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DETERMINING THE THICKNESS OF A FURNACE LINING
BY MEANS OF NEUTRON ACTIVATION
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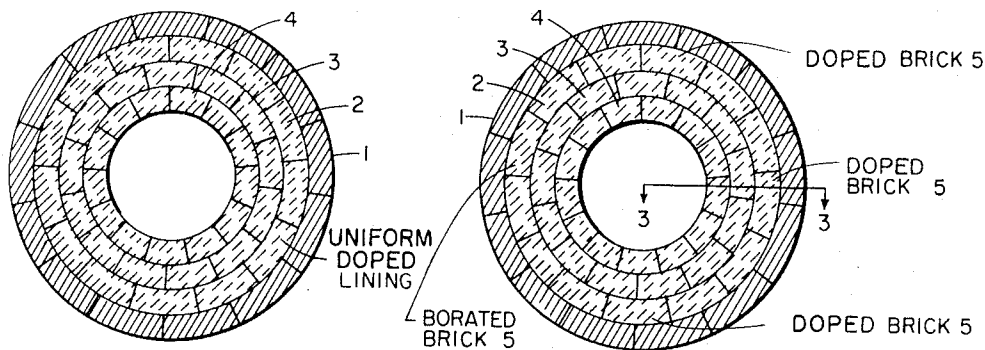


Fig. 1

Fig. 2

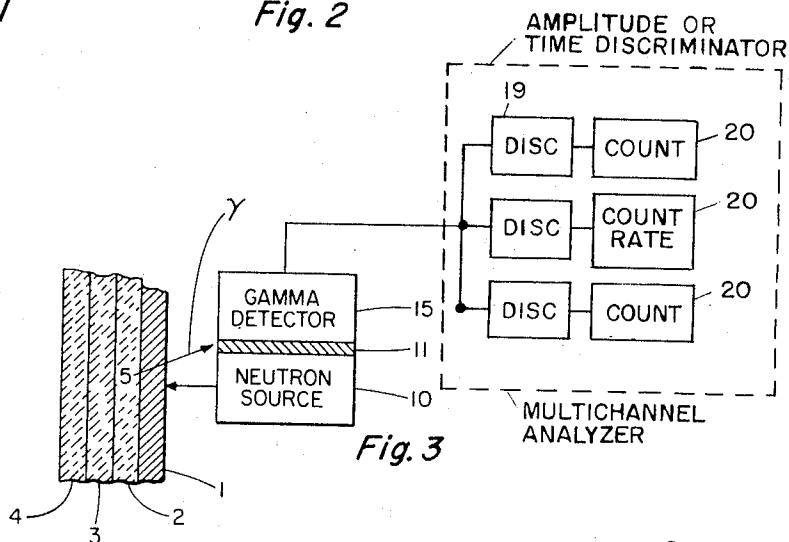


Fig. 3

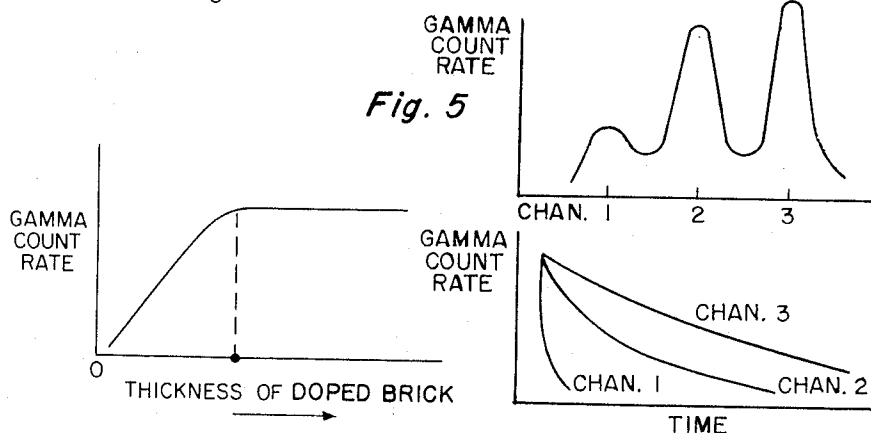


Fig. 4

Fig. 6

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DETERMINING THE THICKNESS OF A FURNACE LINING BY MEANS OF NEUTRON ACTIVATION

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This invention relates to a furnace lining and more particularly relates to a method of detecting the wear of such a lining.

