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SYSTEM FOR EXTRACTING HEAT FROM A LIQUID METAL TARGET

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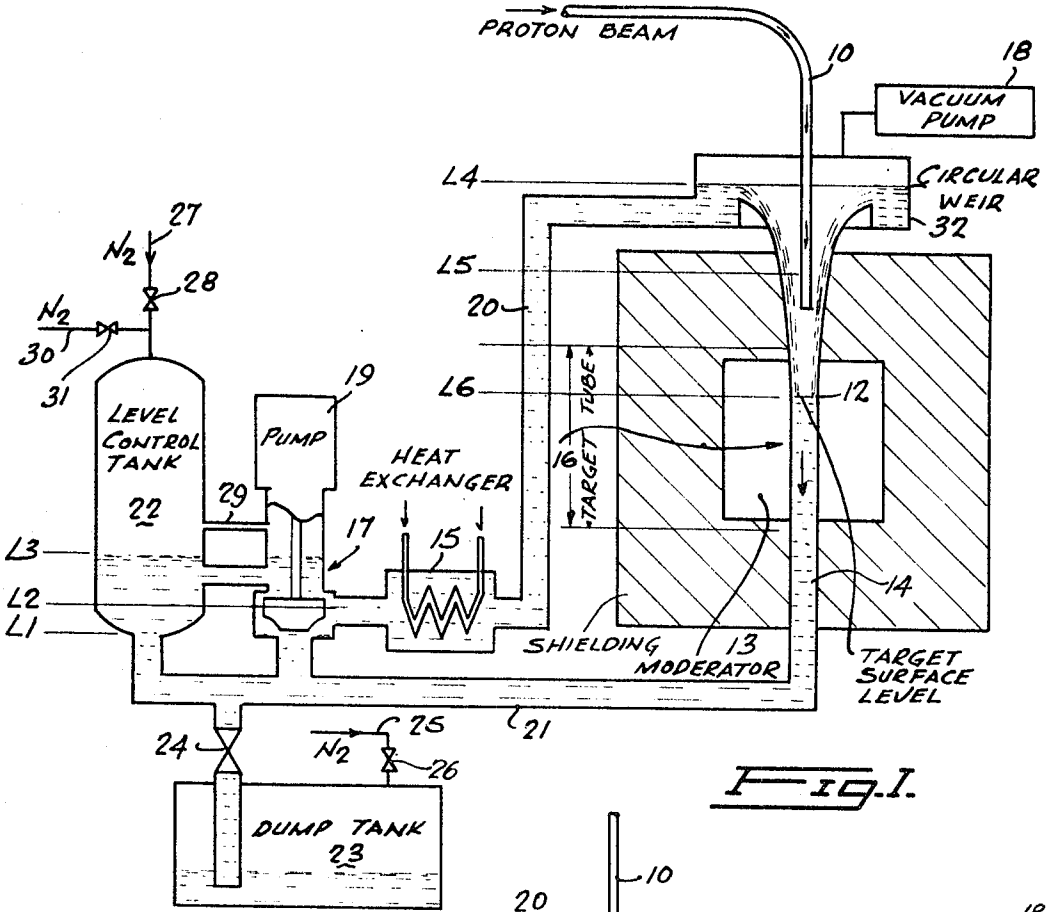


Fig. 1.

