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# CRITICAL ELEMENT DEVELOPMENT OF DOUBLE SEAL DOOR FOR TRITIUM CONTAINMENT

August 1994

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In fusion experimental reactors, the in-vessel components such as blanket are activated due to D-T operation and they have to be assembled and replaced by remote operation through port penetration of plasma vacuum vessel. A double seal door is inevitably required at an interface between vacuum vessel port and maintenance cask in order to avoid the dispersion of tritium and activated dust during in-vessel component handling.

The double seal door should have two open／close doors with four seal surfaces so as to keep leak tightness both of the vacuum vessel and the maintenance cask when doors closed, and to provide access space for handling in-vessel components when doors opened. A prototype compact double seal door with an attractive kinematics of parabolic trajectory has been proposed so as to minimize dead space for the door open／close operation, compared with ordinary slide or hinge type door.

Based on this design concept, a sub-scaled model of double seal door with trapezoidal cross-section of around 0.2 m² has been fabricated. Through the preliminary experiments such as open／close performance, the double seal door mechanism with parabolic trajectory has been successfully demonstrated. As for leak tightness, seal characteristics of a polyimide ring irradiated up to 10 MGy have been measured.

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This work is conducted as a ITER Technology R&D and this report corresponds to 1993 ITER Emergency R&D Task Agreement (JB-D1-3) .
+ Department of ITER Project

Keywords: Fusion Experimental Reactor, Remote Handling, Double Seal Door, Standard Component, Tritium Containment

# 二重シール扉の要素開発

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（1994年7月4日受理）

核融合実験炉においては，D－T運転に伴いブランケットなどの炉内構造物が放射化され，これらの構造物は真空容器のポートを利用して遠隔操作により分解組立や保守を行わなければならない。炉内構造物の保守時にトリチウムや放射化ダストの漏洩を防ぐために，メンテナンスキャスクと真空容器のポートとの間に二重シール扉が不可欠である。

二重シール扉は，2つの開閉扉と4つのシール面を持ち，閉じたときには真空容器側とメンテナンスキャスク側の双方を密封し，扉が開いたときには炉内構造物を取り扱うためのアクセス空間を確保することが要求される。この様な二重シール扉の概念として，放物線軌道を有する新しい開閉機構を考察し，扉の開閉時におけるデッドスペースを従来のスライド式やヒンジ式に比べて飛躍的に縮小する設計を提案した。また，この設計概念に基づき，台形断面形状で面積約0.2㎡の縮小モデルを作成し，開閉動作及び放物線軌道の動作確認を行い，機構が正常に作動することを実証した。シール性については，ポリイミド製Oリングの照射効果を把握するために，10 MGyまで照射したOリングのシール特性試験を実施した。

本書は，新たに考案した小型二重シール扉の設計概念とその縮小モデルを用いて行った特性試験結果及びポリイミド製Oリングの照射効果について報告する。

本研究はITER工学R&Dの一環として実施したもので，本報告は1993年ITER緊急R&Dタスク協定（JB－DI－3）に基づくものである。
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## 1. Introduction

Fusion experimental reactors require remote handling technology for assembly and maintenance of reactor components, since they are activated due to D-T operation and personnel access is prohibited. In particular, the in-vessel components such as blanket and divertor are categorized into a schedule maintenance component and thus frequent and reliable remote handling operation are highly required; the in-vessel components are transported through port penetrations of vacuum vessel. In this regard, contamination control is quite important so as to avoid dispersion of tritiated and activated dust during the in-vessel component handling.

In order to limit such dispersion during activated component handling, a cask type transporter and a double seal door[1] have been proposed as a container of activated component and a partition door of both of the maintenance cask and the vacuum vessel port, respectively. A double seal door is a key component placed at an interface between the maintenance cask and the vacuum vessel port so as to accomplish leak tightness.

For this purpose, the Japan Atomic Energy Research Institute (JAERI) has been developing a compact double seal door which can be reliably used under nuclear environment and space constraint. In the meantime, international collaboration efforts have been made through the framework of Engineering Design Activity (EDA) of ITER (International Thermonuclear Experimental Reactor) and a sub-scaled model test of double seal door has been engaged in close contact with the Joint Central Team (JCT).

According to the 1993 ITER Emergency R&D Task Agreement (JB-DI-3), a sub-scaled model of compact double seal door with attractive kinematics of parabolic trajectory has been fabricated. The preliminary tests show reliable open/close operation with relatively small dead space compared with ordinary slide or hinge type door. This paper gives the design concept and the basic performance test results of a sub-scaled double seal door as well as leak test results of polyimide seal ring irradiated up to 10 MGy.

## 2. Design requirements

### 2.1 Operating schemes

A double seal door is in principle composed of two open/close doors with several seal surfaces and should satisfy the following operating schemes.

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## 2. Design requirements

### 2.1 Operating schemes

A double seal door is in principle composed of two open/close doors with several seal surfaces and should satisfy the following operating schemes.

(1) To provide leak tightness of a maintenance cask and a vacuum vessel port independently when the maintenance cask is removed from the vacuum vessel port.

(2) To provide open space for handling in-vessel components through the vacuum vessel port penetration when the cask is connected to the port.

## 2.2 Operating conditions

The double seal door is placed at an interface between the maintenance cask and the vacuum vessel port, and gives a partition wall for activated components. Accordingly, it is required to provide a sound barrier in terms of safety and reliability under the nuclear conditions is required. The major operating conditions, which is tentatively defined, are summarized in Table 1.

Table 1 Tentative design conditions of double seal door

| Items | Unit | Parameters |
|---|---|---|
| Nominal pressure | | Atmospheric pressure |
| Environments | | Inert gas / Air |
| Operating temperature | °C | ~ 100 |
| Radiation dose rate | R/h | ~ $10^7$ |
| Cross-section of port space | $m^2$ | 2 ~ 10 |

## 2.3 Leak tightness and proof pressure

The double seal door is required to satisfy primary leak tightness for preventing dispersion of activated dust and vacuum leak tightness is not demanded. In this regard, leak tightness of the double seal door could be specified to be no external leak in soap bubble test under the nominal pressure; this may correspond to a leak rate of less than $10^{-3}$ $Pam^3/s$.

A proof pressure of the double seal door may be defined as the same as a pressure vessel, which means a proof pressure to be 1.5 times of the nominal pressure.

## 2.4 Space requirements

The double seal door has to be enveloped within the maintenance cask; the overall structure and open/close operation space are specified so as to minimize the cask size and a transportation space of the cask in the reactor building.

