The Applicant identified below requests the grant of a patent to the nominated person identified below for an invention described in the accompanying standard complete patent specification.

Applicant and Nominated Person:

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Invention Title:

NEUTRON BEAM GENERATOR

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Details of basic application(s):
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Applicant states the following:

1. The nominated person is the assignee of the actual inventor(s).
2. The nominated person is authorized to make this application by the applicant of the basic application.
3. The basic application(s) was/were the first made in a convention country in respect of the invention.

The nominated person is not an opponent or eligible person described in Section 33-36 of the Act.

10 September 1996

De Beers Industrial Diamond Division (Proprietary) Limited
By PHILLIPS ORMONDE & FITZPATRICK
Patent Attorneys for the Applicant
By

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Our Ref: 464328

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The invention concerns a neutron beam generator (18) which includes a particle accelerator (24) for accelerating, in pulsed manner, a particle beam produced by an ion source (22). The generator also includes a gas cell (42) containing gas with which the particle beam is to interact to produce the required neutron beam (16). There is an evacuated passage (26) for transporting the accelerated particle beam to the gas cell and a port (38, 40) between the gas cell and the passage. Port control means (50) is provided which is synchronised with the accelerated particle beam pulses and which operates to open the port to allow the accelerated particle beam pulses to enter the gas cell through the port and to close or obstruct the port, thereby to prevent or reduce leakage of gas from the gas cell through the port, between such pulses.
The following statement is a full description of this invention, including the best method of performing it known to applicant(s):
BACKGROUND TO THE INVENTION

This invention relates to a neutron beam generator.

The specification of South African patent application 94/10192 describes a fast neutron imaging technique for use in detecting the presence of a certain substance in a host body, for example a diamond inclusion in a particle of kimberlite. In the simplest form of the technique, individual kimberlite particles are irradiated with a beam of fast neutrons, i.e. neutrons which have a kinetic energy level of the order of mega-electron volts. An absorption image is obtained and from this image it is possible to determine whether the substance in question is present in the host particle. The neutrons should be monoenergetic, i.e. with a well-defined energy level which is at or near a resonant absorption energy level for the substance in question. For instance, in the case of diamond in kimberlite detection, the neutrons may have a well-defined energy level of about 7.8 MeV which is a resonant carbon absorption level and at which there is good contrast between diamond and kimberlite absorption.

In a variant of the technique, the samples are irradiated with a fast neutron beam at two distinct energy levels, one of which is a resonant energy level for the substance in question and the other of which is a non-resonant level. In the case of detection of diamond within kimberlite, the neutron beam energy levels may, for instance, be 7.8 MeV and 7 MeV respectively. The absorption images obtained at the two energy levels are subtracted from one another to provide a third image which is analysed for the presence of the substance in question.
Irrespective of which technique is used, it is necessary to use a neutron beam of sufficiently high flux and energy to penetrate the sample and produce a well-defined absorption spectrum. Conventionally, neutron beams are generated by accelerating a proton or deuteron beam to a kinetic energy of the order of mega-electron volts and impinging the beam on a suitable target material. The nuclear reactions between the beam and target result in the emission of neutrons. The neutron spectrum which is emitted is dependent on the nuclear structure of the various atoms involved in the reaction.

An object of the present invention is to provide a high flux neutron beam generator capable of generating a fast neutron beam at an appropriate energy level for, for instance, detection of diamond inclusions in kimberlite.

**SUMMARY OF THE INVENTION**

According to the present invention there is provided a neutron beam generator which comprises a particle accelerator for accelerating, in pulsed manner, a particle beam produced by an ion source, a cell containing gas with which the particle beam is to interact to produce a neutron beam, an evacuated passage for transporting the accelerated particle beam to the gas cell, a port between the gas cell and the passage, and port control means which is synchronised with the accelerated particle beam pulses and which operates to open the port to allow the accelerated particle beam pulses to enter the gas cell through the port and to close or obstruct the port, thereby to prevent or reduce leakage of gas from the gas cell through the port, between such pulses.
In the preferred embodiments, the port control means comprises a port control member formed with at least one opening therein and means for moving the port control member relative to the port so that the port is alternately opened by alignment of an opening in the port control member with the port and closed or obstructed by alignment with the port of a portion of the port control member where there is no opening.

