the whole length of the graphite structure. Each of the sections 179, 180, etc., has a shape similar to the cross section AA' in Figure 16c. The sections 179 and 180 are separated by a ring of uranium carbide 184 and similarly, sections 182 and 183 are separated by such a ring 185. The cooling agent flowing downward in duct 186 passes through the channel 187 into the interior of the ring 184 and about half of the amount entering into the ring 184 passes through the slits in 180, 181 and 182 into the interior of the ring 185. From here the cooling agent goes through the channel 188 and into the duct 189.

This arrangement represents again parallel flow. The length of the uranium carbide rod between 2 adjacent rings 187 and 188 will be smaller towards the center of the graphite structure and larger towards the periphery of the power unit as discussed above in conjunction with Figure 16.

A number of square-shaped graphite bricks 178 placed side by side in the manner shown in Figure 16a will form a tetragonal lattice of uranium carbide rods. If a graphite brick of a slightly different shape is used and placed side by side in the manner illustrated in Figure 16b, we obtain a trigonal lattice of cylindrical uranium carbide rods.

Figure 16 shows a graphite column 161, containing a string of short cylinders of uranium carbide, 162, 163, 164, 166. By placing a number of such graphite columns side by side, standing in a vertical position, one obtains a cubic lattice of short uranium carbide cylinders. The square shaped graphite rod 161 has a circular bore in its center and cylindrical graphite rods 167, 168, 169, 170, and 171 alternate with the above-mentioned short uranium carbide cylinders in this bore. A cooling agent, for instance, liquid bismuth, flows through the graphite column in the duct 172 and a certain fraction of this flow enters through the duct 173, the graphite rod 169. About half of this quantity flows through the uranium carbide cylinders 164 and 166 and the channel

174 to the duct 175 which passes downward through the graphite column 161. The rest flows through the uranium carbide cylinders 163 and 162 and enters through the channel 176 into the duct 175.

This type of flow we shall call parallel flow and in particular sections of the lattice which are shown in the drawing, two lattice elements are in series. The number of lattice elements which are in series may be different in different parts of the lattice. Near the center of the graphite where the neutron density is largest, we may have only few lattice elements in series or perhaps all lattice elements in parallel. Towards the periphery of the graphite structure, however, where the neutron density is lowest, a larger number of lattice elements may be connected in series. In this manner we may, if we wish, have approximately the same rise in temperature in the cooling agent which passes from one duct 172 to the other duct 175, in spite of the fact that the neutron density, and accordingly the heat production, differs greatly between the center of the graphite structure and the periphery.

Figure 15 shows how a vertical graphite column is built from several sections. In Figure 15, 161 is the square shaped graphite rod shown in Figure 17 and 177 is another square shaped graphite rod which is joined to the former in the manner shown in the figure. A ground surface of conical shape forms the seal for the cooling agent which flows through the ducts 172 and 175.

Figure 16a shows in what manner a cubic lattice is built from such square shaped rods, which, like 161, have equal sides.

Figure 16b shows in what manner a close-packed lattice may be built up from graphite rods for which the ratio of the two sides is 3:2. These two figures, 16a and 16b, may be understood without further explanation if viewed in conjunction with Figure 16.

Figure 16c shows a cross-section and a side view of the uranium carbide plugs numbers 162, 163, 164, and 166 in Figure 16. Section AA' in Figure 16c shows the slits in which the liquid cooling agent can flow through the uranium carbide plug.

It is of advantage to surround the lattice which is embedded in a slowing agent with a layer which is composed of a scatterer that has a low absorption for thermal neutrons. Heavy elements which have a low absorption, such as lead or bismuth, can be used, and bismuth is preferable to lead from the point of view of low neutron absorption for equal scattering cross section. Graphite can be used as a scatterer and a layer of graphite about 50 cm thick has a considerable effect in reducing the critical thickness of the lattice. Layers containing one or more of such scattering elements may be used, and the combination of graphite and a heavy element if used as a scattering layer acts also partially as a neutron and gamma ray shield.

Such shields are necessary in order to protect personnel from the action of these penetrating radiations. In order to get perfect shielding, one has to use, outside the reflector, a shield which contains elements that absorb thermal neutrons. A shield built of layers of graphite and iron is suitable; graphite and iron built up in alternate layers form a satisfactory shield against neutrons and gamma rays, if the weight ratio is about 2 to 3 in favor of iron and the thickness of the layer is adequate.

Use of Beryllium.

Uranium spheres surrounded with a layer of beryllium or cylindrical uranium rods surrounded with a cylindrical layer of beryllium, may be used as lattice elements in a lattice which is embedded in graphite or heavy water. Spheres of uranium metal, 5 cm in diameter, surrounded by a $2\frac{1}{2}$ cm layer of beryllium metal are, for instance, an example of the lattice element which can be used in graphite to be in the potentially chain reacting unit. An example for a lattice element in which a cylindrical rod of uranium is surrounded with a layer of beryllium is shown in Figure 80.