## 3. Design features of double seal door

The double seal door is required for every port penetration where the maintenance cask is installed for the in-vessel maintenance and inspection. In the present design, a biggest port penetration is a upper vertical port which is located at the top of the vacuum vessel and is utilized for blanket module maintenance. The cross-section of upper vertical port is trapezoidal and the open space is around 10 $m^2$.

Design efforts have been made to develop a double seal door particularly for blanket module maintenance through the upper vertical port and the design features developed are described in the following sessions.

### 3.1 Double seal mechanism

#### (1) Typical configuration

Figure 1 shows typical configuration and open/close operation of the double seal door in each step of blanket maintenance operation. In this figure, black circles and white circles show complete sealing and unsealing of the corresponding door surfaces, respectively. The remaining double circles indicate transition stage between sealing and unsealing. According to the sequence of maintenance operation as shown in Fig. 1, key features of the double seal door are mentioned below.

STEP-1 : Initial setup

The maintenance cask is off from the vacuum vessel port and their openings are completely sealed with a cask door and a port door. In this case, the double seal door is separated into two pieces which are cask door and port door.

STEP-2 : Installation of cask and connection of double doors

The maintenance cask is installed on to the port flange of the vacuum vessel port and an interface between the cask door and the port door becomes seal tight; this means that the cask door and the port door are connected together and formed into an integrated structure as a double seal door.

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STEP-3 : Connection between cask and vacuum vessel port

The maintenance cask is connected to the vacuum vessel port and an interface between the cask and the port flange becomes seal tight. In this step, an interface between the cask door and the maintenance cask becomes loose connection.

STEP-4 : Preparation of double seal door open

In order to remove the double seal door and to provide open space for blanket handling, an interface between the port door and the port flange becomes loose connection.

STEP-5 : Double seal door removal

The double seal door composed of the cask door and the port door is moved from the port opening region to vertical position inside the maintenance cask so as to allow the blanket module maintenance through the port opening space.

(2) Connection methods

Figure 2 shows various connection methods of the cask door and the port door so as to form an integrated double door structure. In case of spring force type, the connection force can be passively provided by spring and any special tools for the connection are not required. However, a large number of spring has to be installed in order to fix the doors with leak tight, resulting in structural complexity. The bolt and spring combined type and the bolt-nut type give reliable connection with reasonable number of spring but extra end-effectors and tools for positioning and screwing the bolts are required.

As a consequence, the air locking type seems to be a primary candidate for the connection of the double seal door. In this concept, sufficient connection forces can be provided by pneumatic actuators and simple connection and disconnection operation can be expected without extra tools. Figure 3 show typical arrangement of air locking type connection and a pneumatic actuator is placed in the space between the cask door and the port door. Based on this concept, a prototype of this air locking type connection has been fabricated and installed into a sub-scaled model of double seal door.

### 3.2 Open/Close kinematics

External space for open/close operation of the double seal door has to be minimized in order to reduce the cask size and the transportation space. For this purpose, various kinematics for open/close operation of the double seal door have been investigated and possible candidates are shown in Fig. 4. In case of the roll type geometry, the space required for open/close operation can be minimized but less reliability in terms of seal tightness is concerned due to rolled seal surface.

Figure 5 shows the maintenance cask geometry depending on open/close kinematics of the double seal door. The hinge type door and the sliding type door require relatively large maintenance cask in height and in width compared with the lifting type door, respectively.

Accordingly, the lifting type door has been chosen as a primary candidate and the basic feasibility of compact kinematics with parabolic trajectory has been verified through a sub-scaled model test.

### 3.3 Seal ring materials

The double seal door requires a number of cyclic operation and thus the seal materials have to meet repeatable use under radiation condition of around $10^7$ R/h. Table 2 shows various sealing methods investigated for the double seal door application. In case of the metal ring, repeatable use is not possible. The spring coil and spiral gasket are also limited in repeatable use up to several times. Finally, organic ring and inflated seal seems to be adequate seal methods for the double seal door from standpoint of repeatability.

Further issues are to improve and qualify radiation resistance of seal materials. For this purpose, preliminary irradiation test of a polyimide seal ring has been conducted and leak characteristics of the polyimide ring irradiated up to 10 MGy at a dose rate of around $10^6$ R/h have been measured.

## 4. Test results

### 4.1 Fabrication of a sub-scaled model

Based on the design concept mentioned above, a sub-scaled model of double seal door has been fabricated. The detailed structure and the external view of the sub-scaled model are shown in Figs. 6 and 7, respectively. The

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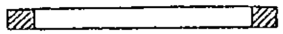
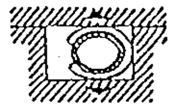
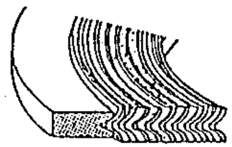
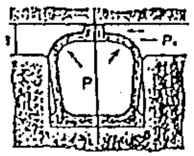
**Table 2 Comparison of Packing Type**

| | Type | Shape | Features | Notes |
|---|---|---|---|---|
| 1 | Organic Packing |  | •Material : Nitrile rubber, Silicone rubber, Fluorine-contained rubber (Viton)<br>•Standard : JIS B 2401<br>•It keeps good seal touch even for plural settings. The radiation hardness is $10^9$R | |
| 2 | Metal Hollow O-ring |  | •Material : SUS (Plated with silver)<br>•It is generally used as high vacuum seal. Because it is made of metal, it keeps until 250℃ baking and gets no damage from radiation. It is useless for plural settings because of plastic deformation. | |
| 3 | Spring Coil |  | •Material : SUS / A1<br>•It is made from coil spring and envelope. The coil spring is put in the envelope (metal hollow O-ring) and this achieves better fitting at seal surface. It keeps a few times settings. | |
| 4 | Spiral Gasket |  | •Material : SUS, Graphite, Inorganic paper, etc.<br>•It achieves good seal condition without skillful treatment as No.1~3, but not for high vacuum seal.<br>•It keeps plural settings because of elastic deformation, and has high radiation hardness. | |
| 5 | Inflated Seal |  | •Material : Nitrile rubber, Silicone rubber, Fluorine-contained rubber (Viton)<br>•Sealing is achieved with inflation of rubber by pressurized air from outside. It keeps good seal touch even for particular shape or rough surface. | |

sub-scaled model has trapezoidal cross-section with a opening space of around 0.2 $m^2$. The double seal door is connected through wire to a lifting winch and can be opened/closed in parabolic trajectory.

Air locking system composed of pneumatic actuators with locking mechanisms are installed in the space between the cask door and the port door so as to connect and disconnect the double doors in remote operation. A organic seal rings are placed at interfaces of the maintenance cask, the cask door, the port door and the port flange.

