

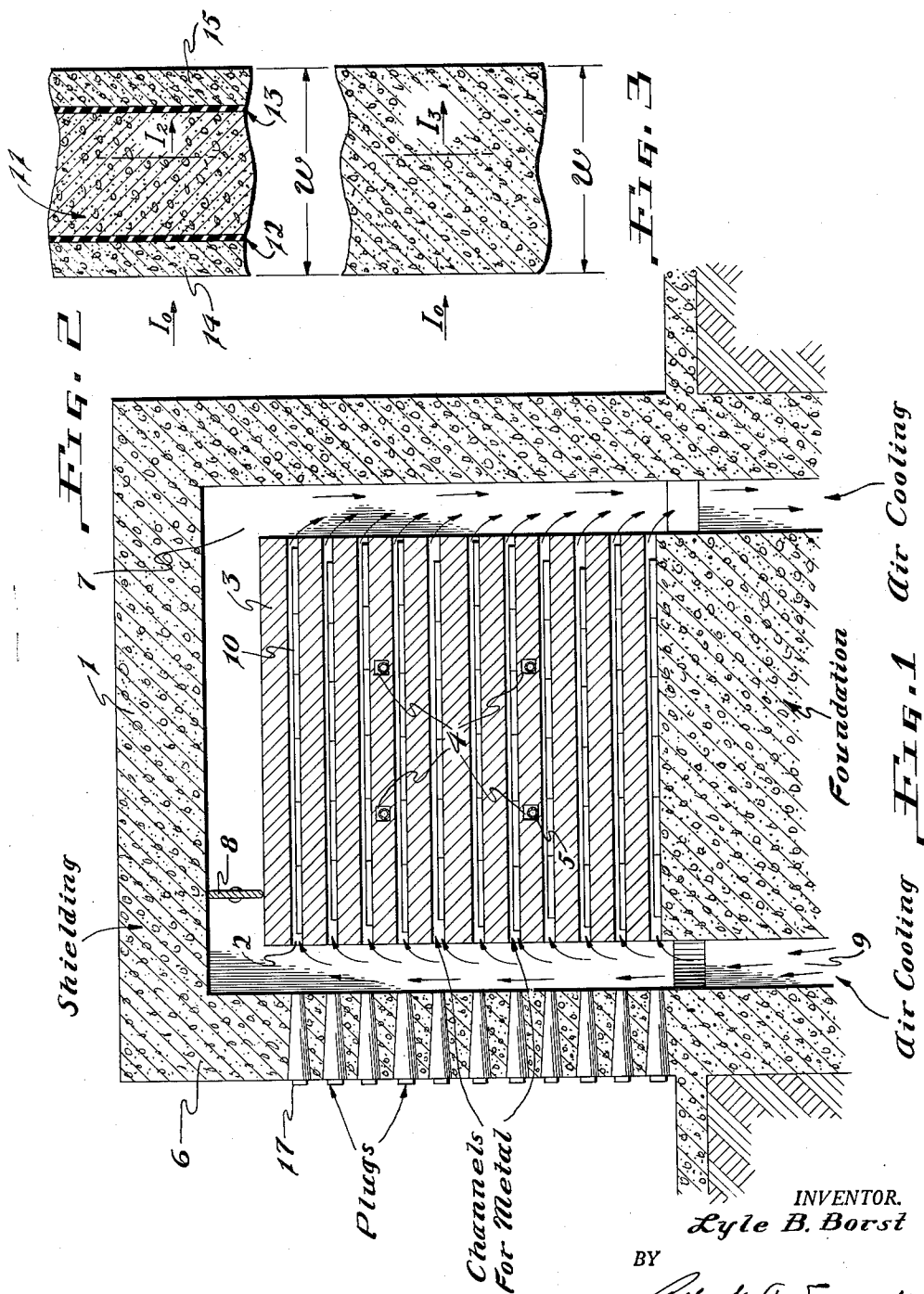
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NEUTRONIC REACTOR SHIELDING

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NEUTRONIC REACTOR SHIELDING

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1 Claim. (Cl. 204—193.2)

This invention relates to improvements in shielding against radioactivity. More particularly, this invention concerns improved shielding against very high activities and particularly activities such as neutrons.