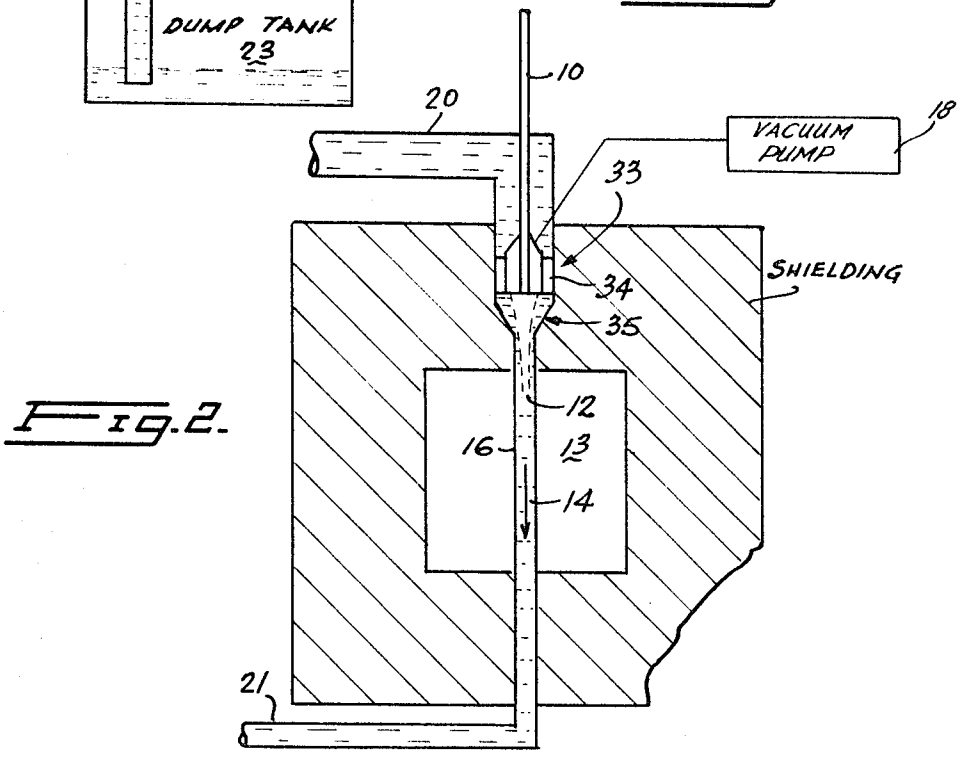


Fig. 2.

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SYSTEM FOR EXTRACTING HEAT FROM A LIQUID METAL TARGET

Ronald I. Hodge, 16 Laurier Ave., Deep River, Ontario, Canada

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U.S. Cl. 176—11 9 Claims

ABSTRACT OF THE DISCLOSURE

A system for extracting heat from a liquid metal target against a surface of which a stream of high energy particles impinges and for maintaining a vacuum adjacent the surface of the liquid metal, including a loop around which the liquid metal is circulated. A vacuum pump is maintained in communication with the source of high energy particles and a pump is provided in the closed loop to cause the liquid metal to circulate. No vacuum window is required.

The present invention relates to an intense neutron generator having a metal target irradiated by a proton beam from an accelerator having a beam current for example of up to 100 milliamperes and energies of up to 1 gev. In order to provide a target for generating neutrons and also to remove the heat generated by irradiation it has been proposed to use a liquid metal such as a lead-bismuth eutectic alloy flowing in a heat exchange loop, with the generated heat being extracted through a heat exchanger. The total power of such a proton beam may be, for example, of the order of 60 megawatts, of which approximately 35 megawatts is converted to heat when the proton beam is projected against the metal target.

One of the problems involved with the generation of neutrons by this process is that a beam of protons must first be generated and then projected down an evacuated beam tube to the liquid metal target. The high enery protons used to irradiate the target are generated in apparatus which is evacuated to a vacuum of about 10^{-6} torr. Thus it is necessary to maintain the integrity of the vacuum in the beam tube. One possible solution to this problem would be to provide a vacuum tight window made of a material transparent to protons. Unfortunately no known material is sufficiently transparent to avoid internal heating and radiation damage when used to seal a proton beam tube.

The present invention overcomes these problems by providing a liquid metal target for the proton beam and at the same time providing a vacuum seal for the beam tube, without the use of a window at the end of the beam tube.

In accordance with the present invention, the beam tube is introduced into the vapour space of what is in effect a Torricellian barometer. Preferably a vacuum pump is connected to the vapour space to maintain a predetermined vacuum. This removes in-leaking air and volatile contaminants generated in the liquid metal.

In general liquid is introduced into a vertical tube at an intermediate level and flows down the tube to a sink at pressure p_s. Above the entry level a vacuum is maintained, i.e. a space in which the pressure is $p_a \approx 0$. In the flow length there are frictional losses Δp. Two conditions must be met:

(i) The vapour pressure of the liquid must nowhere exceed the local static pressure, and particularly at entry must not exceed the desired vacuum pressure p_a.

(ii) The entry must be at a height L above the sink such that

$$L = \frac{(p_s - p_a + \Delta p)}{\rho g}$$

where

ρ is the mean density of the liquid, and g is the local gravitational acceleration.