4.2 Open/Close performance tests of a sub-scaled model

Using the sub-scaled model of double seal door, a cyclic open/close operation has been conducted in accordance with the operating sequence as shown in Fig. 1. After several cyclic operation, leak tightness of the double seal door has been measured in soap bubble method under the nominal operating pressure of around 0.1 bar.

As a result, reliable open/close operation in parabolic trajectory has been verified, as schematically shown in Fig. 8. In addition, it is found that the air locking system based on pneumatic actuators provides simple connection and disconnection of the double doors and sufficient seal tightness of less than $10^{-3}$ $Pam^3/s$ (no external leak in soap bubble testing) under the nominal operating pressure.

As a whole, the basic feasibility of the compact double seal door developed has been successfully demonstrated. Further issues are to qualify the radiation resistance of seal materials.

4.3 Leak characteristics of polyimide seal ring

In order to develop radiation hard seal materials for the double seal door application, a polyimide seal ring for a 25-A pipe flange has been irradiated up to 10 MGy at a dose rate of around $10^6$ R/h. After the irradiation test, the irradiated polyimide has been set on seal surface between flanges and the leak tightness has been measured[2]. As a result, no leak is observed at a sensitivity of $1 \times 10^{-8}$ $Pam^3/s$ but further investigations including high temperature application are necessary.

Figure 9 shows typical leak test results as a function of tightening torque of bolts. In this figure, compressibility is defined as a ration of initial clearance between two flanges to the clearance change due to tightening of bolts, which

is to evaluate uniformity of compression pressure on the seal surface and to assess hardening due to irradiation. In case of non-irradiated polyimide, relatively uniform compression on the seal surface is observed. On the contrary, irradiated polyimide up to 10 MGy shows large deviation of compressibility along the seal surface even in large tightening torque compared with non-irradiated case; this is caused by hardening of polyimide due to irradiation.

## 5. Conclusion

A double seal door is a key component to provide a sound barrier to tritiated and activated dust during the in-vessel component handling. Critical issues relating to the double seal door are to develop reliable seal mechanism operating within limited space constraint under radiation conditions. A sub-scaled model of compact double seal door with an attractive kinematics of parabolic trajectory and trapezoidal cross-section of around 0.2 $m^2$ has been fabricated together with air locking system for connection and disconnection of the double doors. Through the preliminary experiments such as cyclic open/close performance, the double seal door mechanism with parabolic trajectory and tight connection due to pneumatic actuators have been successfully demonstrated. As for radiation resistance, seal characteristics of a polyimide ring irradiated up to 10 MGy have been measured and the technological assessment for further investigations has been made .

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## References

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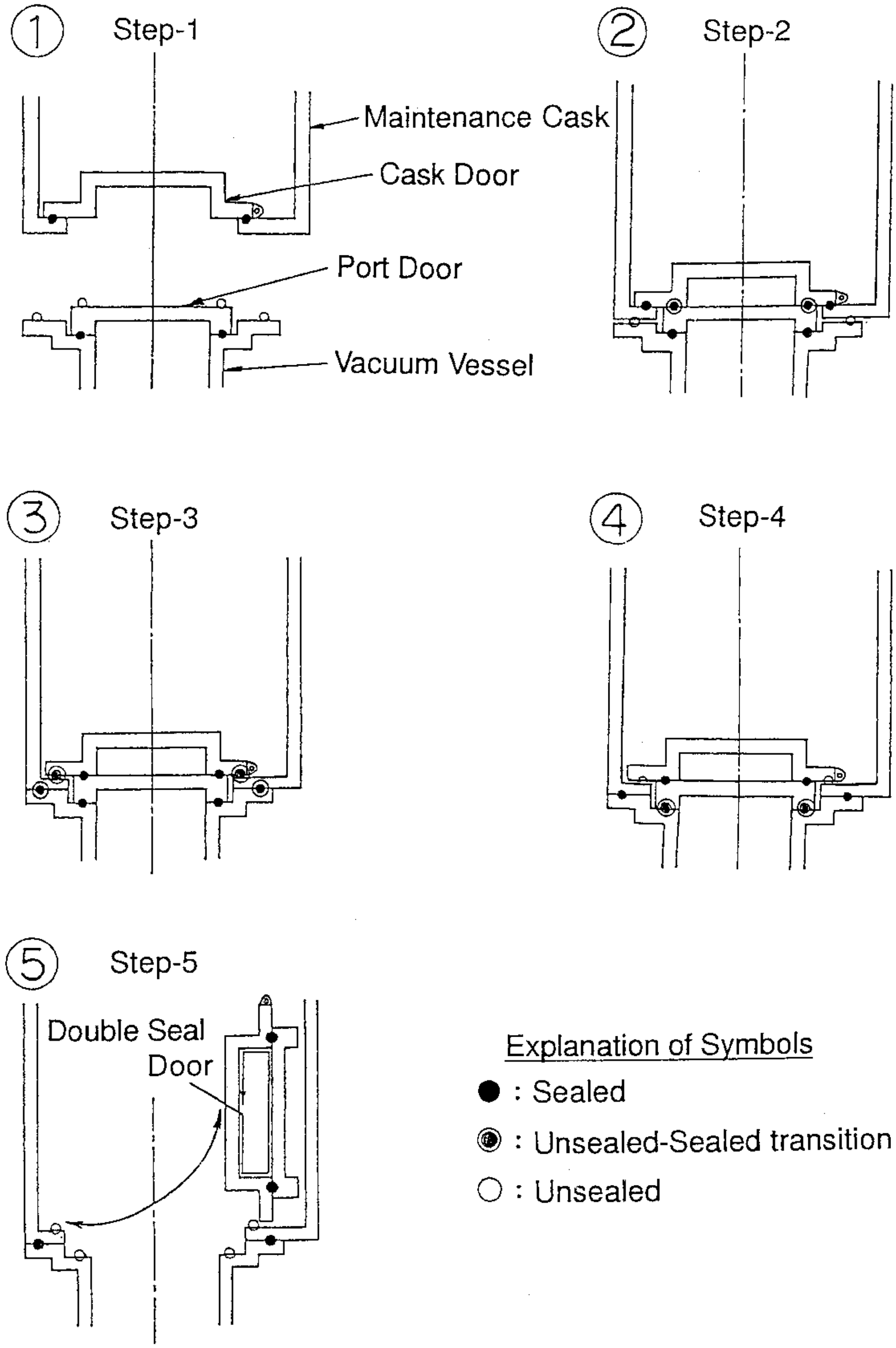