While certain radioactive emanations have been known and used for some time and have served many useful purposes, it has also been appreciated that there is considerable danger associated with the handling and use of such radiations. It has already been proposed in the art to use shielding for protecting workers and equipment. However, compared with the magnitude and type of radiations obtainable at present, the prior art methods of shielding are insufficient.

In the past shielding has involved protection against the radiations from radium or similar substances or against X-rays, namely the most common sources of radiation which heretofore have been employed industrially. The use of lead shielding material, certain rubber materials and certain concretes or plasters have been found to constitute satisfactory shielding against X-rays and the like.

More recently, however, with the advent of the cyclotron, the subject of shielding has again presented problems not only because of the greater intensities of radiations, but because of the emission of neutrons against which shielding is required. The publication "Applied Nuclear Physics" by Pollard and Davidson, published by John W. Wiley & Sons, New York, 1942, discusses protection against radiations including the protection against cyclotron radiations. For example, it is there indicated that water or other hydrogen-containing media is the principal shielding material for use against neutrons. While tanks containing water under certain conditions constitute effective neutron shielding, it is apparent that the fabrication of complicated shielding configurations for containing water is limited or presents considerable difficulty. Also, there is the attendant danger that tanks may leak thereby rendering the shielding ineffective. In addition, water is not too effective at high neutron energies but functions at neutron energies below 100,000 electron volts, namely low energy and slow neutrons.

Recently there have been other developments in method and means of producing radiations whereby there are obtained neutron emissions and other radiations of a magnitude which far exceeds the intensities previously obtained by means of the largest X-ray equipment, cyclotron or similar devices. When it is considered that the activity involved is comprised largely of neutrons, and that neutrons are several times more potent than, for example, gamma or X-rays, it is apparent that the provision of suitable shielding for such high intensity sources presents a problem of considerable magnitude.

I have found, however, a solid type of shielding material for use against such radiations which may be em-

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ployed either alone or in conjunction with media such as water or other hydrogen-containing substances.

This invention has for one object to provide an improved shielding medium for use against neutrons.

Still another object is to provide a shielding medium that is effective against neutrons of high energies.

Still another object is to provide a solid type of shielding medium that is easy to pour or cast into various configurations.

A still further object is to provide a shielding medium that is structurally strong and otherwise lends itself to large scale construction and use.

Still another object is to provide a shielding material that is susceptible of variation in composition dependent upon the nature and intensity of the radiations against which shielding is desired.

Still another object is to provide a shielding material that is particularly useful in shielding chain reactions involving nuclear fission.

Other objects will appear hereinafter.

I have found that certain types of cement or concrete compositions containing in addition to or in place of certain of the standard ingredients such as cement, aggregate, sand, water, and the like, but also containing barium sulfate not only forms a shielding medium against gamma rays but provides a shielding medium which effectively slows down fast neutrons. I have found that the material of the present invention is particularly useful in forming a shielding medium for surrounding a chain reaction involving nuclear fission, as for example, the shielding of a pile or comparable unit.

Inasmuch as the types of reactions giving off neutrons of high energy and related information concerning the generation of extremely high intensity radiation is relatively new and known in the art to a limited extent, certain preliminary description is set forth primarily for background. That is, the construction of means for accomplishing nuclear reactions involving fission and the operations of such nuclear reactions therein are described below for giving a better understanding of the conditions and environment under which my improved shielding may be utilized. However, the specific details of constructing a pile, neutron reactor, or comparable device for carrying out chain reactions is not a limitation on the present invention, and is not claimed herein excepting insofar as it may cooperate with the particular shielding described.