In the preferred arrangements, the liquid is introduced as a film on the upper surface of the vertical tube and makes in effect its entrance by flooding the tube at the height L described above.

If the liquid entrance were lower than L, the liquid surface would rise to L and the entrance would then be submerged. There would be no through flow in that part of the liquid above the entrance. Such an arrangement might be suitable in low power applications.

In accordance with one aspect of the invention a lead-bismuth alloy is introduced over a weir and allowed to run down the sides of the target tube until it reaches the target level, and the proton beam is thus allowed to penetrate the moderator tank before striking the liquid metal target. Above the target, the centre of the tube is free of liquid metal, for the proton beam and this space may be evacuated to the same vacuum as the rest of the beam tube. The flow may be easily and stably attached to the walls by inlet swirl, i.e. by introducing the liquid metal as a whirlpool. The vapour pressure of a lead-bismuth eutectic alloy at about 250° C. is lower than the internal pressure in known proton accelerators so that the evacuated zone is not rapidly contaminated by lead-bismuth vapour.

In the drawing which illustrates embodiments of the invention;

FIGURE 1 shows a schematic diagram of a lead-bismuth circulating circuit in accordance with the present invention in which the vacuum in the beam tube is preserved, and

FIGURE 2 shows an alternative target tube entry section.

As shown in FIGURE 1, a beam tube **10** is provided down which a stream of protons is guided to strike the liquid metal target at **12**. The target is contained within the target tube **16** and surrounded by a moderator **13** such as heavy water. Assorted beam holes are provided through the moderator in accordance with known practice so that streams of neutrons will be obtained for experimental purposes. The liquid lead-bismuth in the target tube **16** flows at **14** away from the target area **12** to a heat exchanger **15**, where the heat generated by the proton beam striking the liquid metal target is extracted. The pump **17** is provided to circulate the lead-bismuth eutectic around the heat exchange loop and the vacuum pump **18** is provided to maintain a suitable vacuum at the open end of the beam tube **10**. The pump **17** is driven by a motor **19** and is connected to conduits **20** and **21** as well as to the level control tank **22**, and the dump tank **23**.

The operation of the apparatus of FIGURE 1 can best be understood by assuming that the circuit is empty and all of the lead-bismuth eutectic is in the dump tank **23**. The lead-bismuth can be pumped from the dump tank **23** via the valve **24** to fill the system by pressurizing the dump tank **23** with nitrogen or any other suitable inert gas fed through the line **25** and the valve **26**. With the system properly filled, the level of the lead-bismuth liquid can be raised to the point L_3. This level in the level control tank **22** and in the pump **17** may then be maintained by control of the pressure of inert gas such as nitrogen fed from the line **27**, via the valve **28** into the level control tank **22**, and via the passage **29** into the pump **17**, excess nitrogen suitably being released

from the level-control tank **22** via the line **30** and the valve **31**. The level of the liquid in the rest of the system can then be increased by applying further pressure on line **25** until the level rises to the level L_5. The level L_5 is then the reference filling level for the system before circulation of the liquid begins. The pump **17** is started and the liquid now moves to the levels L_4 and L_6 by virtue of the flow of the liquid about the circulating loop. The vacuum pump **18** is used to maintain the vacuum in the space above the liquid and in the beam tube **10**.

The level L_6 at which the surface **12** is located is determined by the pressure at the level L_3 in the level control tank, the pressure at the surface **12** (a vacuum), and the vertical difference in elevation between L_3 and L_6 as well as the frictional loss of head from L_6 to L_3 when the liquid flows through the loop.

The pressure at the pump inlet must not fall below a value at which cavitation occurs. For example, a value of 5 feet of lead-bismuth has been found satisfactory elsewhere. The hydrostatic head L_6–L_1 must exceed this value by at least an amount equal to the hydraulic losses in the conduit **21**. L_6 is fixed in practice by the fact that it must coincide with the elevation chosen for the top of the target. Therefore L_1, the pump elevation must be chosen to give the correct value for $L-L_1$. Once the system is built, $L-L_1$ can be adjusted either by using an adjustable resistance in the pipe from L_6 to L_1 to vary the hydraulic loss of conduit **21**, or by varying the pressure in the level control tank.