Fig. 1 Typical configuration of double seal door

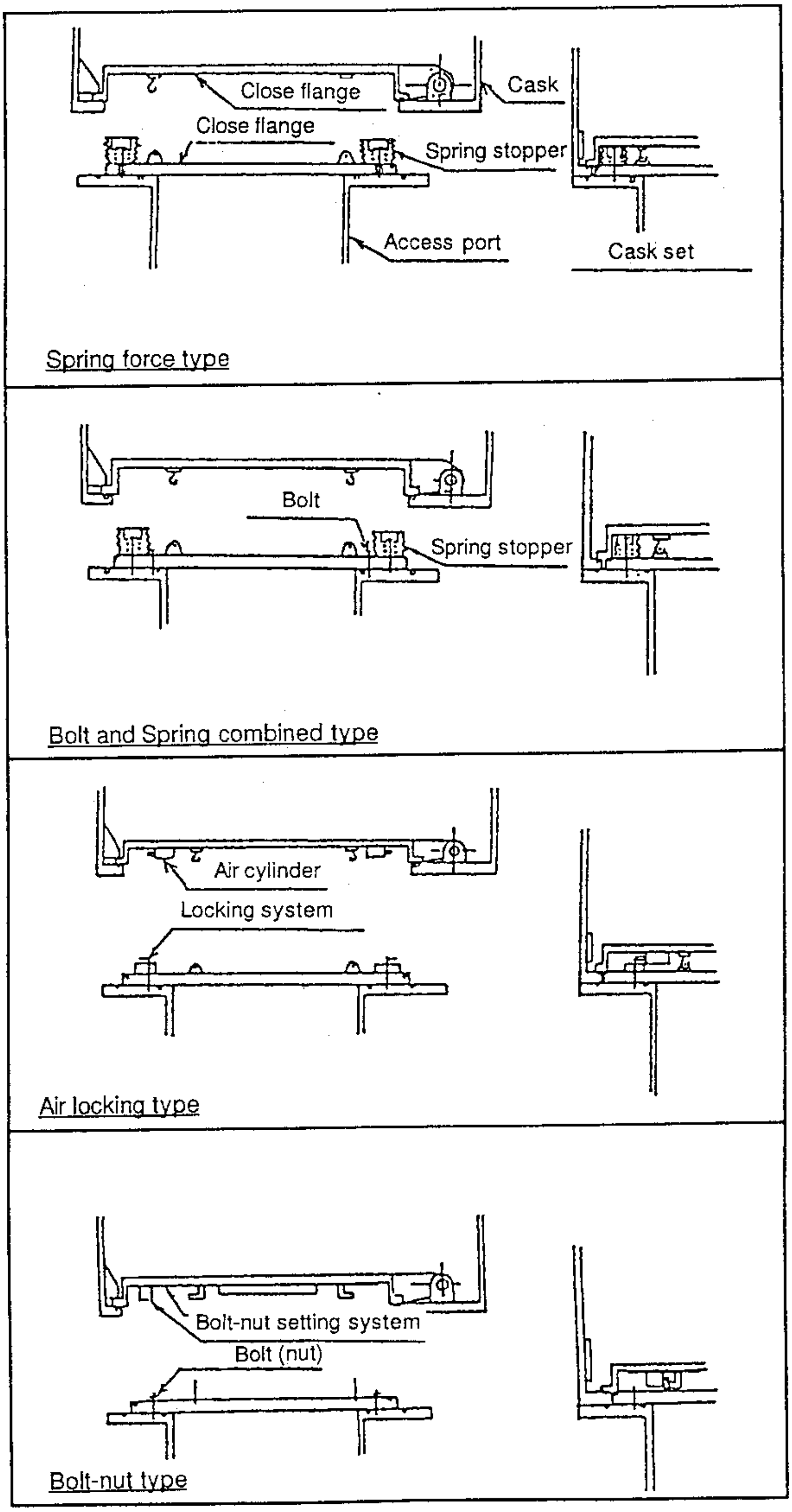



Fig. 2 Connection methods of double seal door

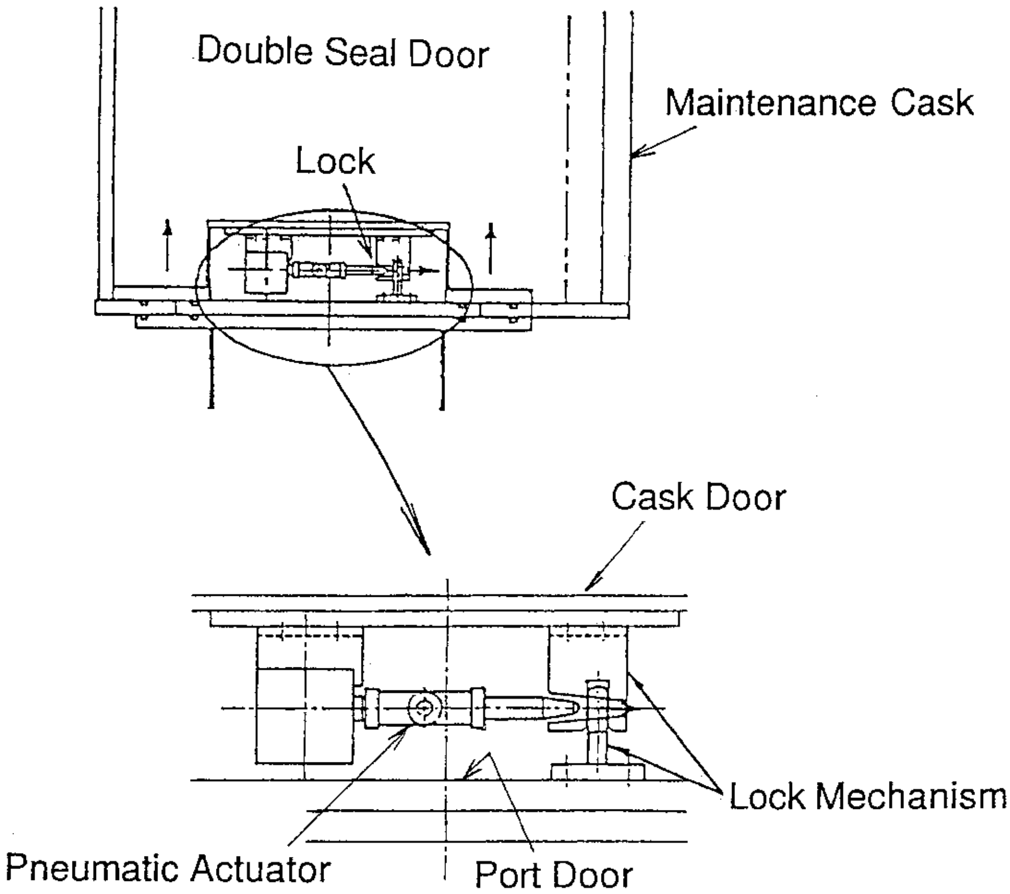