In one version, the port control member comprises a rotatable disc arranged with its axis parallel to the axis of the port and formed with a plurality of openings which are equiangularly spaced apart on a circle intersecting the axis of the port, and the moving means comprises a rotary drive for rotating the disc about its axis.

A particularly preferred embodiment of the invention has a plurality of evacuated chambers arranged in series between the evacuated passage and the gas cell with aligned, interleading ports between the respective chambers, an aligned port between the passage and a first of the chambers and an aligned port between a last of the chambers and the gas cell, at least some of the ports being controlled by port control means synchronised with the accelerated particle beam pulses. In this case, there may be vacuum pumps operating to evacuate the chambers to different pressures. For optimum prevention of loss of gas from the gas cell it is preferred that the vacuum pumps operate to maintain successively lower pressures in the chambers in a direction away from the gas cell and towards the evacuated passage.

There may, for instance, be ports between the last chamber and the gas cell and between the last chamber and the chamber adjacent thereto which are controlled by synchronised port control means.
In another embodiment of the invention, the port control member comprises a cylinder arranged with its axis transverse to the axis of the port and formed with a diametrically extending opening through it, and the moving means comprises a rotary drive for rotating the cylinder about its axis such that the opening periodically aligns with the port.

The, or each, opening may be open. Alternatively, each opening can be spanned by a thin metal foil capable of passing a particle beam pulse and of preventing passage of gas from the gas cell.

Further according to the invention, the neutron beam generator may comprise means for charging the gas cell with gas under pressure and means for cooling the gas. There may, for instance, be a gas source, a gas line extending from the gas source to the gas cell through which gas is charged into the gas cell, and means in the gas line for cooling the gas.

**BRIEF DESCRIPTION OF THE DRAWINGS**

The invention will now be described in more detail, by way of example only, with reference to the accompanying drawings in which:

**Figure 1** diagrammatically illustrates a neutron beam generator of the invention;

**Figure 2** shows a diagrammatic enlargement of the region marked "A" in Figure 1;
DESCRIPTION OF EMBODIMENTS

Figure 3 shows a face view of the rotating disc used in the generator seen in Figure 1;

Figure 4 shows an alternative type of port control apparatus; and

Figure 5 diagrammatically illustrates a relevant portion of another embodiment of the invention.

Figure 1 shows a conveyor belt 10 on which a series of kimberlite particles 12 are transported through an irradiation zone marked generally with the numeral 14. As they pass through the zone 14, the particles are irradiated with a fast neutron beam 16 produced by a neutron beam generator 18 according to the present invention.

As described in the specification of South African patent application 94/10192, to which reference should be made for the details, a neutron absorption spectrum is derived for each particle passing through the zone 14. From the absorption spectrum it is possible to ascertain which of the particles 12 contain diamond inclusions 20.

Particles which contain diamond inclusions are subsequently separated from the remaining particles after being projected in free flight from the conveyor belt 10. The way in which particle separation takes place is described in the specification of the aforementioned patent application.
In this application of the present invention, where it is desired to identify diamond-containing kimberlite particles, the neutron beam 16 will typically have a closely defined energy level of about 7.8 MeV, which is a resonant energy level for carbon. In practice, as described in the specification of the aforementioned patent application, the neutron beam may be modulated between resonant and non-resonant energy levels to produce two absorption spectra, with a subtractive technique then being used to identify those particles with diamond inclusions. In the example cited in the specification of the patent application, the neutron beam is modulated between a resonant energy level of 7.8 MeV and a non-resonant energy level of about 7 MeV.

The required neutron beam, whether in the simple single energy mode or the dual energy mode, is produced by impingement of a high energy particle beam on a suitable target. In practice, it is necessary to transport the high energy particle beam to the target in a vacuum system to minimise loss of particle beam energy. It is believed that the required neutron beam can most suitably be produced by impingement of a high energy deuteron beam with a deuterium gas target.

In the illustrated example, deuterons from an ion source 22 are accelerated to the required energy level by an RFQ (radio frequency quadrupole) particle accelerator 24.

