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ANALYSIS OF AN IN-PILE REACTOR TUBE

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Abstract

This paper presents the results of an analysis of an in-pile pressure tube and its components which are subjected to a severe dynamic overpressure pulse. The in-pile tube is part of a closed loop used in the Power Burst Facility at The National Reactor Testing Station, Idaho. This facility is used to test power reactor fuels. The paper describes the hardware, loading conditions and modeling techniques. A two dimensional dynamic nonlinear finite element computer program HONDO was used in the analysis.

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INTRODUCTION

The Power Burst Facility (PBF) [1][1] located at the Idaho National Engineering Laboratory (formerly the National Reactor Testing Station) is an open pool reactor designed to test power reactor fuel elements to adverse environments. The fuel elements which are to be tested are placed into an in-pile tube (IPT) which is then inserted into the reactor core. The IPT is part of a closed loop which contains its own coolant, pumps and pressure suppression equipment [2]. Thus the IPT is isolated mechanically from the PBF. The fuel elements can be subjected to a variety of test conditions by varying the reactivity of the reactor and the flow and pressure of the coolant within the in-pile loop.

In one of the planned tests [3], the fuel is subjected to a very severe environment and it is anticipated that the fuel cladding will fail thus exposing the hot fuel to the water which is at 2200 psig (15.2 MPag) and 650°F (343°C). The interaction between the fuel and water causes a pressure pulse to be produced in the water. Separate studies have shown that the maximum pressure pulse is 7500 psi (51.7 MPa) above the ambient pressure in the IPT and has a rise time of 20 μsec and a linear decay of 65 to 220 msec.

The pulse propagates through the in-pile loop loading the various components. This paper will restrict its attention to the stress analysis of the lower portion of the IPT and its support system.

Description of The In-Pile Tube

The in-pile pressure tube (Fig. 1) is an Inconel 718 forging approximately 16 ft. (4.88 m) long with a nominal outside diameter of 8.00 in. (20.32 cm) and an inside diameter of 6.10 in. (15.49 cm). The upper end has a removable head in order to insert fuel samples. The lower interior portion of the IPT is spherical in shape. To protect the IPT from direct

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[1] Numbers in brackets designate references at end of paper.

contact with fuel debris and to provide easy removal of the debris a catch basket consisting of an Inconel 718 outer liner, a ZrO_2 insulator and a Ta-10W inner liner is placed in the lower portion of the IPT, Fig. 2. The outside lower portion of the IPT forms the male part of the breech block mechanism which is used to secure the IPT to the support structure to resist tensile loading. In addition, the IPT is secured against a locking shaft which carries the compressive loading.

This paper will concern itself with the analysis of the catch basket region, in particular the ZrO_2 insulator, the breech lock mechanism and the compressive locking shaft. There were additional areas that were analyzed but for reasons of brevity these will not be discussed here.

Material Properties and Models

For the Ta-10W and Inconel 718 standard values for the material properties were obtained from the materials specifications and from handbooks. These two metals were modeled as an elastic-plastic material with strain hardening. Both a pressed and cast ZrO_2 are used in the design and it was not possible to obtain adequate information in order to properly characterize this material. In particular the response to tensile stresses is not well known. Best estimates were used, and the ZrO_2 was modeled as an elastic-perfectly plastic material. This would allow easy detection in the analysis if the stresses exceeded the yield point. Material properties will not be reproduced here.

METHODS OF ANALYSIS

Stress Analysis

The IPT system under investigation is axisymmetric and the loading is axisymmetric thus permitting the use of two dimensional computer programs. However, some analyses of the spherical area of the ZrO_2 insulator were done by a one dimensional finite difference computer program. The two dimensional analyses that will be reported on herein were done by use of the computer program called HONDO [4]. This is a finite element program for the large deformation elastic and inelastic transient dynamic response of two dimensional solids. The program employs a four node isoparametric quadrilateral element, and uses a central difference method to integrate the equations of motion. The program contains eight material subroutines covering elastic, viscoelastic, elastic-plastic, crushable foam and soil behavior. The program functions completely in core and because no stiffness matrices are generated and stored fairly large problems are easily accommodated.

Pre and Post Processors

The finite element mesh required by HONDO was generated by a separate program called QMESH [5]. This program permits the easy input of complicated structures and in addition it has a self-contained plotting program, and will smooth and restructure the mesh to obtain the "best" layout. The program also renumbers the nodes to obtain a small band width. However, this last feature is not required by HONDO.

All of the results from HONDO were written onto a magnetic tape. Then different plotting programs [6] were used to examine the response at either a node or element, and to plot contours of different stress components in areas of interest. The use of plots is essential in understanding the response of a structure.

RESULTS

Catch Basket Region

In this section we will discuss the analysis of the catch basket region and the upper portion of the compressive locking shaft. Due to the low strength of the cast and pressed ZrO_2, attention was focused on these two materials. The ZrO_2, based on the information on hand at the time of the analysis, was modeled as a elastic perfectly plastic material. The method of analysis, in brief, consisted of applying a 2200 psi (15.2 MPa) static pressure to the in-pile tube. This was done with a program called SASL [7]. The resulting values were then read by HONDO as initial conditions and then the dynamic overpressure was applied to a model containing the water coolant, Fig. 3. (The finite elements are not shown due to the fineness of the mesh.) The finite element model consisted of 571 elements and 643 nodes.