In the making of steel and other metals, the outer steel shell or wall of the furnace has its inner surface lined with refractory brick to contain the molten steel and prevent contact of the molten metal with the furnace shell. Should the molten metal come into contact with the furnace shell, the shell would rupture and result in a serious accident and substantial damage.

The replacement and repair of such furnace linings is expensive because of the production losses resulting from the long shut-down periods required as well as the cost of replacing the lining per se. As a result, it is desirable to detect when the lining is almost completely worn out before shutting down the furnace for such repairs.

The detection of such wear of the refractory brick liner is difficult because the liner is inside the steel shell and thus it is not readily observable. One prior method for detecting liner wear utilizes thermocouples embedded in the brick work as shown in U.S. Patent 2,915,305. Another prior method as shown in U.S. Patent 3,078,707, utilizes resistance elements embedded in the brick work. A still further method as disclosed in U.S. Patent 2,874,303 utilizes radioactive pellets distributed within the brick liner.

The methods using resistance elements and thermocouples have the disadvantage that these elements become defective over the lifetime of the lining due to the intense heat.

The method using a radioactive isotope in the lining has several disadvantages. One disadvantage is that the steel smelted in such a furnace is contaminated by a release of the pellets as the liner wears out. Since such isotopes usually have a half-life of several years, it is becoming increasingly difficult to find uncontaminated steel such as is required for the building of radiation detectors. Another disadvantage of this prior system is that it requires a constant scanning of the steel or slag not only as an indicator of liner wear but also as an indicator of the steel contamination. In addition, the prior system presents a radiation health hazard to those normally working in the furnace area, as well as to those employed to reline the furnaces; in addition, a radiation health hazard is presented to the ultimate consumer of a product made from the steel such as an automobile or kitchen utensil.

In the prior art method of using radioactive isotopes placed in the furnace liner prior to operation of the furnace, gamma detectors measure the amount of such radioactivity in the slag or in the steel as an indication of the liner wear. These radioactive isotopes must have a life time which is long in comparison with the expected life time of the furnace liner if such a system is to function properly since the activity of the isotope decays with time and the useful detection of such radioactivity is desired only after substantial wear of the liner has occurred. While some of the disadvantages of this prior system have already been discussed, it is clear that there are other disadvantages of this system. For example, the furnace is radioactive during the whole life time of the liner even though this radioactivity of the liner is useful in detection of liner wear only as the liner is almost completely worn

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out. In addition, if for example, erosion of the liner is not uniform as is usually the case, a large segment or chunk of radioactive material may break loose and thus indicate that the entire liner has worn out.

Accordingly, there is a need for a device and method which will detect the wear of the furnace lining without being affected by high temperatures and which will not contaminate the steel nor affect the health of employees while yet accurately indicating when the lining is almost worn out.

It is an object of this invention to satisfy the above-mentioned need.

It is an object of this invention to detect furnace liner wear using radiation techniques with minimum harmful effects on maintenance and operating personnel.

Another object is to detect furnace liner wear using radiation techniques with minimum contamination of the steel.

Another object is to detect furnace liner wear using radiation techniques which indicate positively the thickness of the liner remaining as opposed to the amount of liner which has eroded.

A further object is to detect furnace liner wear in which the liner may be made radioactive periodically by irradiation from an external controllable source at any time during operation of the furnace.

One aspect of the invention provides apparatus and methods for detecting the wear of the furnace liner by neutron irradiation of the furnace and detection of gamma rays emitted by the activated natural constituent elements of the brick without any doping of the bricks. In particular, irradiation of the furnace with fast or thermal neutrons will activate the silicon, aluminum, and other elements in the brick to emit gamma rays of known characteristic energy levels for known characteristic short half-lives. The neutron source may be pulsed or continuous and subsequently during the half-life of the activated brick constituent, gamma rays may be counted as an indication of liner wear.

According to a second aspect of this invention the furnace liner may be doped or tagged with one or more high neutron cross-section materials which upon neutron irradiation emit known characteristic gamma rays either promptly (within 10⁻¹² seconds) or during a short half-life. The neutron source may be pulsed or continuous and subsequently or substantially instantaneously thereafter the emitted gamma rays may be detected. A measurement and/or comparison of the count rates of various gamma rays is used as an indication of liner wear. Such tagging materials preferably have a high neutron cross section for the energy (fast or thermal) of the neutron irradiation and emit a gamma ray which is prompt or delayed and of sufficient amplitude or energy to pass through the steel plate of the furnace to permit detection in the presence of the neutron source while not causing contamination of the steel or a hazard to operating personnel.