The nature of an RFQ accelerator is such that the deuteron beam is accelerated in a pulsed manner, i.e. in beam bunches with a duty cycle typically of a few per cent. Instead of an RFQ accelerator, a cyclotron or circular accelerator may be used to produce the pulsed particle beam.
The accelerated deuteron beam is transported in an evacuated tube 26, serving as a vacuum passage, to a pin hole collimator 28. Evacuation of the passage 28 is achieved by means of vacuum pumps 30. As seen in Figure 2, the pin hole collimator 28 includes transverse plates 32 and 34 formed with small, aligned holes 36 and 38 respectively. The holes 36 and 38 typically have a diameter of about 2 to 3mm. The hole 38 is aligned with a hole 40 in a gas cell 42 accommodating deuterium gas 44 under pressure. The holes 38 and 40 in combination serve as a port through which the collimated, accelerated deuteron beam can pass from the tube 26 into impingement with the deuterium gas 44 in the gas cell 42. The nuclear reaction which takes place on impingement of the high energy deuteron beam with the gas target generates the fast neutron beam 16 at the appropriate energy level.

When the port constituted by the holes 38 and 40 is open to allow passage of the deuteron beam into the gas cell, deuterium gas can leak from the gas cell into the tube 26. To avoid excessive loss of deuterium gas, a port control apparatus is provided.

The port control apparatus includes a circular disc 50 seen in face view in Figure 3. The disc has a central axis 52 and is formed with a large number of equiangularly spaced openings 54 located on an imaginary circle close to the periphery of the disc.

The disc is mounted, for rotation about the axis 52, between the upper end of the tube 26 and the bottom wall of the gas cell 42. A motor 56 engages the disc and drives it in rotation about the axis 52. The action of the motor 56 is synchronised with respect to the operation of the RFQ accelerator 24 so that when a deuteron beam pulse or bunch arrives at the hole 38, an
opening 54 in the disc 50 is aligned with the holes 38 and 40, i.e. with the interleading port between the tube 26 and the gas cell 42. The deuteron beam pulse can accordingly pass into the cell for impingement on the deuterium gas. The synchronisation is also such that when no pulse is present, i.e. between successive pulses of the RFQ accelerator, there is no opening 54 in alignment with the holes 38 and 40 and the interleading port is in a closed condition.

As stated above, in the open port condition, some deuterium gas can leak into the tube 26. However when the port is closed no such leakage is possible and the pressure of deuterium gas in the gas cell 42 is largely maintained. It is believed that with the alternate opening and closing of the interleading port it will be possible to limit the loss of deuterium gas to acceptable levels for prolonged generation of the required fast neutron beam even with openings 54 in the form of clear holes through the disc 50.

Loss of gas from the cell 42 can be further reduced by providing thin metal foils which span across the openings 54 in the disc 50. The metal foils are thin enough to allow passage of the accelerated particle beam pulses with only a small loss of kinetic energy, but are nevertheless capable of preventing gas flow through the disc. It is believed that metal foils which are available under the trade mark Havar will operate well in practice. Such foils are prone to melting or disintegration when subjected to beam currents in excess of a few microampere, while beam currents of hundreds of microampere will generally be required for generation of the desired neutron beam in the implementation of the present invention. However, with the illustrated arrangement of spaced openings each spanned by a foil, a new foil is aligned with the port each time a beam pulse or bunch arrives at the port.
The full beam current is accordingly averaged out over a great number of foils and it is anticipated that with sufficient foils, i.e. openings, and correct synchronisation, the average beam current will be insufficient to cause to damage to the individual foils.

Figure 4 illustrates an alternative port control apparatus. The port control apparatus in this embodiment is provided by a round cylinder 60 which is rotated about its axis 62 and which is formed with a transverse opening 64 extending diametrically through it. In practice, the cylinder is arranged between the holes 38 and 40 with its axis 62 perpendicular to the port constituted by those holes. At one rotational position of the cylinder, the opening 64 is aligned with the holes 38 and 40, corresponding to an open port condition, so that an arriving beam pulse or bunch can pass from the evacuated tube 26 into the gas cell 42. In all other rotational positions of the cylinder, the opening 64 is misaligned with the holes 38 and 40, corresponding to a closed port condition. The rotation of the cylinder 60 is synchronised with the operation of the RFQ accelerator so that the opening 64 is aligned with the port whenever a beam pulse or bunch arrives and is misaligned with the port between such pulses or bunches.