I Replacement

Arrangement Class 1Calpha.

Metal, Series Flow. (gravity flow) --Figure 40 shows an example in which the lattice is built of uranium metal rods. An element of the lattice is shown in the Figure. 401 is part of a graphite column which contains a cylindrical rod 402 of uranium metal which is surrounded by a thin steel tube 403, contained in a cylindrical bore in the graphite column 401, leaving an annular gap 404 between the graphite and the steel tube. This cylindrical uranium rod is hollow but no cooling agent is passed through the hollow space in the axis of the rod. The cooling agent flows in the downward direction through the whole length of the entire graphite structure in the annular gap 404. Figure 14 shows in what manner two adjacent sections of the graphite column are joined together. In Figure 14, 401 is the lower graphite brick and 405 is the adjacent brick, which are joined toegher to form part of the vertical graphite column which goes through the entire graphite structure.

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Figure 43 shows another example in which there are 4 uranium rods, (each within a thin steel tube) placed within a cylindrical bore in the graphite brick 401. 411 is a steel plate which serves to hold the 4 uranium rods shown in Figure 43 in position. That fraction of the cooling agent which flows within the uranium rod aggregate proper is deflected by the steel plate 411 and united with the main flow of the cooling agent which passes between the steel plate 411 and the surface of the cylindrical bore in the graphite column.

Figure 45 shows how one may assemble a lattice having lattice elements as those shown in Figure 40, in a manner which permits the removal of the uranium rod 402 of Figure 40 from the graphite structure. In Figure 45, (1), (2), (3), (4), and (5) are adjacent square graphite columns arranged in a vertical position. Uranium rods 402 form a lattice which has a tetragonal symmetry. A liquid Bi-Pb alloy flows from the pipe (10), (11), and (12) into the steel cylinders (13), (14) and (15) respectively. These steel cylinders communicate with the steel cylinders (16), (17) and (18) and the Bi-Pb alloy will have a certain level in the cylinders (13) to (18) and will flow under the action of agrvity into the gaps 404 between the uranium rods 402 and the graphite. Bi-Pb alloy flows along the surface of the uranium rod through the whole structure and is collected in the bottom, goes through a heat exchanger and is pumped back to the top of the structure. The steel rods (19) are attached to the uranium rods 402 and the uranium rods can be pulled out of the structure be means of the steel rods.

Uranium metal rod arrangemt -- parallel flow. --In Figure 33, 331 is a square shaped graphite brick with a cylindrical bore in the center. A uranium rod 333 covered by a thin-walled steel tube, 334 goes through the bore in the center of the grahpite brick, leaving an annular space 335 free for the flow of the cooling agent. 332 is another square shaped graphite brick which forms together with 331 part of a vertical graphite column which goes through the entire pile structure. The cooling agent moves in the downward direction in the duct to 336. It enters the annular space 335 through the channel 337 from where about half flows upward and half flows downward in the annular gap surrounding the cylindrical uranium rod 333. The cooling agent which has been in thermal contact with the uranium rod 333 is collected in the duct 338 in which it passes through the pile in the downward direction.

Another similar arrangement in which the uranium rod is composed of a number of sections which are joined together in the same place in which the sections of the graphite column are joined together is shown in Figure 30. 301 and 302 are adjacent graphite bricks in the vertical graphite column. 305 is the annular gap surrounding the uranium rod 303. 304 is a thin steel tube which covers the uranium rod 303. The cooling agent enters from the duct 306 into the annular space surrounding the two sections of the uranium rod which are shown in the figure through the channels 307 and 308. 309 and 310 are steel disks which center the uranium rods in the bore in the graphite column. Channels in these steel dicks, like, for instance, the channel 311, permits a drainage of the cooling agent in case a liquid cooling agent is used. Otherwise, the same applies to the construction shown in Figure 30 as applies to the construction in Figure 33.

The construction shown in Figure 32 is very similar to the construction shown in Figure 30, the only difference being that instead of a solid uranium rod, we have here a hollow uranium rod, the inner wall of which is covered by a thin-walled steel tube, and the cooling agent flows both through the annular gap outside and the steel tube inside the uranium rod.

Figure 31 differs from the previous figures 32 and 33 only inasmuch as we have here an aggregate of uranium rods inside a thin steel tubes and these aggregates which have the contour of a cylindrical rod form the lattice element in place of a single massive uranium rod shown in the previous figures.

Carbide Rods--Bi Cooling.--Figure 17 shows a square shaped graphite rod 178 which forms part of the vertical graphite column that goes through the whole graphite power unit. A circular bore in the center of the square graphite rod contains cylindrical rods of uranium carbide 179, 180, 181, 182, and 183 etc. These pieces of uranium carbide are piled up one on top of the other and aggregate into a long cylindrical rod of uranium carbide going through the whole length of the graphite structure. Each of the sections 179, 180, etc., has a shape simiar to the (cross) section AA' in Figure 16c. The sections 179 and 180 are separated by a ring of uranium carbide 184 and similarly, sections 182 and 183 are separated by such a ring 185. The cooling agent flowing downward in duct 186 passes through the channel 187 into the interior of the ring 184 and about half of the amount entering into the ring 184 passes through the slits in 180, 181 and 182 into the interior of the ring 185. From here the cooling agent goes through the channel 188 and into the duct 189.