In accordance with the above aspect the doping or tagging of the brick may be uniform throughout the liner, or bricks having a distinctive and/or different tagging ingredient may be selectively positioned throughout the liner so that a measurement of distinctive gamma rays which are characteristic of the particular tagging materials indicate the amount of liner remaining.

The above objects and advantages of this invention are accomplished as described in the following detailed description of the invention in which:

FIG. 1 is a cross section of a furnace showing a uniformly doped liner.

FIG. 2 is a cross section of a furnace showing doped bricks at spaced points within a liner.

FIG. 3 shows the preferred arrangement of the wear detection apparatus including a neutron source and gamma detector outside of the furnace.

FIG. 4 is a graph showing the variation in detected gamma count rate as a function of the erosion of the brick liner and more especially the remaining thickness of the brick liner as detected by any of the methods of this invention.

FIG. 5 is a graph showing the count rate in three channels of a multichannel analyzer in which each channel counts distinctive gamma rays and in which a comparison of the count rates in the channels indicates liner wear.

FIG. 6 is a graph showing comparison of the count rates in three channels of a multichannel time analyzer as an indication of liner wear.

FIG. 1 shows the cross section of a furnace having the usual outer elongated cylindrical steel shell 1. Within the shell 1 are three concentric cylindrical rings 2, 3, and 4 of refractory brick which form linings within the furnace. Such furnaces when used for smelting iron are generally elongated vertical cylinders extending to 100 feet in height. Coke, limestone and iron ore are deposited in the furnace from the top and molten steel is tapped from the bottom for casting and subsequent rolling. Of course, the invention has application to electric and other furnaces which operate somewhat differently while still using a refractory lining.

In FIG. 1 the lining 2 which is closest to the inner surface of the steel shell is made entirely with bricks which have been doped with a high neutron cross-section material for reasons to be described subsequently.

In FIG. 2 another embodiment of the liner is shown in which doped bricks 5 are placed at selected predetermined points in lining 2. All of the remaining bricks in liners 2, 3, and 4 are of the conventional refractory brick type. The term doping as used in this specification refers to the addition of high neutron cross-section material and is not limited to a coating on the brick but preferably refers to a homogenous mixture of the additive material and the clay at the time of manufacture of the brick.

In FIG. 3 a partial cross section of FIG. 2 is shown of a short section along the length of the furnace. A neutron source 10 is positioned outside the furnace adjacent the doped brick and is arranged to irradiate the furnace and the brick with thermal neutrons and fast neutrons. Thermalization may occur within a moderator at source 10 or within the brick.

A gamma detector 15 of the scintillation or solid state semiconductor type is also positioned outside the furnace and separated from the neutron source by a lead shield 11. Detector 15 connects to a multichannel analyzer which may include amplitude or time discriminators and count rate circuits. FIG. 4 shows the response curve obtained from this reaction as a function of the remaining thickness of the brick liner.

The invention according to this disclosure detects the wear of a furnace liner by neutron activation of the brick liner and detection of the radiation emitted by the activated brick material as a measure of remaining brick thickness.

Irradiation of a material may cause a number of nuclear reactions and the probability of a particular reaction will depend in part upon the type of material irradiated and the energy of irradiation.

For the irradiation of the brick liners of this invention neutron irradiation is desired in preference to electromagnetic, proton or other types of radiation.

This invention contemplates the use of either fast, intermediate, or thermal neutrons. The advantage of neutrons is that they are neutral and have sufficient mass to penetrate and to activate the brick liner.

The selection of fast versus slow neutrons for irradiating the furnace depends upon a number of factors discussed below.

Important factors in the irradiation of a furnace liner are the use of a low level neutron flux source, and high energy emission from the activated brick.

The low level neutron flux is desired so that the apparatus of this invention may be used safely by the normal furnace operating and maintenance personnel. High energy gamma emission is desired from the activated brick so that this energy may pass through the liner and steel shell to the detector.

With thermal neutron irradiation, the reaction involved is the capture of the neutron by the furnace brick and the emission of a gamma ray(s).

With fast neutron irradiation the reaction involved is the capture of a neutron and the emission of a proton, alpha particle, gamma ray or another neutron depending upon nuclear reactions and the particular application.