The construction to be described will be generally referred to as a pile. The pile constitutes an environment in which to expose natural uranium or comparable material under conditions whereby nuclear fission is obtained along with the generation of fission products and various radiations such as neutrons, gamma rays and the like.

Various materials (i.e. elements having a light nucleus) as heavy hydrogen, helium, beryllium, and carbon may be used as the environment for the material undergoing fission. For example, high purity graphite blocks constitute a convenient construction material. Suitable openings may be provided in the blocks for inserting the material to undergo fission.

The shape of the pile may, for example, be spherical but because of constructional consideration, for simplicity a rectangular or cubical pile is the particular embodiment

described herein. The particular dimensions and spacing of the uranium material therein would be governed by the overall size and the amount of material to undergo pile treatment. A construction of the order of 7 to 20 feet or more on each dimension would be satisfactory. As indicated, suitable openings and channels may be provided for placing in and removing from the pile, the material to undergo the chain reaction. Also openings or conduits may be provided in or through the pile for access thereto for other purposes.

There may also be provided adequate control means for operating the pile. This would include rods, compressible springs or the like, designated as regulating means or shim rods, positioned within or adapted to be inserted into the pile in a manner so that the effective amount thereof may be varied. These regulating and safety means may be comprised of cadmium, boron, mercury, gadolinium or alloys thereof. For example, boron alloy steel is satisfactory. Such materials absorb neutrons. By varying the amount of such material concentrated in the zone of high neutron activity, the above referred to chain reaction may be controlled. The entire graphite section may be enclosed in my improved shielding composition confining the radiations therewithin as will be described in detail hereinafter.

When a properly constructed pile has been charged with a uranium material, such as natural uranium including a content of uranium ($^{92}\text{U}^{235}$), and the control means are adjusted, fission will be brought about by a random slow neutron or by the spontaneous splitting of an atom of $^{92}\text{U}^{235}$. As is known, natural uranium has a concentration of about one part U^{235} to 139 parts of U^{238} . When fission occurs in the environment described with the emission of neutrons, the neutrons that escape from the apparatus are limited and the speeds of others are reduced, permitting the setting up of a chain reaction. By suitable control, as indicated, the chain reaction proceeds giving off intense radiations.

For further understanding of the construction which has been discussed broadly in the preceding paragraphs, reference is made to the attached drawing forming a part of the present application.

FIG. 1 is a diagrammatic sectional view of a pile construction illustrating one type of unit in connection with which my shielding may be employed. Fig. 2 is a detailed view taken through a section of one species of shielding in accordance with the present invention for showing on a larger scale a composite arrangement of shielding such as has been employed utilizing my invention. FIG. 3 is a sectional view illustrating a section of ordinary concrete for comparative purposes herein.

Referring to FIG. 1, 1 represents the overall construction of an illustrative graphite pile. The passageways 2 are channels for the uranium material as above discussed. The shielding is broadly indicated at 6, and this incloses the graphite 3, but suitable provisions may be made to include openings 17 in the shielding for access to the channels so that the channels may be charged with the metal to undergo fission in the chain reaction. Also other openings and passageways may be provided as at 4 for the introduction of control means broadly indicated at 5. The particular type of control means is not a limitation on the present invention. The means may be inserted from various points and would be in accordance with good engineering practice. That is, consideration would be given to desirability of locating control driving mechanism and related parts so as to least interfere with pile operation. The control means, however, would preferably be located so that its effectiveness will operate in a zone of high neutron intensity, as for example, in or near the center of the pile graphite or other media in which the chain reaction is being controlled.

The shielding 6 as shown may preferably inclose the graphite pile on all sides, but may be spaced therefrom as indicated at 7 to provide passageway through the pile for

the circulation of the cooling medium such as air. The shielding indicated at 6 represents the broader aspect of my invention. That is, it is similar to ordinary concrete excepting that it contains special aggregate as will be described. Suitable damper means indicated at 8 may be placed at one or more points for controlling and directing the air flow. Other details of construction may be included such as air conduit 9. Metal undergoing fission is indicated at 10.