Only a few selected plots are shown. These include the von Mises stress vs. time at element No. 217, Fig. 4, and contour plots of the axial stress at two selected times, Figs. 5 and 6. The area shown is in the region of the spherical cast ZrO_2 plug. Incidentally, zero time is not the time at which the pressure pulse is produced, but rather an arbitrary time at which calculations were begun. The results indicated that the stress level in the cast ZrO_2 exceeds the given compressive strength of 12,800 psi (88.3 MPa). This is seen in Fig. 4 at 350 μsec. In addition, at other locations the magnitude of the stress was near the failure level. Since it is essential to have the ZrO_2 remain intact to act as a thermal insulator it was recommended that this material be better characterized. This is currently being done. When a definitive material model is available the analysis can be redone. The stresses in the other materials did not exceed their allowable values.

Breech Block Assembly

The pressure pulse produced by the interaction of the fuel and water propagates both downward (discussed in the previous section) and upward till it impinges on the head, Fig. 1. The loading of the head then produces a tensile loading of the IPT. This is transmitted down the length of the tube and is reacted by the breech block assembly. Due to the distances involved this loading of the lower portion of the IPT occurs much later than the initial loading of the catch basket region.

The breech block is connected to the IPT by interrupted threads and this would require a three dimensional analysis. However, it was felt that the thread could be assumed to be continuous if an equivalent shear area was used. Hence, the two dimensional program HONDO, which executes in a relatively short time, could be used.

The method of solution was to model a portion of the in-pile tube and the locking subassembly. The threads are modeled as three connected elements, while the rest of the elements along the interface are not connected. The model consisted of 440 nodes and 360 elements. Note, that the entire in-pile tube is not required in the analysis. The overpressure pulse of 7500 psi (51.7 MPa) was applied to the head at the top of the IPT, Fig. 7. Figs. 8 and 9 show the shear stress contours in the thread area at two selected times. The magnitude of the stress is low in comparison to the allowable value for Inconel 718 and hence it was concluded that this portion of the design was adequate.

Acknowledgement

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Captions

Fig. 1 Cross-Section of In-Pile Tube (IPT)

Fig. 2 Catch Basket

Fig. 3 Finite Element Model

Fig. 4 von Mises Stress vs. Time at Element No. 217 (Cast ZrO_2)

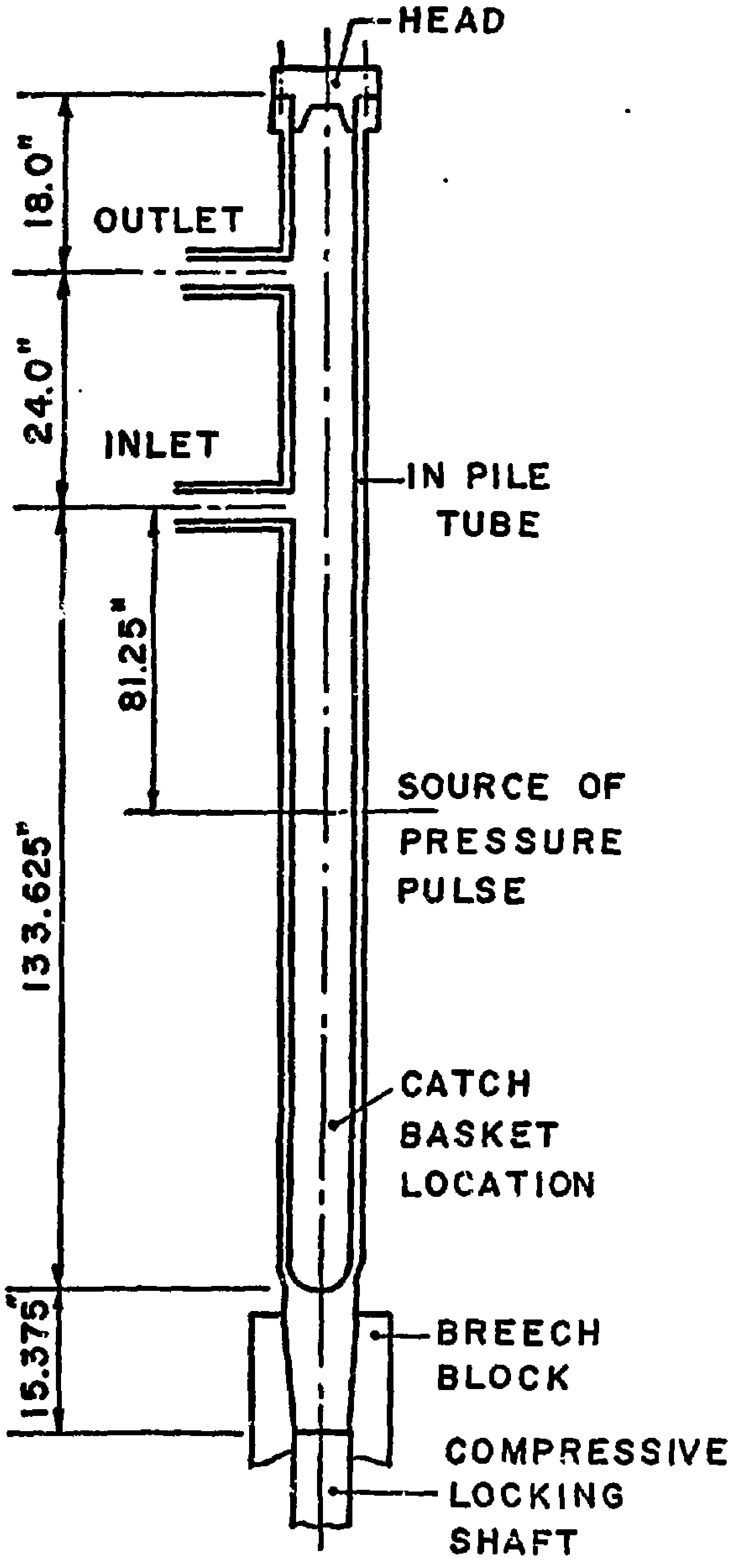
Fig. 5 Axial Stress Contours at 372.51 μsec.