During rotation, the cylindrical surface of the cylinder moves in close contact with the opposing walls of the pin hole collimator and gas cell, so there is little or no leakage of gas in the closed port condition. As described above for the disc 50, the opening 64 can be spanned by a thin metal foil which reduces gas leakage in the open port condition.

Figure 5 illustrates a relevant portion of another embodiment of the invention. In this Figure, the same reference numerals as in earlier figures
are used to designate corresponding components.

In Figure 5, the evacuated tube 26 is connected to the first of a series of three chambers 66, 68 and 70. The chambers 66, 68 and 70 are connected together in series between the tube 26 and the gas cell 42 with interleading, aligned ports 72, 74, 76 and 78 placing the passage, chambers and gas cell in communication. In this embodiment, there are two circular discs 50 mounted on a common shaft 80 driven by the motor 56. As in Figure 3, each of the discs 50 has a series of circumferentially spaced openings 54 adjacent its periphery. The arrangement of the shaft 80 and the openings 54 of the two discs is such that as the discs rotate, successive openings in the discs align with the ports 76 and 78. The rotation of the discs is synchronised with the operation of the RFQ accelerator such that on arrival of a deuteron beam pulse or bunch at the ports 76 and 78, the pulse can enter the gas cell. Between the pulses, the openings 54 are not aligned with the ports 76 and 78 so leakage of gas from the gas cell into the chambers is prevented or at least reduced.

When the discs are in an open position, i.e. allowing passage through the holes ports 76 and 78, some deuterium gas can leak out of the gas cell and into the chamber 70 through the port 78. There is also the possibility of gas leakage into the chambers 66 and 68. Even when the discs are in closed positions, i.e. when the openings 54 are not aligned with the ports 76 and 78, the spinning discs may seal imperfectly, once again giving rise to possible gas leakage from the gas cell 42.

To counteract loss of gas, vacuum pumps 82, 84 and 86 are connected to the chambers 66, 68 and 70 respectively. The vacuum pumps withdraw gas
which has leaked into the chambers and recirculate it via a pump 88 to the
gas cell 42. This limits the loss of deuterium gas and promoting prolonged
generation of the required fast neutron beam. In practice, the vacuum pumps
82, 84 and 86 may operate at different pressures. In particular, the vacuum
pumps preferably operate to maintain the internal pressure in the chamber
68 lower than that in the chamber 70 and that in the chamber 66 lower than
that in the chamber 68. Thus the chamber pressure decreases with increasing
distance from the gas cell 42, with the result that gas which has leaked is
effectively withdrawn from the chambers and recycled to the gas cell before
it can reach the passage 26.

Although Figure 5 only shows port control means, i.e. the spinning discs 50,
controlling gas leakage through the ports 76 and 78, it will be understood
that further, suitably synchronised port control means can also be provided
to control leakage through the other, upstream ports 72 and 74. Also,
although the discs 50 are described as spinning synchronously on a common
shaft, it would be possible for the discs to have independent drives
appropriately synchronised with the operation of the RFQ accelerator.

It will be understood that the openings 54 in the discs of Figure 5 could also
be covered by metal foils as described previously.

It will be understood that in each of the embodiments described above, the
gas cell 42 is charged with gas under pressure from an appropriate source
through a gas line communicating with the gas cell. By way of example,
Figure 5 indicates a gas source with the numeral 90 and the gas charging
line with the numeral 92. As a further measure to limit the leakage of gas
from the gas cell, it is also within the scope of the invention to cool the gas
with which the gas cell is charged and thereby to reduce its pressure. By cooling the gas appropriately high gas densities for acceptable fast neutron beam generation can be attained in the gas cell 42 at lower pressures than would otherwise be the case.