The wall thickness of the target tube **16** may be chosen to resist collapse in the section which has zero internal pressure and a pressure approximately one atmosphere on the outer wall. This occurs at the upper end of the tube **16** adjacent the weir **32** in FIGURE 1. At the lower end of the target tube **16** the reverse situation occurs, where the internal pressure is highest, giving a low value of tensile stress in this region.

A small amount of whirl will produce a flow attached to the tube wall for the case of a well shaped weir. For the most severe possible case—that of the right-angled weir, produced by a constant diameter target tube, attached to the bottom of a tank, stable and attached flow is achieved by whirl angles of 45° or more. The whirl angle is measured between the flow direction and a radius at the lip of the weir.

The following is an example of a typical system in accordance with the present invention wherein the conduits **20** and **21** of the liquid lead-bismuth loop are 8 inch inside diameter lines. The flow is about 3.3 cubic feet per second, and the temperature difference is about 250° C. The hydraulic loss in conduit **21** is calculated to be equivalent to about 8 feet of lead-bismuth. Therefore the level L_6 will be approximately 13 feet above the level L_1. Current layouts indicate that a value of L_6–L_1 of about 18 feet is necessary to allow installation of the equipment.

FIGURE 2 shows an alternative form of target tube entry section, the circular weir **32** of FIGURE 1 has been replaced with an annular section **33** equipped with vanes **34** followed by an annular nozzle **35**. The lead-bismuth eutectic emerges from the annular nozzle **35** as a falling film which adheres to the walls of the target tube **16**. As before the vacuum pump **18** may be connected to the target tube above the surface **12**. This form of the invention has the advantage that shielding is simplified and that the system possess a reduced overall diameter.

Accordingly the present invention provides a practicable system for providing a liquid lead-bismuth target for an intense neutron generator which provides the necessary heat exchange loop for removing the heat due to the proton beam impinging against the lead-bismuth target and at the same time provides simple and reliable means for maintaining the vacuum integrity of the proton acceleration system without the use of a proton window.

I claim:

1. A system for extracting heat from a liquid metal target against a surface of which a stream of high energy particles impinges and for maintaining a vacuum adjacent said surface comprising a closed loop around which said liquid is adapted to be circulated, said loop including a heat exchanger, and a target tube, said liquid metal partially filling said target tube to a predetermined level, a vacuum pump connected to the liquid-free space in said target tube, and a beam tube projecting into said target tube such that when liquid flows through said loop the vacuum pump is in direct communication with the end of the beam tube and maintains a predetermined vacuum in the proton accelerating system.

2. A system according to claim **1** wherein a weir is included in said closed loop over which said liquid flows.

3. A system according to claim **1** wherein an annular nozzle is included in said closed loop through which said liquid flows.

4. A system according to claim **1** including a dump tank into which all of the liquid lead-bismuth in the system may be dumped.

5. A system according to claim **1** including a level-control tank coupled to said pump and having an inlet at the upper part of said level-control tank for the admission of an inert gas, to control the height of liquid in the target tube.

6. A system according to claim **2**, wherein said weir is circular and said liquid flows over said weir toward the centre thereof.

7. A system according to claim **3** wherein a plurality of vanes are provided in said closed loop above said nozzle to cause rotation of said liquid about said beam tube.

8. A system according to claim **4** including a source of inert gas under pressure connected to said dump tank whereby said liquid may be forced out of said dump tank to fill said system.

9. A system according to claim **6** wherein means are provided to cause said liquid to swirl over said weir.

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ARCHIE R. BORCHELT, *Primary Examiner.*

U.S. Cl. X.R.

250—84.5

UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 3,453,175 July 1, 1969

Ronald I. Hodge

It is certified that error appears in the above identified patent and that said Letters Patent are hereby corrected as shown below:

In the heading to the printed specification, after line 5, insert -- assignor to Atomic Energy of Canada Limited, Ottawa, Ontario, Canada, a corporation of Canada --.

Signed and sealed this 16th day of June 1970.

(SEAL)
Attest:

Edward M. Fletcher, Jr.
Attesting Officer

WILLIAM E. SCHUYLER, JR.
Commissioner of Patents