Fig. 6 Axial Stress Contours at 445.45 μsec.

Fig. 7 Finite Element Model for Tensile Loading Study

Fig. 8 Shear Stress Contours at 352.85 μsec.

Fig. 9 Shear Stress Contours at 596.72 μsec.



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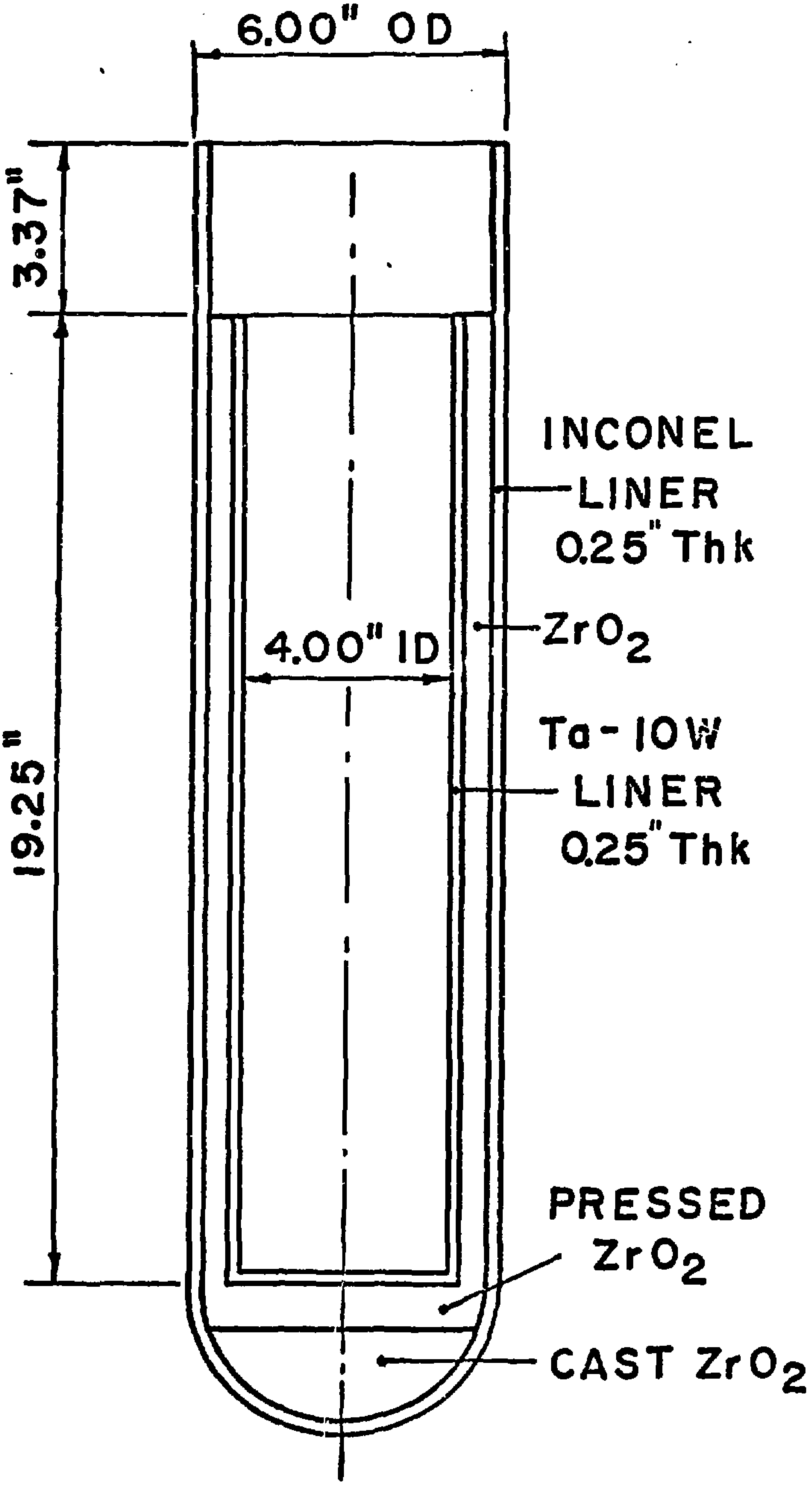