This arrangement represents again parallel flow. The length of the uranium carbide rod between 2 adjacent rings 187 and 188 will be smaller towards the center of the graphite structure and larger towards the periphery of the power unit as discussed above in conjunction with Figure 16.

A number of square-shaped graphite bricks 178 placed side by side in the manner shown in Figure 16a wil form a tetrgonal lattice of uranium carbide rods. If a graphite brick of a slightly different shape is used and placed side by side in the manner illustrated in Figure 16b, we obtain a trigonal lattice of cylindrical uranium carbide rods.

Figure 16 shows a graphite column 161, containing a string of short cylinders of uranium carbide, 162, 163, 164, 166. By placing a number of such graphite columns side by side, standing in a vertical position, one obtains a cubic lattice of short uranium carbide cylinders. The square shaped graphite rod 161 has a circular bore in its center and cylindrical graphite rods 167, 168, 169, 170, and 171 alternate with the above-mentioned short uranium carbide cylinders in this bore. A cooling agent, for instance liquid bismuth, flows through the graphite column in the duct 172 and a certain fraction of this flow enters through the duct 173, the graphite rod 169. About half of this quantity flows through the uranium carbide cylinders 164 and 166 and the channel 174 to the duct 175 which passes downward through the graphite column 161. The rest flows through the uranium carbide cylinders 163 and 162 and enters through the channel 176 into the duct 175.

This type of flow we shall call parallel flow and in particular sections of the lattice which are shown in the drawing, two lattice elements are in series. The number of lattice elements which are in series may be different in different parts of the lattice. Near the center of the graphite where the neutron density is largest, we may have only few lattice elements in series or perhaps all lattice elements in parallel. Towards the periphery of the graphite structure, however, where the neutron density is lowest, a larger number of lattice elemts may be connected in series. In this manner we may, if we wish, have approximately the same rise in termperature in the cooling agent which passes from one duct 172 to the other duct 175, in spite of the fact that the neutron density, and accordingly the heat production, differs greatly between the center of the graphite structure and the periphery.

Figure 15 shows how a vertical grap hite column is built from several sections. In Figure 15, 161 is the square shaped graphite rod shown in Figure 17 and 177 is another square shaped graphite rod which is joined to the former in the manner shown in the figure. A ground surface of conical shape forms the seal for the cooling agent which flows through the ducts 172 and 175.

Figure 16a shows in what manner a cubic lattice is built from such square shaped rods, which, like 161, have equal sides.

Figure 16b shows in what manner a close-packed lattice may be built up from graphite rods for which the ratio of the two sides is 3:2. These two figures, 16a and 16b, may be understood without further explanation if viewed in conjunction with Figure 16.

Figure 16c shows a cross-section and a side view of the uranium carbide plugs number   in Figure 16. Section AA' in Figure 16c shows the slits in which the liquid cooling agent can flow through the uranium carbide plug.

(4)

It is of advantage to surround the lattice which is embedded in a slowing agent with a layer which is composed of a scatterer that has a low absorption for thermal neutrons. Heavy elements which have a low absorption, such as lead or bismuth, can be used, and bismuth is preferable to lead from the point of view of low neutron absorption for equal scatting cross section. Graphite can be used as a scatterer and a layer of graphite about 50 cm thick has a considerable effect in reducing the critical thickness of the lattice. Layers containing one or more of such scattering elements may be used, and the combination of graphite and a heavy element if used as a scattering layer acts also partially as a neutron and gamma ray shield.

Such shields are necessary in order to protect personnel from the action of these penetrating radiations. In order to get perfect shielding, one has to used, outside the reflector, a shield which contains elements that absorb thermal neutrons. A shield built of layers of graphite and iron is suitable;about 2 meters of graphite and 50 cm of iron built up in alternate layer form a satisfactory shield against neutrons and gamma rays.

Describe shielding better!!

Fe-Pb-C
Water-Pb

(5)

9

Use of Beryllium

Uranium spheres surrounded with a layer of beryllium or cylindrical uranium rods surrounded with a cylindrical layer of beryllium, may be used as lattice elements in a lattice which is embedded in graphite of heavy water. Spheres of uranium metal, 5 cm in diameter, surrounded by a $2\frac{1}{2}$ cm layer of beryllium metal are, for instance, an example of the lattice element which can be used in graphite to be in the potentially chain reacting unit. An example for a lattice element in which a cylindrical rod of uranium is surrounded with a layer of beryllium is shown in Figure 80.