Referring now to the shielding construction, one special embodiment is as shown in FIG. 2. The inner portion of the shielding as indicated at 11 includes the shielding composition of the present invention the component parts of which will be described in detail hereinafter. Surfaces of this inner portion may be coated with a waterproofing material such as bituminous composition as indicated at 12 and 13 but this is not mandatory. These surfaces may be further overcoated by standard cement compositions or slabs indicated at 14 and 15.

As indicated, the particular internal structure, such as the graphite section 3, the cooling means 9 and related parts form no part of the present invention and are not a limitation excepting insofar as the special composition and structure of the present shielding may cooperate therewith.

Considering now the composition of the shielding material with which the present invention is particularly concerned, its method of preparation and related details are described below.

In general, the shielding material may be regarded as somewhat similar to standard concrete in that it is made up of aggregate, cement, and water. However, in this novel shielding material there are certain ingredients incorporated in proportions and under conditions not comparable to ordinary concrete. That is, in shielding material of the present invention, there is incorporated content of barium sulfate (barytes) aggregate. In certain special embodiments a content of the porous type of aggregate exemplified by that disclosed in Patent No. 1,707,395 of Hayde may be incorporated. Also in certain species a substantially larger amount of water than normally employed may be used.

The patent of Hayde discloses in detail a particular type of porous aggregate which I may use as a matter of choice as one of the ingredients of the shielding material. The aggregate is manufactured from a raw material of an argillaceous or clayey character which upon being burned will harden and form a clinker or mass which is subsequently crushed before mixing with the cementitious material. In manufacturing the aggregate the basic raw material is first broken up into suitable sizes which may, for example, be such as to pass a screen of about 4-inch mesh. The material thus prepared is then burned in a suitable kiln at a temperature in excess of 1500°C . so as to first expand the material, destroy the organic matter therein, and produce a hard mass or clinker of cellular formation. The temperature and burning period is regulated so as to give a hard cellular formation without burning the material to such an extent as to vitrify it.

The individual materials used in making up my shielding compositions should be of a good grade. That is, Portland cement may be used, but preferably it should be carefully handled and stored under conditions so that there is no detrimental effect thereupon by moisture or weather conditions. Also, preferably a reasonably new cement, namely one which has not been in storage sufficiently long to have any opportunity to deteriorate is employed.

The aggregates should be substantially free of, or contain a minimum of soft, friable, thick, flaky, elongated or laminated particles, lignite or other deleterious substances. Also, the aggregate material should not contain strong alkali or organic materials. The size and amount of the aggregate and other related information will be described in further detail below.

Likewise the water used should be clean and free from injurious amounts of acids, alkalies, oil, organic matter or other deleterious substances.

The ingredients may be mixed together in conventional equipment and in accordance with standard practice. However, it is preferred that the shielding composition be cast or poured not later than approximately one hour after its preparation.

Further details concerning the ingredients and their mixing will be apparent from the following data:

A cement, preferably a low heat cement is employed having its chemical composition within the following limits:

	Percent
Tricalcium silicate, $3 \text{ CaO} \cdot \text{SiO}_2$ -----	21 to 45
Dicalcium silicate, $2 \text{ CaO} \cdot \text{SiO}_2$ -----	25 to 50
Tricalcium aluminate, $3 \text{ CaO} \cdot \text{Al}_2\text{O}_3$ -----	4 to 8
Tetracalcium aluminoferrite, $4 \text{ CaO} \cdot \text{Al}_2\text{O}_3 \cdot \text{Fe}_2\text{O}_3$ -----	10 to 15
Calcium sulfate, CaSO_4 -----	2 to 3.5
Free calcium oxide, CaO -----	0.1 to 1.0
Magnesium oxide, MgO -----	1.6 to 3.5
Ignition loss -----	0.6 to 1.9

The sieve analysis of the particular porous type of aggregate described above, used in some of the mixes as described herein conformed approximately to the following:

Sieve No.	Percent Passing Limits	Actual Test, Percent Passing
4 -----	98-100	99.6
8 -----	90-94	93.1
16 -----	55-61	60.4
30 -----	35-38	37.0
50 -----	21-23	21.3
100 -----	13-15	13.6
F.M. = -----	2.88-2.69	2.75

The fineness modulus (F.M.) preferably is maintained between 2.70 and 2.90.