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19.25"
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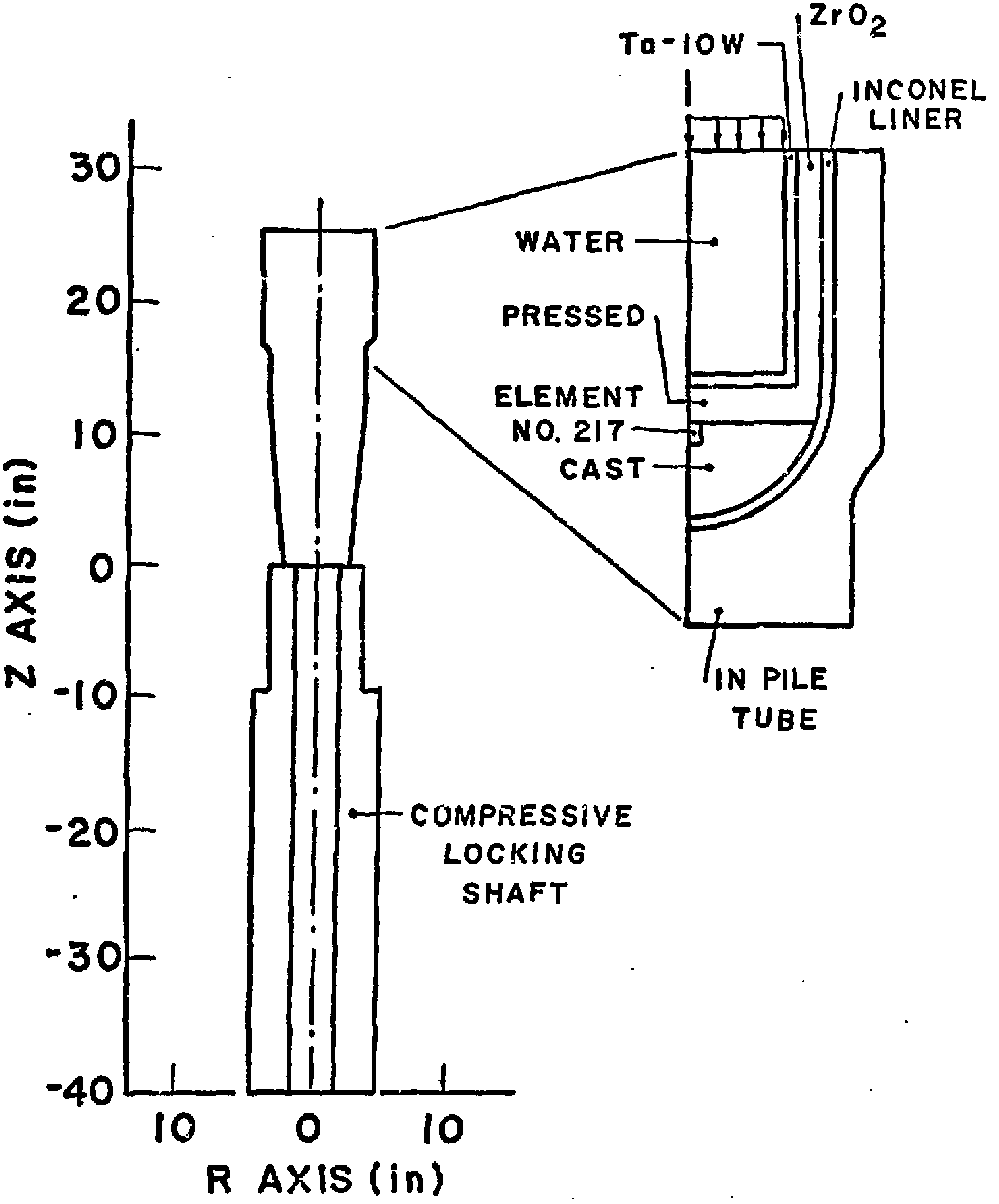
ZrO_2
4.00" ID
Ta-10W LINER 0.25" Thk
PRESSED ZrO_2
CAST ZrO_2