Fig. 3 Double seal door connection with pneumatic actuator

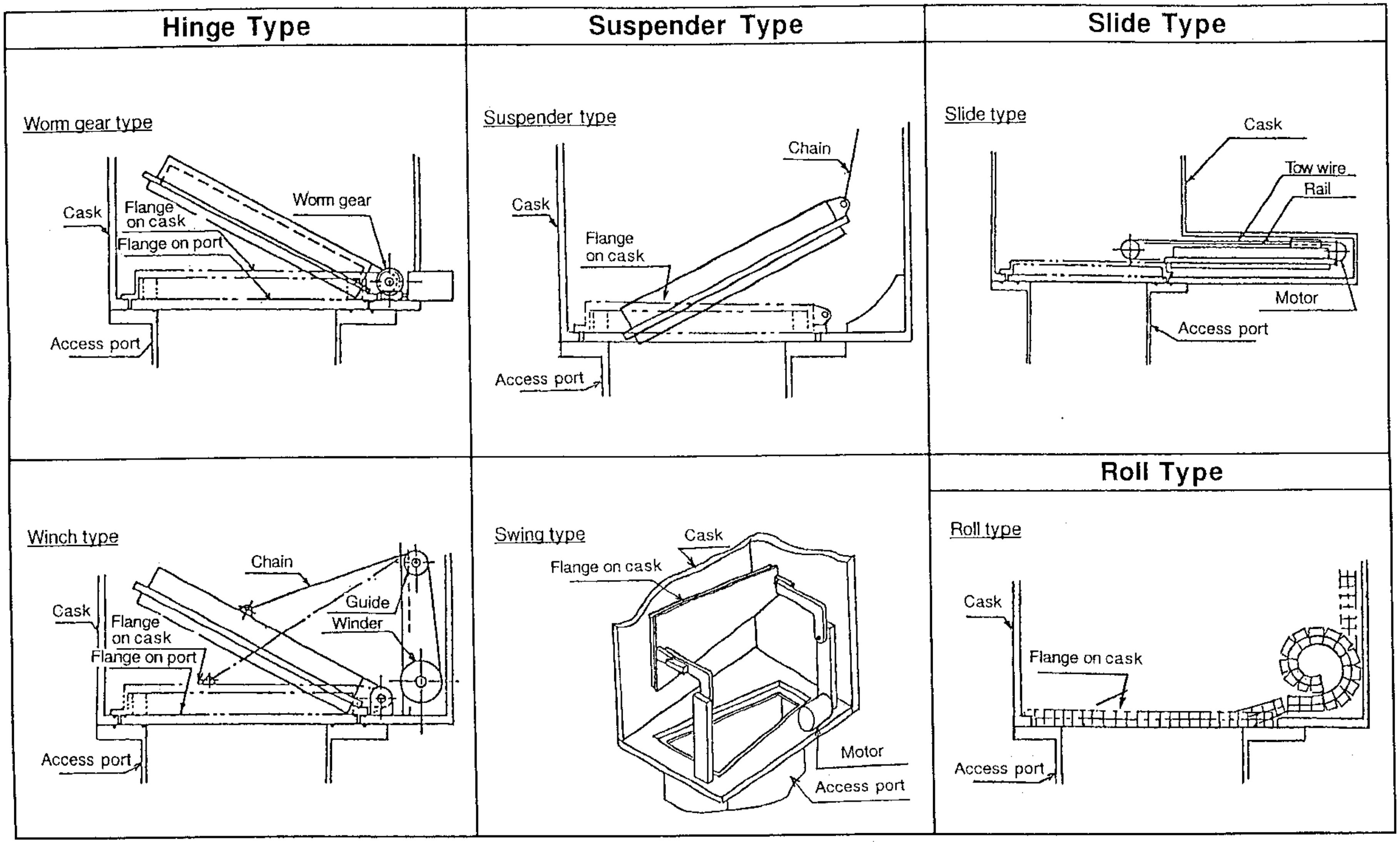



Fig. 4 Possible open/close schemes for double seal door