The reaction rate of such neutron capture processes is proportional to the neutron flux and the nuclear cross section of the brick material. Thus in using either fast or thermal neutron irradiation it is desired that cross section of the capturing material (brick) be high so that a low level flux of the order of 10^5 – 10^6 n/cm.²/sec. source may be used.

Detection without doping

While it is preferred to detect the wear of the liner by doping one or more bricks within the liner, it is also possible to detect such wear by neutron irradiation of the furnace liner and detection of gamma rays from the natural constituent elements of the brick.

The major constituent elements of brick are oxygen and silicon, but there are also large amounts of aluminum and iron.

Neutron irradiation of aluminum results in an active nucleus for 2.3 minutes and emission of 1.78 m.e.v. gamma rays. Iron on the other hand has a half-life of several days.

Accordingly, when using the apparatus of FIG. 3, gamma rays will be emitted from liners 2, 3, and 4. One channel of the analyzer is biased to pass only gamma rays having an amplitude of 1.78 m.e.v. corresponding to the aluminum and the rate of these rays will be counted at 20. Thus, as the brick liners erode, the 1.78 m.e.v. gamma ray count rate at 20 decreases in the manner shown in FIG. 4.

Some of the problems involved with this method of relying upon the natural elements of the brick is that the gamma background is more prominent. This background results from the neutron source and the activation of the steel shell and molten steel.

In order to eliminate the background from the steel, it is preferred to first pulse the neutron source and then immediately thereafter count the 1.78 m.e.v. gamma rays for the time period of the aluminum half-life of 2.3 minutes or for a shorter time if desired. Thus, even though the steel may have a large nuclear cross section, because of its long half-life, only a few gamma rays are emitted during the 2.3 minute counting time period.

Detection with boron as doping material

Another method of detecting the liner wear is to dope one or more of the bricks with a high neutron cross-section material as shown in FIGS. 1 and 2. Doping of the bricks has the advantages that: (1) the bricks may be doped with a material having a higher nuclear cross section than any of the natural constituents of the brick; and (2) that the doping material may emit a characteristic radiation which is distinctive from the radiation emitted by the brick constituents, the steel or the neutron source. In addition, doping of the brick has the advantage that the doped bricks may be placed at known positions in the liner. In addition, doping permits the use of distinctive doping materials in the different brick liners to better determine when a particular liner is almost worn out.

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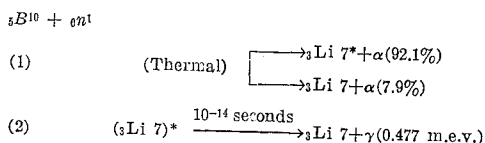
Two types of doping materials may be used for this invention. The first type is one which emits prompt gamma rays while the second type emits gamma rays over a short life time. An example of the first type is boron which has a high neutron cross section and gives off a high energy prompt gamma ray within 10^{-12} seconds which may be detected even while the neutron source is operating. Examples of the second type have a longer half-life and should have a minimum half-life of two minutes and a maximum half-life of two hours so that detection may occur after the pulsing of the neutron source without contaminating the steel or casing a health hazard. Doping materials of this second type may include antimony 122, bromine 80, gadolinium 161, rubidium 86 (m), silicon 28 among others.

In the preceding discussion, it has been assumed that if a furnace is lined with boron and is irradiated with thermal neutrons, prompt gamma rays will be emitted from the brick detected. Essentially this is true in this invention but further discussion is essential to clearly define the conditions under which the problem of this invention is solved.

The problem of irradiation with a neutron source can be appreciated when it is noted that almost every element will emit gamma rays by capture of a neutron. In addition, the gamma ray spectrum from most such materials is complex, i.e. contains a number of gamma rays at different energy levels. Thus, for example, if a steel furnace were irradiated with neutrons, prompt gamma rays would be emitted from the steel and refractory brick and their individual component elements; thus gamma rays would be emitted which were characteristic of nickel in the furnace shell, carbon and iron in the steel, and many others which have no relationship to the lining material and the problem of detecting wear of the liner.

The energy of the gamma ray emitted by an element after capture by a neutron is proportional to the mass of the element, its radiative cross section, the neutron flux and inversely with the atomic number of the element. Thus, boron, cadmium, gadolinium and other materials which have a high cross section for neutron absorption would appear to have practical application to this invention. However, it has been found that the higher neutron cross-section materials also have a more complicated gamma spectrum. In addition, to other advantages, boron for example, is basically an alpha emitter.