Fig. 2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Ta-10W
INCONEL LINER
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Fig. 3

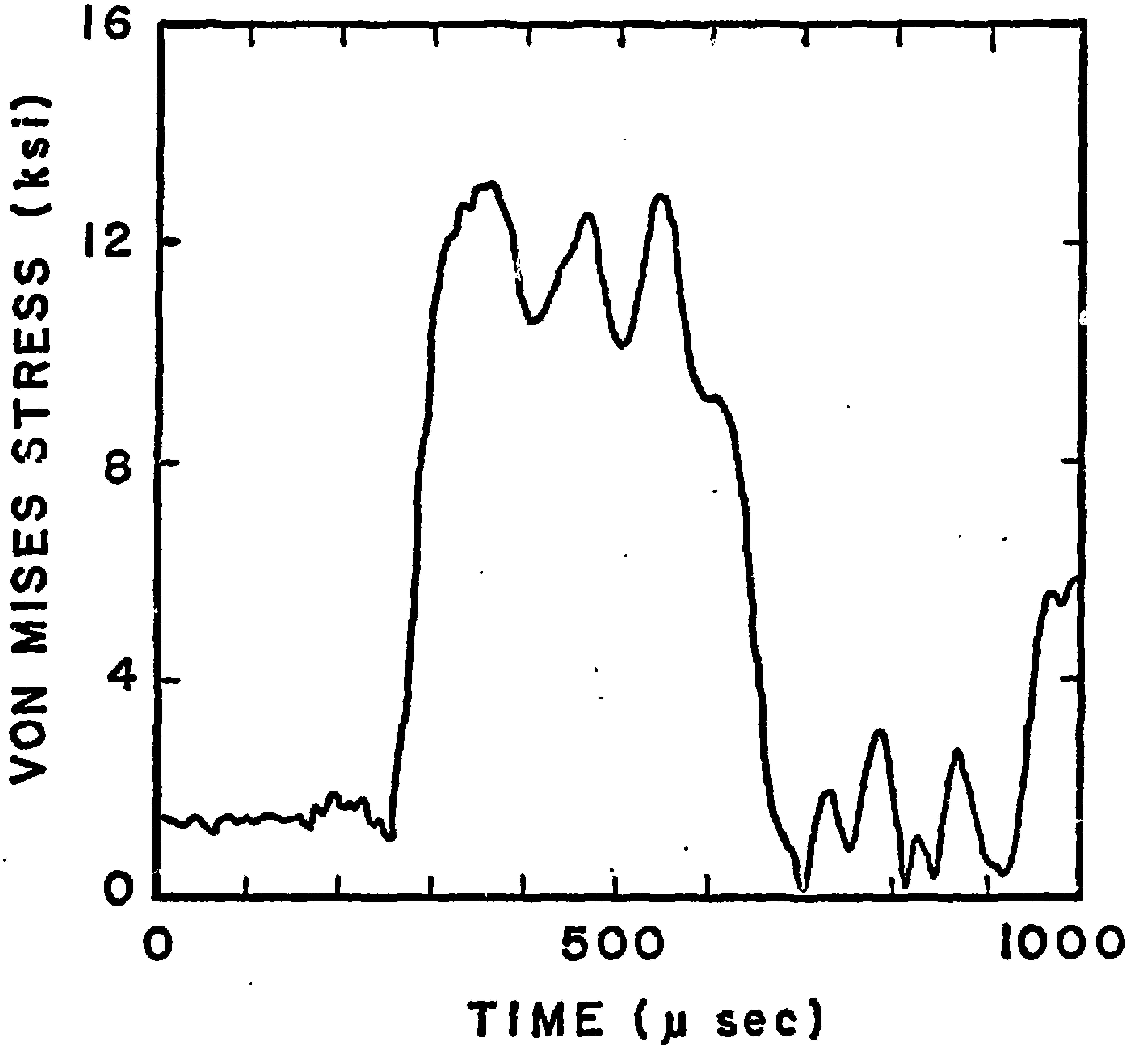

Fig. 4 [illegible]