The special aggregate comprised barytes (barium sulfate) of two sizes, the sieve analysis of which is approximately as follows:

Sieve No. or Size of Mesh	Aggregate "A", Percent Passing	Aggregate "B", Percent Passing
7/8" -----	100	-----
3/4" -----	95-100	-----
3/8" -----	70-90	-----
4" -----	35-65	100
8" -----	5-25	90-100
16" -----	-----	50-80
30" -----	-----	22-42
50" -----	-----	5-15
100" -----	-----	0-5
F.M. = -----	5.95 to 5.20	3.33 to 2.68

A further understanding of my invention may be had by a consideration of the following examples. In Example I the general aspects of compositions in accordance with the present invention are illustrated. In the other examples certain species of compositions are illustrated.

Example I

The components comprising the mix were present in the following percentages ranges by weight on a dry basis.

	Percent
Low heat cement -----	15 to 45
Special aggregate "A" and/or "B" -----	30 to 60
Sand or other conventional ingredients -----	0 to 40

Sufficient water, in accordance with the practice in the art, to obtain good mixing was incorporated with the above ingredients.

Examples of mixes illustrating species of compositions under the invention are described below.

Example II

	Lbs.
5 Low heat cement—about 7 bags per cu. yd. -----	658
Special aggregate "A" plus "B" ¹ -----	2015
Porous type aggregate -----	943
Mixing water about 55 gals. -----	459
10 Water absorbed by porous type aggregate about 7% or -----	66
Total water -----	525
Slump approximately 3 3/4" A.S.T.M. Standard Method	
15 Strength at 28 days 2000 lbs. to 2500 lbs. per sq. in.	

¹ Special aggregate 50% "A" and 50% "B" with permissible variation $\pm 5\%$.

A still further example is as follows:

Example III

Basic weights are per cu. yd. of concrete. Surface moisture content of special aggregate was $\pm 1.5\%$. The surface moisture on the porous type aggregate was estimated as about 5%. The water absorbed by the porous type aggregate was estimated as about 26%.

	Basic dry weight
Cement—7.5 bags (per cubic yard) -----	705
Special aggregate (barytes) -----	1991
30 Porous type aggregate -----	892
Mixing water added—48 gal.	
Surface water in special aggregate -----	1.5%=30 lbs.
Surface water in Haydite -----	5%=45 lbs.
	(75 lbs.=9 gal.)

	Lbs.
35 Total water—57 gal. -----	475
Water absorbed by Haydite—26% -----	231
40 Strength about 2400 lbs. per sq. in. at 28 days	
Slump, approx. 5 1/2" A.S.T.M. Standard Method	

Example IV

	Basic dry weight
Porous type aggregate sand (moisture 33%) -----	1779
45 Barium sulfate coarse aggregate -----	3017
Low heat cement -----	1058
Water -----	61

Example V

	Basic dry weight
50 Porous type aggregate sand -----	1177
Barium sulfate coarse aggregate -----	2021
Low heat cement -----	705
Water -----	42
55 Slump (A.S.T.M. Standard Method) -----	6

The chemical composition of the low heat Portland cement used in Examples IV and V was:

Symbol	Percentage	Chemical Compound
60 C_3S -----	44.24	Tricalcium Silicate.
C_2S -----	30.85	Dicalcium Silicate.
C_3A -----	5.17	Tricalcium Aluminate.
C_4AF -----	13.22	Tetracalcium Aluminoferrite.