In practice, the gas with which the gas cell 42 is charged may be cryogenically cooled, before entering the gas cell, in a heat exchange apparatus 94 located in the gas charging line 92. The gas may, for instance, be cooled to a temperature of the order of 150°K. At the reduced pressure of the cooled gas there is less tendency for the gas to leak from the cell.
THE CLAIMS DEFINING THE INVENTION ARE AS FOLLOWS:

1. A neutron beam generator which comprises a particle accelerator for accelerating, in pulsed manner, a particle beam produced by an ion source, a cell containing gas with which the particle beam is to interact to produce a neutron beam, an evacuated passage for transporting the accelerated particle beam to the gas cell, a port between the gas cell and the passage, and port control means which is synchronised with the accelerated particle beam pulses and which operates to open the port to allow the accelerated particle beam pulses to enter the gas cell through the port and to close or obstruct the port, thereby to prevent or reduce leakage of gas from the gas cell through the port, between such pulses.

2. A neutron beam generator according to claim 1 wherein the port control means comprises a port control member formed with at least one opening therein and means for moving the port control member relative to the port so that the port is alternately opened by alignment of an opening in the port control member with the port and closed or obstructed by alignment with the port of a portion of the port control member where there is no opening.

3. A neutron beam generator according to claim 2 wherein the port control member comprises a rotatable disc arranged with its axis parallel to the axis of the port and formed with a plurality of openings which are equiangularly spaced apart on a circle intersecting the axis of the port, and the moving means comprises a rotary drive for rotating the disc about its axis.
4. A neutron beam generator according to either one of claims 2 or 3 comprising a plurality of evacuated chambers arranged in series between the evacuated passage and the gas cell with aligned, interleaving ports between the respective chambers, an aligned port between the passage and a first of the chambers and an aligned port between a last of the chambers and the gas cell, at least some of the ports being controlled by port control means synchronised with the accelerated particle beam pulses.

5. A neutron beam generator according to claim 4 comprising vacuum pumps operating to evacuate the chambers to different pressures.

6. A neutron beam generator according to claim 5 wherein the vacuum pumps operate to maintain successively lower pressures in the chambers in a direction away from the gas cell and towards the evacuated passage.

7. A neutron beam generator according to any one of claims 4 to 6 wherein the ports between the last chamber and the gas cell and between the last chamber and the chamber adjacent thereto are controlled by port control means synchronised with the accelerated particle beam pulses.

8. A neutron beam generator according to claim 2 wherein the port control member comprises a cylinder having its axis transverse to the axis of the port and a diametrical opening through it, the moving means comprising a rotary drive for rotating the cylinder about its axis such that the opening periodically aligns with the port.
9. A neutron beam generator according to any one of claims 2 to 8 wherein each opening is spanned by a thin metal foil capable of passing a particle beam pulse and of preventing passage of gas from the gas cell.

10. A neutron beam generator according to any one of the preceding claims wherein the particle is an RFQ accelerator or cyclotron.

11. A neutron beam generator according to any one of the preceding claims and comprising means for charging the gas cell with gas under pressure and means for cooling the gas.

12. A neutron beam generator according to claim 11 and comprising a gas source, a gas line extending from the gas source to the gas cell through which gas is charged into the gas cell, and means in the gas line for cooling the gas.

13. A neutron beam generator according to any one of the preceding claims wherein the gas cell accommodates deuterium gas and the particle beam accelerated by the particle accelerator is a deuteron beam.

14. A neutron beam generator substantially as herein described with reference to any one of the embodiments illustrated in the accompanying drawings.

DATED: 10 SEPTEMBER 1996
PHILLIPS ORMONDE & FITZPATRICK
ATTORNEYS FOR: De Beers Industrial Diamond Division (Proprietary) Limited
The invention concerns a neutron beam generator (18) which includes a particle accelerator (24) for accelerating, in pulsed manner, a particle beam produced by an ion source (22). The generator also includes a gas cell (42) containing gas with which the particle beam is to interact to produce the required neutron beam (16). There is an evacuated passage (26) for transporting the accelerated particle beam to the gas cell and a port (38, 40) between the gas cell and the passage. Port control means (50) is provided which is synchronised with the accelerated particle beam pulses and which operates to open the port to allow the accelerated particle beam pulses to enter the gas cell through the port and to close or obstruct the port, thereby to prevent or reduce leakage of gas from the gas cell through the port, between such pulses.
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