The probability for thermal neutron capture by elemental boron with the direct liberation of a gamma ray is small since the cross section for this reaction is only 0.5 barn. However, the probability of an (n, α) reaction is quite large since its reaction cross section is 795 barn. However, boron 10 has a cross section of 4017 barn and its capture of a thermal neutron can be represented by the following nuclei balance equations:



*Excited.

The indicated branching ratio in Equation 1 which leads either to the excited state or ground state of lithium 7 varies with the incident neutron energy. With thermal neutrons 0.025 e.v. the branching ratio of $\text{Li } 7^*/\text{Li } 7$ ground is 11.6. However, for higher energy neutron sources this ratio is substantially lower; for example, the branching ratio is only 5.0 for .35 m.e.v. neutrons and .44 for 1.90 m.e.v. neutrons.

Thus by using a low energy thermal neutron source 10, the use of homogeneously borated brick at 5 in FIG. 3 will produce large quantities of single energy (477 k.e.v.)

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gamma rays which are readily and distinctly detected at 15 and counted in one of the channels at 20.

Accordingly, this invention provides in one preferred embodiment, a system in which the outside of a furnace containing borated bricks is irradiated with a thermal neutron source (0.025 e.v.). Large quantities of prompt gamma rays are generated at a single specific energy .477 m.e.v. One discriminator 19 would be adjusted to pass gamma ray signals of this amplitude. In addition, the brick is selected to have a boron content approximately 2% by weight such that in the normal state (where none has eroded) and with a low level neutron flux the detector count rate circuit 20 which counts the .477 m.e.v. gamma rays is operating over its saturation region as shown in FIG. 4 and is further designed so that a large change occurs at the count rate meter after a predetermined portion (such as $\frac{1}{4}$ to $\frac{3}{4}$) of the thickness of the borated brick has eroded. In addition, after a furnace is first relined a calibration curve may be drawn by inserting various thicknesses of borated brick within the furnace and plotting the gamma response to neutron irradiation.

The disadvantages of the prior art are overcome by using borated bricks within the furnace liner such that the bricks can be made radioactive by neutron irradiation at any time during the steel making process and remain active for less than 10^{-12} seconds; thus no contamination or health problems exist.

Activation of short half-life doping materials

One disadvantage of the use of boron doped bricks as suggested above is that the gamma ray emission is prompt, i.e. the gamma ray is emitted within 10^{-12} seconds after neutron irradiation. Accordingly, neutron emission and gamma detection occur substantially simultaneously outside the wall of the furnace. Thus, the detection circuitry of 15, 19, and 20 operates in the presence of a large background count.

In order to reduce this background count as well as for a number of other reasons, it is desirable to dope the brick with materials which when activated by neutron irradiation become short lived radioisotopes. In such a case neutrons could be irradiated at the outside of the furnace as shown in FIG. 3 in a pulsed manner to thereby activate such doped brick. Subsequently, after the pulsing of the neutron source and within the half-life of the activated brick, the gamma detector circuitry can count the emitted gamma rays characteristic of this isotope. The doping material for this embodiment of the invention is preferably one having a minimum half-life of approximately one minute and a maximum half-life of approximately two hours. The criteria for selecting a particular doping material are that it should have a minimum half-life sufficiently long so that after the neutron source has been pulsed, the resulting background radiation has decayed sufficiently before detection is made of the resulting gamma rays from the doped brick. The criteria for the maximum half-life of the doped brick are that it should be sufficiently short so as to avoid contamination or health hazard problems. For example, the maximum life time should be less than the time between irradiation and the time the steel is drawn off from the furnace.

If a fast neutron source is used as the source of irradiation, background irradiation will be present not only from the source but also because of the activation of the silicon and aluminum in the brick. Since the half-life of such materials is of the order of 2.3 minutes, it would be desirable that the half-life of the doping material be greater than 2.3 minutes. Suitable doping materials would include antimony Sb 122 (m) (3.5 minutes), bromine 80 (17.6 minutes), gadolinium 161 (3.6 minutes) selenium SE-81 (m) 57 minutes. However, the doping material may also be one having a half-life substantially shorter than 2.3 minutes so that it can readily be distinguished from the brick constituents.