The correct design for any shielding using the above ingredients would preferably result from trial batches run to determine any peculiarities of given ingredients.

The above compositions may be used as cast. However, with respect to the composition containing large amounts of water, in addition to the barium sulfate content in accordance with my invention, if desired, the surfaces may be sealed with membrane waterproofing or bituminous coatings as indicated in FIG. 2 at 12 and 13.. The membrane waterproofing and the bituminous

coating are commercially obtainable materials which are waterproof and serve to deter moisture evaporation from the cement. Such material is applied to form a complete and impervious moisture retaining envelope. A coat of conventional primer may be applied before these finishes are applied on the shielding.

Care should be observed in rodding the concrete compositions in place to secure maximum density and accurate placement and at the same time preserve the accuracy of the work without disturbing inserts, pipes, sleeves and the like.

In the compositions containing porous aggregate preferably the concrete would be kept wet but not to the extent of dripping. The porous type aggregate material may absorb 25 percent or more of water and hence the material preferably is kept near this saturation. Spraying should be done carefully and uniformly, preferably within approximately 48 hours previous to use.

Compositions in accordance with this invention may require slightly more time for mixing than standard materials and hence the mixing time may be increased to a minimum of 1½ minutes but excessive mixing is to be avoided to prevent pulverizing the aggregates involved. Full speed mixing time usually may be limited to about 2½ or 3 minutes.

The compositions in accordance with this invention are poured or cast in a conventional manner.

If mechanical vibration is utilized this should be carefully carried out. Since the ingredients used in the composition of this invention may differ materially in weight, there may be a tendency toward segregation and this is avoided. Effort is made to keep the temperature of the composition as low as possible by proper wetting and curing methods, and as stated previously, with respect to certain of the compositions care is taken to retain all moisture within the body of the composition until a membrane or moisture sealing envelope is applied.

In the above mixes the porous type aggregate ingredient may be reduced or omitted and a satisfactory neutron shielding still obtained. The compositions may be fabricated into any desired configuration as for example the structure shown in FIG. 2 may be poured. When intricate shapes are involved or inserts as plugs 17 are to be included, the proportions chosen, are such that larger amounts of the finer aggregate are present to obtain workability.

The property of the shielding described herein for slowing down fast neutrons is indicated by the following comparison, reference being made to FIGS. 2 and 3.

In FIG. 2 there is diagrammatically shown a section of shielding of a measured thickness of a composition in accordance with the present invention. That is, the composition indicated by reference numeral 11 was of a mix in accordance with Example IV. This inner section 11 was coated with bituminous materials at 12 and 13 and layers of ordinary concrete applied at 14 and 15.

The overall width or thickness W of the shielding of FIG. 2 was the same as the overall width or thickness W of an equivalent amount of ordinary cement diagrammatically shown in FIG. 3. In the particular situation being described W was approximately seven feet.

For the purpose of comparing the shielding value, an extended source of equal intensity of fast neutrons was applied against one side of the shielding. By extended source reference is made to a relatively widely distributed source of neutrons as compared with a point source or beam. This source is indicated by the symbol I_0 and probably was of the order of 10^{12} neutrons per square centimeter per second. However, since the intensity was of the same magnitude in both instances, the specific value thereof is not material for the purposes of this comparison.

Evidence of neutrons on the opposite side of the shielding of FIG. 2 away from the source was tested for and none were detected. On the other hand, with respect to

the ordinary cement of FIG. 3, neutrons penetrated through the entire thickness W .

Measurements were then made in the interior of the shielding, through suitable test openings which had been provided. A point at approximately four feet from the source (I_0) of the neutrons was taken and measurements made being designated I_2 for the construction shown in FIG. 2. Similar measurements were made at a comparable point (I_3) within the composition illustrated in FIG. 3 at a distance of four feet.