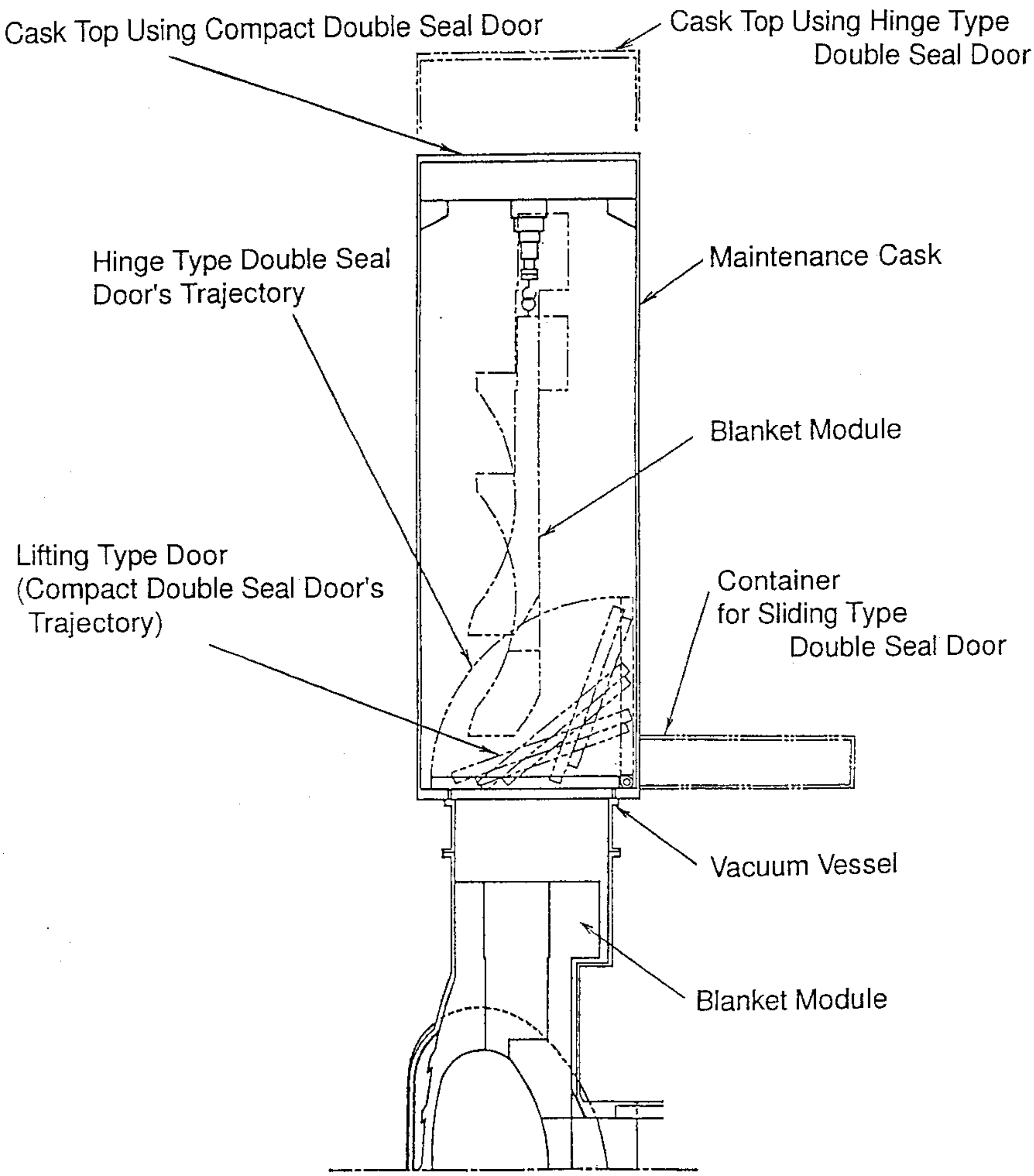
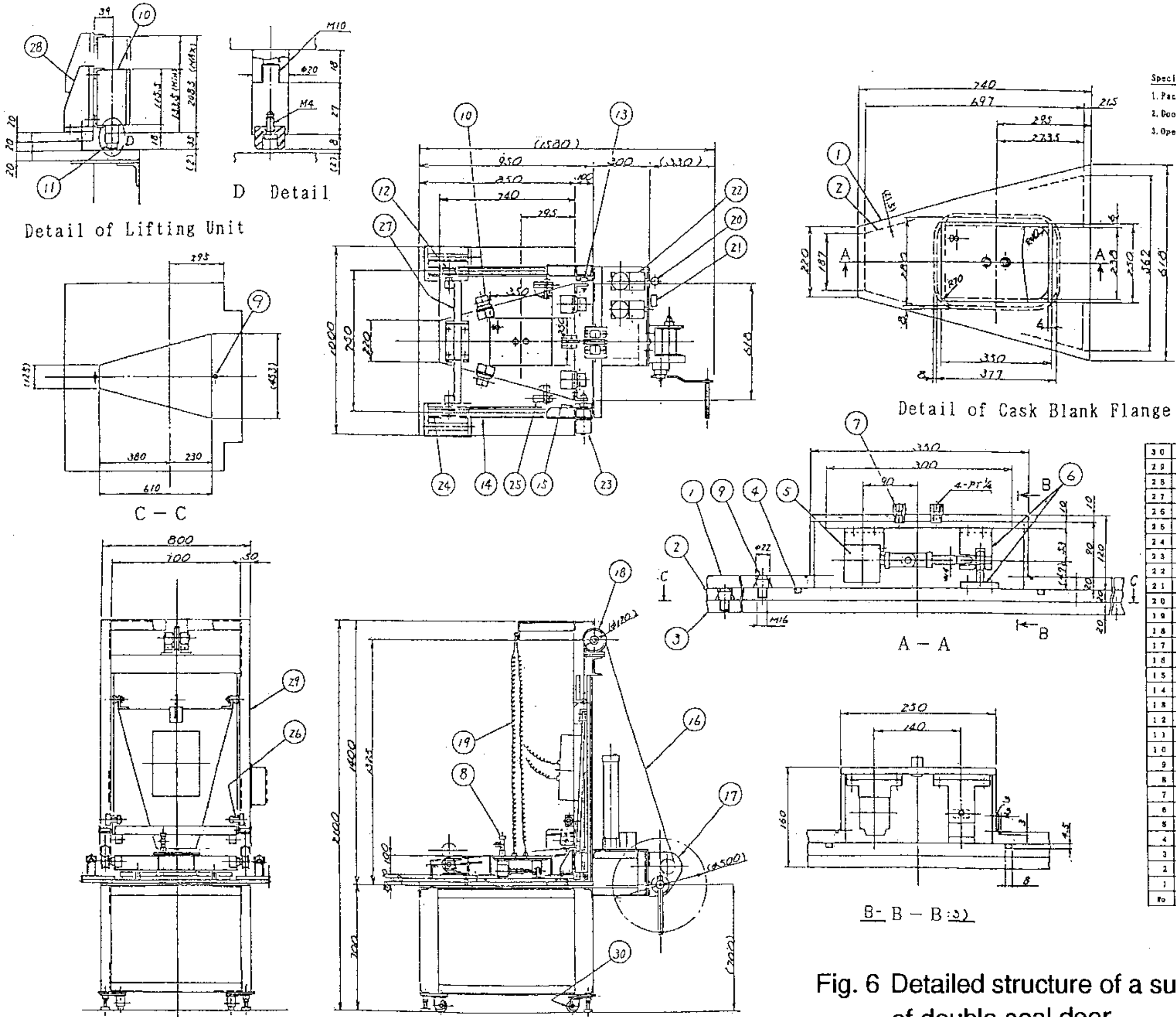



Fig. 5 Maintenance cask configuration for various open/close kinematics of double seal door