Design modifications

Having described the three general methods of detecting liner wear involving neutron irradiation and gamma detection of the natural constituents of the brick, boron doped brick and short lived isotope doped brick, other modification of the invention will be described. Such modifications relate the positioning of the doped bricks, the use of combinations of differently doped brick, various arrangements of the detector apparatus and other modifications.

The specific details of this invention can vary considerably, dependent upon the furnace operation and the desired result and protection. For example, in some furnaces molten steel is made and is then completely drawn from the furnace for the making of "pigs" as is well known, while in a foundry, for example, the furnace is tapped to draw off molten steel in small ladles for casting. In the first case there is very little actual contact of human beings with the steel while in the latter case foundry men are continuously in contact with the molten steel. Accordingly, in the latter case it is desirable to use bricks which when irradiated have a very short half-life of the order of a minute, for example, while in the former case there is no objection to using a doped brick which when irradiated has a considerably longer half-life since such steel will be in the soaking pits for several days.

In addition the selection of a particular doped brick for the lining will depend upon the position of the doped brick in the lining and the desired result. While it is preferred to have the doped brick in liner 2, the doped brick could be placed in some instances in liners 4, 3, or 2 or any combination of liners as desired. For example the doped brick may be positioned in liner 4; since this is the first liner to wear out, it is not a good indicator of liner wear but may be useful in combination with a doped brick in liner 2 or 3 for example. Since the doped brick in liner 4 is in direct contact with the steel it should have a very short life time. If doped bricks are also used in liner 3, these bricks may be doped with a material having a longer life time than those in liner 4; similarly if doped bricks are used in liner 2, they may have a life time longer than the life time of the doped bricks in liner 3. In addition, these three differently doped bricks will emit three distinctive gamma rays.

While the design requirements vary, as stated above, I prefer using doped bricks in liners 4, 3, and 2 each having known distinctive gamma emission amplitude characteristics and of successively increasing half-life from one minute to ten minutes to one hour respectively. Each of these three bricks emits a characteristic different gamma after pulsed irradiation by the common neutron beam. The gamma detector 15 and three channels of pulse height analyzer of FIG. 3 will be used to distinguish among the three bricks on the basis of amplitude and/or life time of the emitted gamma rays.

This discrimination in amplitude and/or half-life is provided by three discriminators 19 which may be amplitude or time discriminators. For example each of the discriminators in FIG. 3 may be biased at different threshold levels so that one discriminator passes only pulses having an amplitude characteristic of the doped brick in liner 4; similarly the other discriminators are biased to pass only pulses having an amplitude characteristic of the doped brick in liners 3 and 2 respectively.

In one example the analyzer as shown in FIG. 5 separates and counts the three distinctive gamma rays on an amplitude basis so that in the beginning the three distinctive counts in the three amplitude discriminated channels are substantially equal. However, as liner 4 wears out, its characteristic gamma count rate in channel 1 decreases. Subsequently as liner 3 wears out, the count in channel 2 will decrease and finally as liner 2 wears out the third count in channel 3 will decrease and indicate danger.

Thus, in the above suggested modification, the gamma detector 15 with its pulse height analyzer will have three

channels for connection to three count rate meters. The outputs of the count rate meters are connected to comparison circuits for controlling an alarm. In normal operation (with no liner wear) distinct gamma rays of three different energy levels will be received which are characteristic of the three different bricks; accordingly, the readings at the three count rate meters are equal and no alarm is sounded. As the liners start to wear out, a difference in count rate readings exist and an alarm can be sounded when the difference in count rate reading at a comparison circuit exceeds a predetermined amount.

Alternatively, the analyzer of FIG. 3 may distinguish on the basis of the different half-lives of the three doped bricks. The three discriminators may be time discriminators which are gated in sequence by a ring counter for example so that for a first time period, one discriminator passes all of the received pulses, the second discriminator passes all of the pulses in a second succeeding time period and the third discriminator passes all of the pulses in a third succeeding time period. Thus if the doped bricks in the three liners have different half-lives, the individual discriminators are open for time periods corresponding to the half-lives of the individual doped brick and a comparison of the count rates in the three channels will give an indication of the individual liner wear. After the neutron beam has been pulsed, the three channels of the analyzer will count in sequence all of the gamma rays emitted to provide a total count output for each channel. As long as the furnace liner remains intact the total count at each of the channels for a particular time period will remain substantially the same. FIG. 6 shows the decay rates of three isotopes of different half-lives; with channel 1 receiving the gamma rays from the shortest lived isotope in liner 4 while channel 2 receives gamma rays from the long-lived isotope in liner 2. As the various liners wear out, the count rate in the three channels change.