The ratio of I_2 to I_0 of FIG. 2 was of the order of 10^{-8} .

The ratio of I_3 to I_0 of FIG. 3 was of the order of 2×10^{-4} .

In this comparison it will be kept in mind that the I_0 represents a source of neutrons of all energies to the upper limit of the fission energy spectrum. It will be observed that the shielding of FIG. 2 in accordance with the present invention reduced the intensity of the fast neutrons (the most penetrating component) many hundreds of thousands of times that of the same thickness of the ordinary cement section represented in FIG. 3.

It has been found that for fast neutrons the barium sulfate containing concrete compositions in accordance with the present invention, particularly where the neutron intensity is in excess of two million electron volts is especially effective in slowing down such neutrons. At the order of one hundred thousand electron volts or less water is an effective medium. Therefore, in some of the species of compositions of the present invention where both barium sulfate and a water content are present, neutron emissions of high intensity may be readily shielded against.

From the foregoing it will be noted that while certain of the species of shielding compositions may contain substantial amounts of water and while it is known that water shields against neutrons, the content of water in the compositions of the present invention is insufficient to account for the ability to slow down neutrons. Consequently, it is apparent that the ingredients, particularly the barium sulfate content, as above described cooperate in some manner to provide a material particularly effective in slowing down fast neutrons as well as shielding against gamma radiations. Although it has been known that barium sulfate functions as a shielding medium against X-rays, it is believed that it has not heretofore been known in the art that this material would also function to slow down fast neutrons while at the same time acting as shielding against gamma radiations.

The shielding material in accordance with the present invention may be substituted for or used in conjunction with conventional means that have been employed for shielding cyclotrons or other neutron generating units not only with the advantage of easier fabrication and upkeep, but in many instances being considerable more economical to install.

My shielding may comprise concrete with only a content of barium sulfate as above described and such material is effective against fast neutrons. In the above compositions the porous type aggregate component may be omitted or reduced in quantity. However, as indicated, a content of porous type aggregate or other water absorbing aggregate in some instances, may be employed in addition to my invention relative to using barium sulfate.

In general the composition as respect solid components in a mix will comprise cement 15% to 45%, special barytes component 30% to 60%, and other aggregates or conventional components from a small amount to 40%. Sufficient water would be added in accordance with the principles illustrated in the above examples to obtain good mixing and adequately wet porous aggregate if any has been included.

Certain changes may be made in the composition as

for example certain iron compounds such as iron oxides, sulfides or the like may be included for supplementing the content of barytes. Other changes will occur to those skilled in the art.

It is to be understood that all matters contained in the above description and examples are illustrative only and do not limit the scope of this invention, as it is intended to claim the invention as broadly as possible in view of the prior art.

I claim:

In a neutronic nuclear fission reactor including neutron-shield for restraining the egress of neutron radiation therefrom, improved neutron-shield means comprising a mass of solid hydrogenous concrete composition compounded of cement, water, and aggregate, at least a portion of said aggregate comprising barytes, ingredients other than water being in approximately the following proportions by weight: cement 15 to 45%, barytes aggregate 30 to 60%, and the balance other aggregate, said cement comprising the following ingredients in substantially the indicated ranges of proportions by weight:

	Percent
Tricalcium silicate, $3\text{CaO} \cdot \text{SiO}_2$ -----	21 to 45
Dicalcium silicate, $2\text{CaO} \cdot \text{SiO}_2$ -----	25 to 50
Tricalcium aluminate, $3\text{CaO} \cdot \text{Al}_2\text{O}_3$ -----	4 to 8
Tetracalcium aluminoferrite, $4\text{CaO} \cdot \text{Al}_2\text{O}_3 \cdot \text{Fe}_2\text{O}_3$ -----	10 to 15
Calcium sulfate, CaSO_4 -----	2 to 3.5
Free calcium oxide, CaO -----	0.1 to 1.0
Magnesium oxide, MgO -----	1.6 to 3.5

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