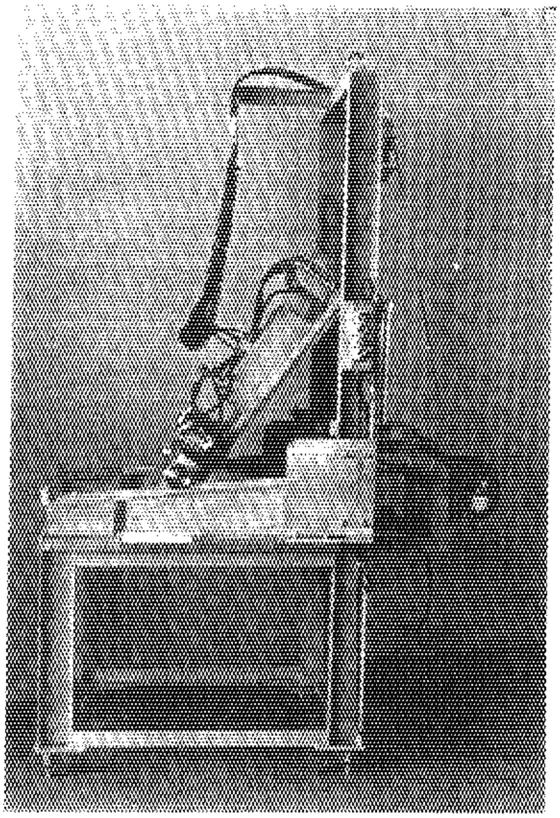



Specifications

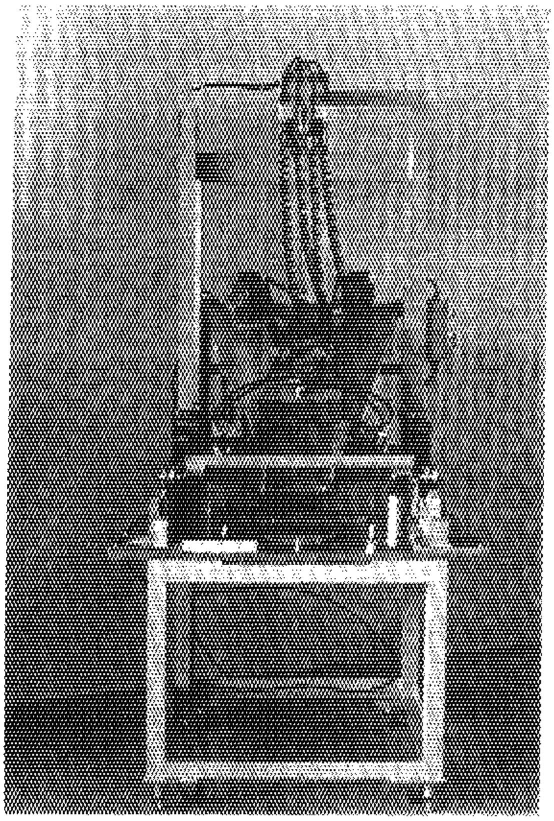
1. Packing : Rectangular Rubber Gasket Sealing
2. Door Lock : Pneumatic Actuater Pin & Hole
3. Open/Close: Shifting Alongside Wall Type

| No | Vol. | Parts Name |
|---|---|---|
| 30 | 4 | Caster Wheels |
| 29 | 1set | Supporting Frame |
| 28 | 4 | Actuater Supporters |
| 27 | 1set | Arm |
| 26 | 2 | Hooks |
| 25 | 2 | Lockig Devices |
| 24 | 2set | Auxiliary Rails |
| 23 | 1 | Switch Box |
| 22 | 1 | Air Hydro Filters |
| 21 | 2 | Electromagnetic Valves |
| 20 | 1 | Air Regulator |
| 19 | 1set | Flexible Tubes |
| 18 | 1 | Idler |
| 17 | 1 | Hand Winch |
| 16 | 1 | Wiring |
| 15 | 1set | Up/Down Guide Rails |
| 14 | 2 | Guide Rails |
| 13 | 2 | Up/Down Guide Wheels |
| 12 | 2 | Door Wheels |
| 11 | 4 | Cushions |
| 10 | 4 | Door Lifting Devices |
| 9 | 4 | Guide Pins |
| 8 | 1 | Safety Valve |
| 7 | 2 | Air Inlet Nipples |
| 6 | 2set | Locking Devices |
| 5 | 2 | Pneumatic Actuaters |
| 4 | 1 | Sealing Gasket |
| 3 | 1 | Flange of Access Port |
| 2 | 1 | Blank Flange of Access Port |
| 1 | 1 | Cask Blank Flange |

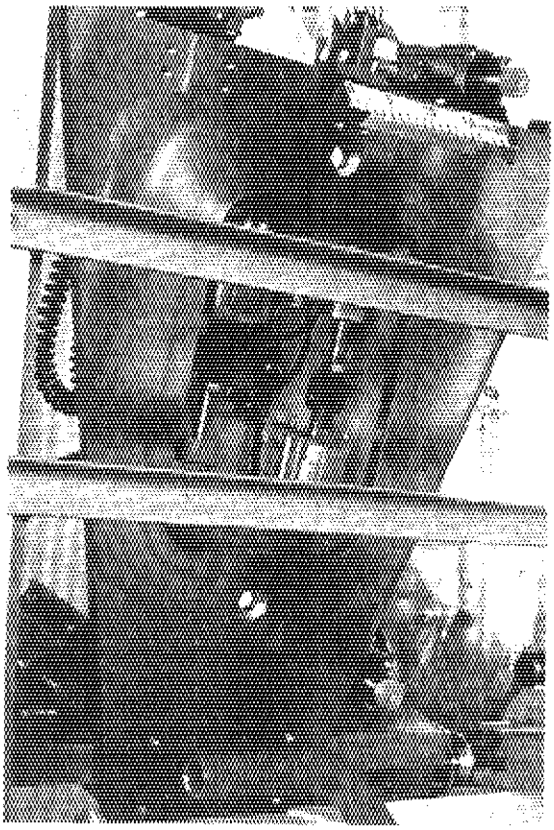
Fig. 6 Detailed structure of a sub-scaled model of double seal door