The use of plurality of pre-doped bricks having different doping material and consequently different half-lives is not limited to use in different liners but may all be used in the same liner such as liner 2 for example and at different points within that liner.

When a plurality of differently doped bricks are used and are irradiated with a common neutron beam utilizing a common detector, the neutron beam should be pulsed "on" and then turned "off" to detect the distinct gamma rays. Preferably the beam should be on for a time period sufficient to activate the brick having the longest life time and the beam should be "off" at least as long as the longest half-life time of the brick. Thus the beam is periodically pulsed with low level thermal or fast neutrons in which the period between pulses is longer than the half life of any of the doping material. Since we are interested in a comparison of the various counts of different half-life materials, detection and counting of the received gamma rays should be made when the neutron beam is off and within a time interval (after the beam is turned off) which is less than the shortest half-life of the doping materials so that the gamma rays from the various materials are counted and compared for equal periods of time when they are all active.

It should be noted that the amount of gamma radiation that occurs in this invention by doping the bricks with a material which is not normally radioactive is independent of the age of the liner and its variation with age depends upon only the thickness of the doped brick remaining within the liner. In the prior art system, the gamma emission from a radioactive isotope placed within a furnace liner decreases with the age of the system. This of course is another reason for the use of long life isotopes in such prior systems. Such decreases with age of the gamma emission from a radioactive isotope make it difficult to assess just how much of the liner has worn out several years after its installation, for example.

The various methods suggested above have several common features but in other respects are distinctly different.

The common features are the irradiation of a furnace with a low flux neutron source and the emission and detection therefrom of gamma rays which vary directly with the thickness of the remaining doped brick. It will be obvious that in normal operation each of the furnaces will be irradiated on a periodic basis either daily or weekly etc.

Having thus described the preferred embodiments of my invention as required and some equivalents, the scope of my invention is defined in the following claims.

What I claim is:

1. The method of detecting the wear of a furnace liner comprising the steps of inserting a borated brick within said liner having a boron content of the order of 2% by weight, irradiating said furnace for producing a low level thermal neutron flux in the vicinity of said borated brick of the order of 10^4 – 10^6 neutrons $1 \text{ cm.}^2/\text{sec.}$, and counting the rate of emission of gamma rays from said borated brick on a count rate meter, where, in the non-eroded state the brick has an energy of .477 m.e.v. and recounting the rate of emission after erosion of a predetermined portion when a large change occurs at the count rate meter indicating needed replacement of the liner.

2. The method of detecting furnace liner wear by neutron irradiation comprising the steps of inserting within the liner borated bricks having a $_{5}\text{B}^{10}$ content sufficient for absorbing neutrons and normally emitting 0.477 m.e.v. gamma rays at a constant rate when more than half of the brick is present and at a decreasing rate when less than half the brick is present, periodically irradiating said furnace adjacent said bricks with 0.025 e.v. neutrons at a flux density of the order of 10^4 – 10^6 neutrons/ $\text{cm.}^2/\text{sec.}$, and detecting the count rate of 0.477 m.e.v. gamma rays in normal operation when the borated brick will be physically separated from the furnace shell, and subsequently detecting the low level gamma count rate after the borated brick

is eroded whereby the furnace may be operated until the brick is almost gone.

3. In the method of making steel in which hot molten steel is retained within a steel shell and is separated therefrom by a brick lining the improved method of detecting liner wear comprising the steps of inserting borated brick within said liner having a boron content for emitting gamma rays at a constant rate even after a substantial portion of the brick has eroded and at a decreasing rate thereafter, periodically checking the condition of the liner by irradiating the steel shell with thermal neutrons with a flux density of 10^4 – 10^6 neutrons/ $\text{cm.}^2/\text{sec.}$, detecting the count rate of 0.477 m.e.v. gamma rays to the exclusion of other particles or rays in normal operation when the borated brick will be physically separated from the furnace shell, and subsequently detecting the low level gamma count rate after the borated brick is eroded whereby the furnace may be operated until the brick is almost gone, and operating an alarm signal only after the count rate of said detected gamma rays decreases from said constant rate.

4. The method as in claim 3 further including the step of obtaining a calibration curve of the borated brick thickness versus the gamma count rate emitted therefrom, and operating said alarm only when a certain fraction of the borated brick remains as indicated by said calibration.

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