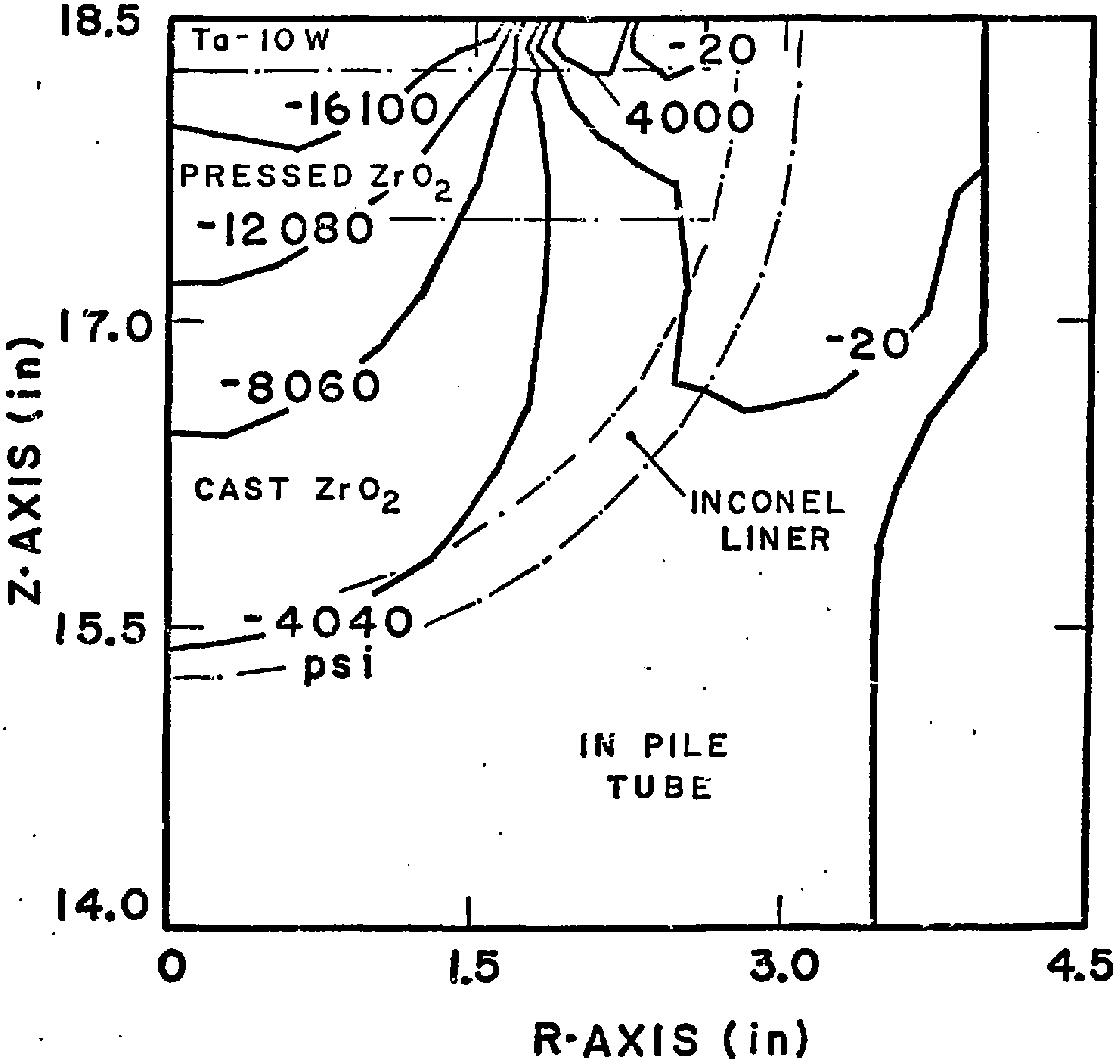

Fig 5
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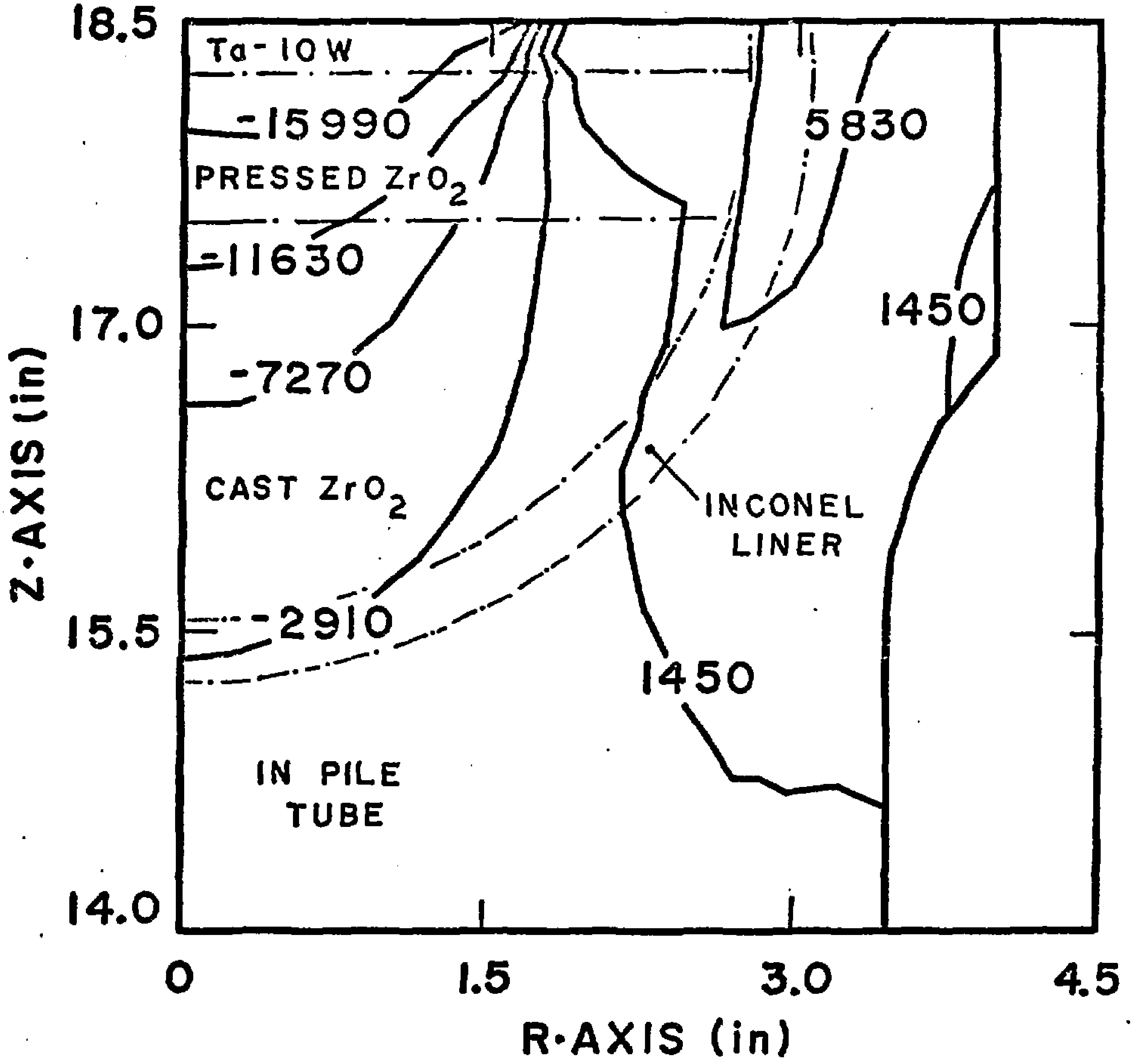