(a) Side view of double seal door



(b) Front view of double seal door



(c) Details of air locking system for double seal door connection

Fig. 7 External view of a sub-scaled model of double seal door

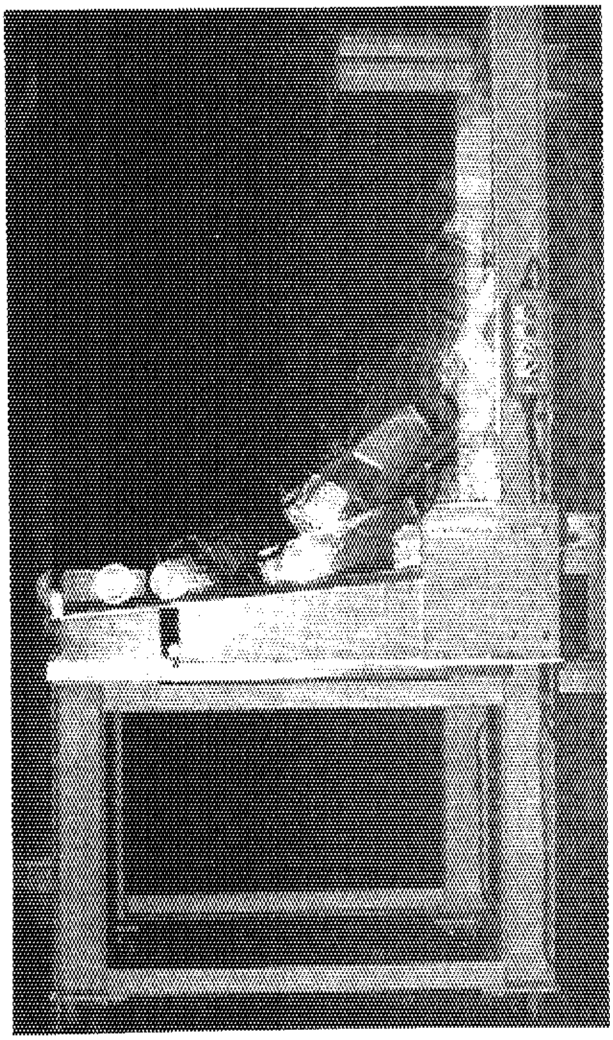
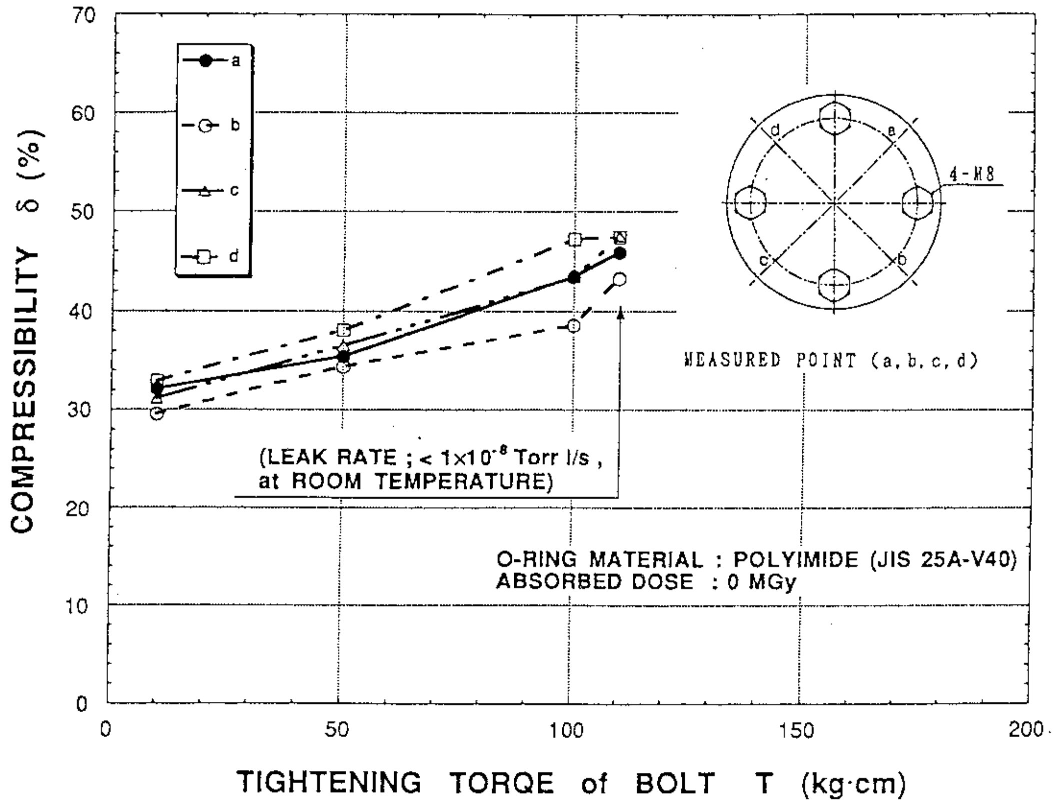


Fig. 8 Measured open/close kinematics with parabolic trajectory



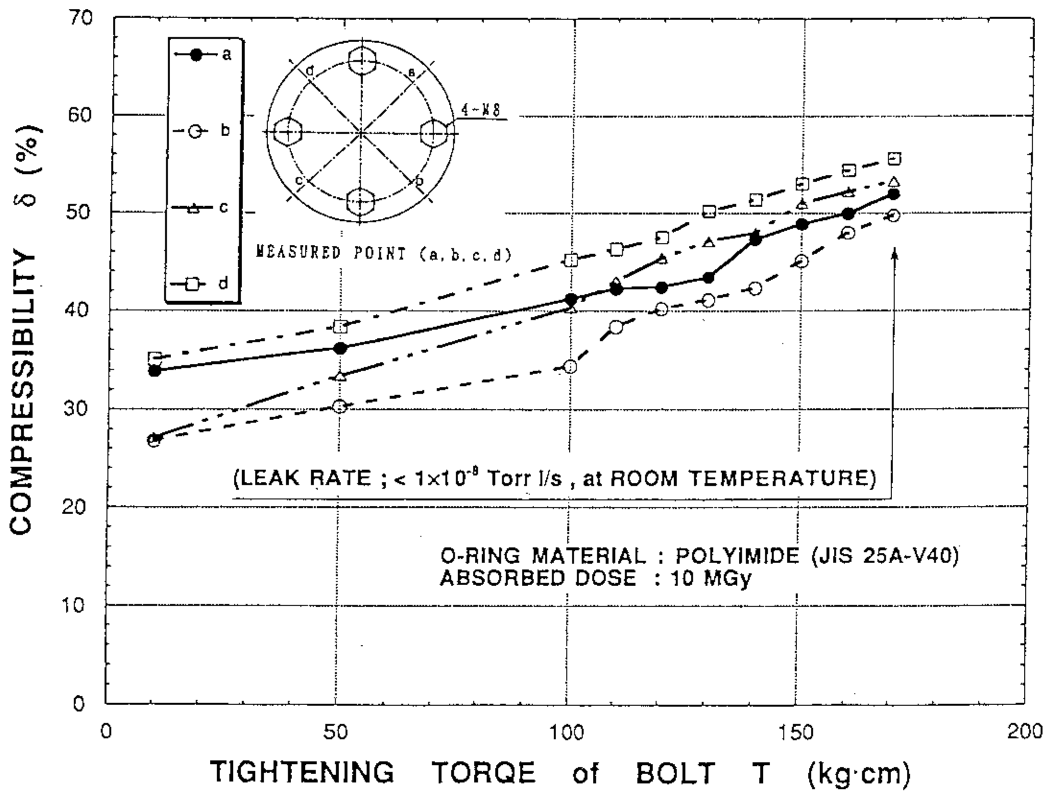




Fig. 9 Leak test results of polyimide seal ring