Fig. 6
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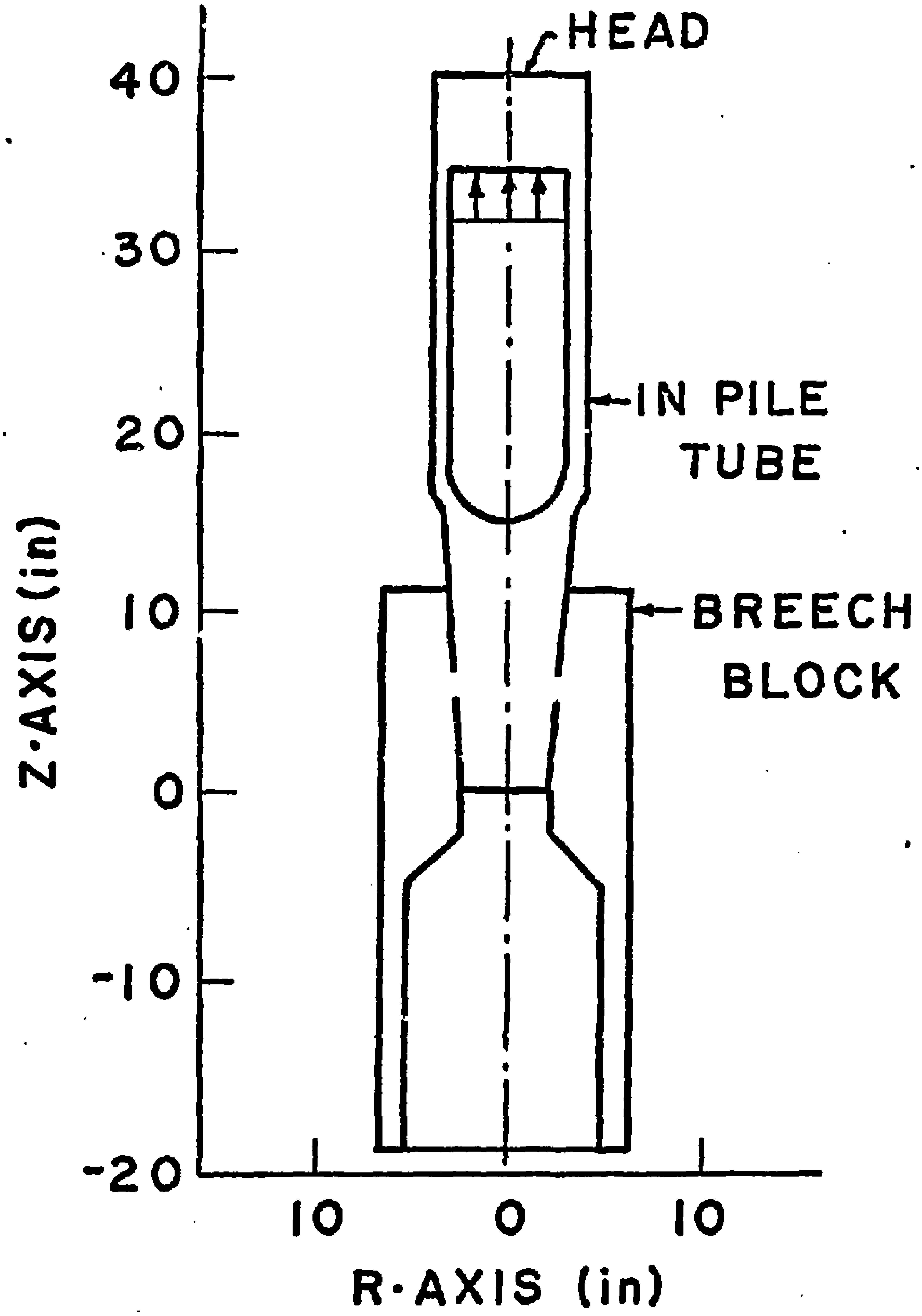

Fig 7
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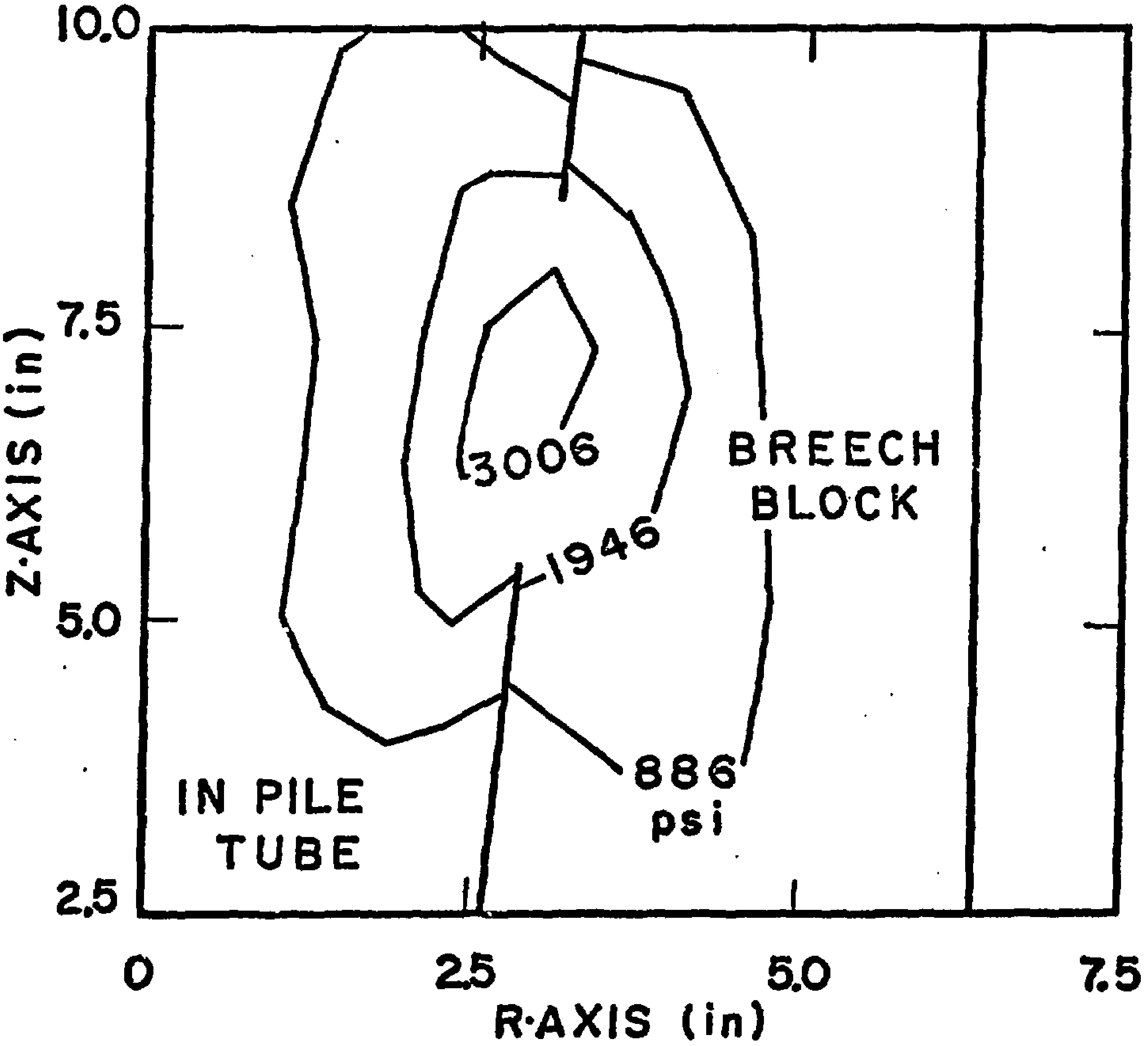

Fig 8
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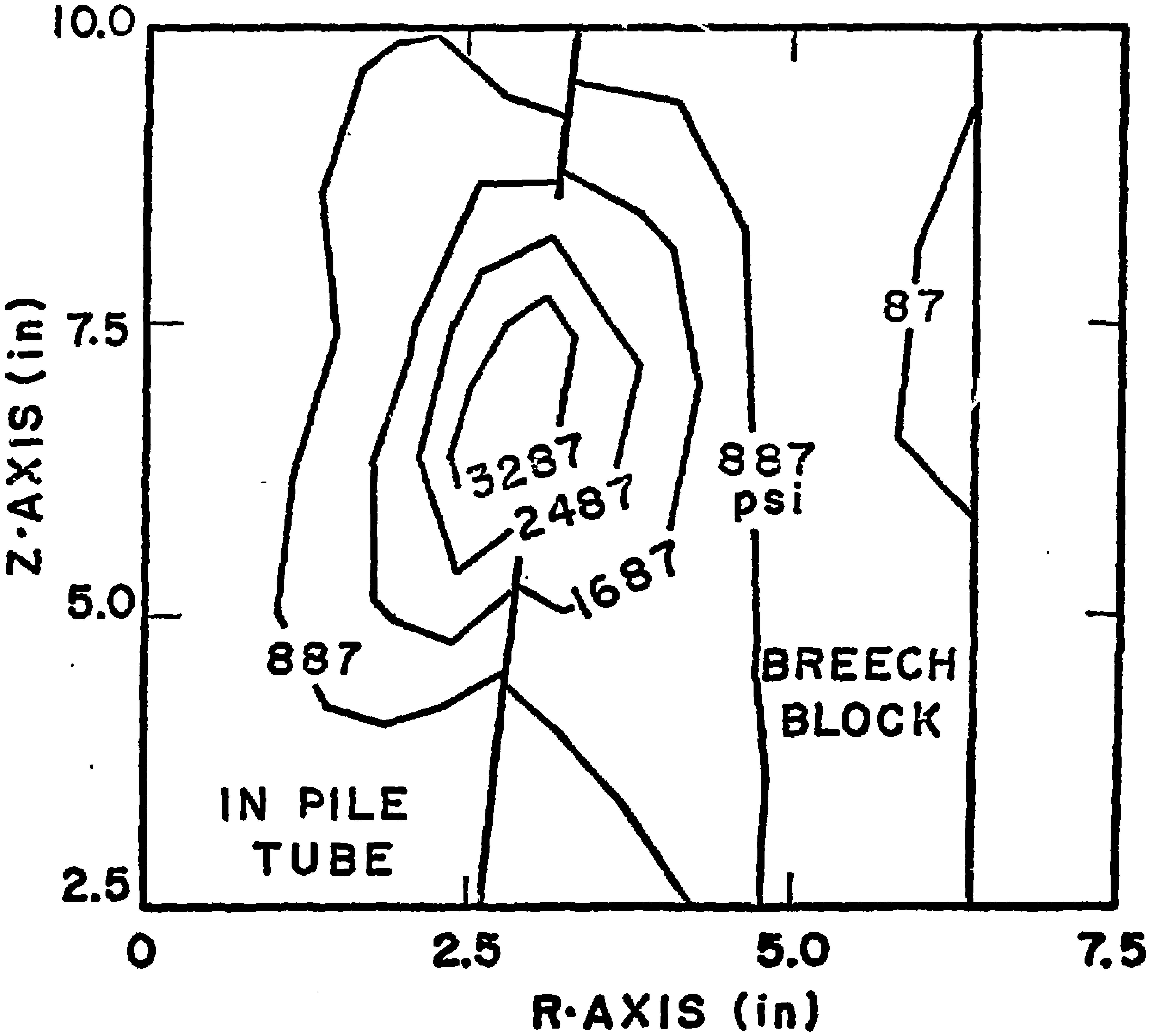

Fig 9
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