A SYSTEM FOR MODEL ACCESS IN TUNNELS WITH AN UNBREATHABLE TEST MEDIUM

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Introduction

In many speciality wind tunnels, test gases other than ambient air are used to meet special testing requirements. A typical example is the use of Freon as the test gas to achieve a realistic density ratio between gas and model for exploring flutter stability boundaries. (1) Another example is the use of pressurized air to elevate the stream density and enhance Reynolds number or dynamic pressure simulation.(2) Such specialty tunnels require a system of access to the model which will allow services and changes to the model without exposing personnel to the unnatural and perhaps hostile environment or requiring the venting and purging of the entire tunnel circuit. This paper will describe the plenum and model access systems for the forthcoming U.S. National Transonic Facility where gaseous nitrogen (N_2) at temperatures between 338 and 78K and at pressures to 9 bars is used as the test medium. The operation at cold temperatures imposes some additional requirements which make the access systems more difficult to design and time consuming to operate than for conventional wind tunnels.

Description of the National Transonic Facility.

The National Transonic Facility (Fig. 1) is a closed circuit transonic pressure tunnel designed to operate at cryogenic temperatures. (3, 4, 5, 6) Operation at combinations of reduced temperature and elevated pressure produces test Reynolds numbers at or near full scale flight values. Low temperatures are achieved by spraying liquid nitrogen into the circuit and using its heat of vaporization to cool the test gas or to stabilize the temperature for cases where operation (compression heat input) is at a constant condition.(7) Elevated pressure is achieved by the mass addition of the nitrogen and is stabilized or reduced by venting. A schematic of the nitrogen supply and vent system is presented as figure 2.

The pressure shell is insulated internally to maintain low temperature gas for long periods of time. Further, in the interest of minimizing operating cost and enhancing energy efficiency, venting and purging the entire tunnel volume must be avoided whenever possible.

The test section (Fig. 3) is slotted and has movable components (top and bottom slotted walls, re-entry flaps, and top and bottom walls of the model support section) which permit remote adjustment for Reynolds number effects on boundary layer growth, flow re-entry losses and diffuser losses. It is important to note that the 2.5 meter square test section is contained in a 8.5 m diameter plenum which has 2.7 m by 3.7 m access doors centered on the horizontal diameter and located near the model pitch center. The first 5.5 m length of the test section side walls can also be lowered to permit relatively free access to the model.

Plenum and Model Access System

Requirements.

A model access system was easily justified for the National Transonic Facility on the basis of the nitrogen saved by not having to vent the entire tunnel for each model modification. The cost investment payback based on realistic workload which included a distribution of different types of testing is about three years.

Two types of operational functions established the model access system requirements. The first is the activity normally carried out between user test programs and involves removing the model and its support that has completed testing and installing the next model and support to be tested. During this process, any required changes in instrumentation or plenum area modifications to accommodate the new model are accomplished. This activity requires that the entire plenum be accessible by service personnel and may require a time interval of a complete work shift or more.

The second operational function considered is the access to the model only. This activity is required during the test program of a specific model for making small changes to the configuration, such as, tail deflection angles or wing flap settings. This function requires personnel access to a limited working space around the model.

The requirement that emerges is for providing an acceptable and hazard-free working environment for each of the above operational functions. This in turn requires that the working space be safely isolated and purged with relatively warm, dry air to bring both the temperature and oxygen constituency to an acceptable level and that these conditions be maintained throughout the period during which personnel are present.

Concept.

The concept that was developed to satisfy the fundamental working requirement for plenum isolation takes advantage of the existing pressure bulkheads at either end of the plenum (Fig. 4) as part of the isolation system. To complete the isolation of the plenum volume, openings in the pressure bulkheads through which the test stream flows must be closed.

An evaluation of a number of different approaches to plenum isolation was performed on the basis of capital cost and operating safety. The approach selected involved moving both the contraction structure and the high speed diffuser structure away from the plenum to expose the plenum bulkhead flanges. (See Fig. 4.) The preliminary design attached the contraction and high speed diffuser structures to their respective bulkhead and permitted them to thermally expand away from the test section. Hence, the basic support scheme, which now allows the movement of the entire structure, existed prior to the decision to incorporate a plenum isolation system. Circular dished heads are used to close the openings created in the bulkhead when the contraction and diffuser are moved away. Because of the mass of the structures which must be moved, and the requirements for remotely-controlled actuation and personnel safety, a rather large and involved operating system is necessary.

Although the system selected is complex and contains a number of components which have to move in the cold environment, the cost analysis indicated that this arrangement is less expensive than a large gate valve arrangement or similar schemes which would require major modifications to the pressure shell design.

Plenum Access System.

In the operating configuration the plenum closure heads are stored (see Fig. 4) beneath the contraction and high speed diffuser structures, each of which is locked to its respective bulkhead flange with 32 cam-type clamps actuated by four electric motor-driven mechanical actuators (see Fig. 5). Each actuator operates eight clamps through a link arrangement. The cam action of the clamps forces the structures into final position on tapered guide pins and loads the flange to obtain the desired sealing of the flange joint. The mechanism shown is similarly used to clamp the isolation head closures to the bulkhead flanges.

To isolate the plenum volume, the flow in the tunnel is stopped; the clamps on the contraction and high speed diffuser are released, and these two structures are retracted from the plenum a distance of about two meters. The motion is accomplished by translating the structures on horizontal rails using long electric motor-driven mechanical actuators as the driving method.

After the contraction and high speed diffuser structures are moved to the retracted position, the closure heads are elevated and positioned to close the openings in the bulkheads. These large heads are moved on a track using four electric motor-driven mechanical actuators (two each side) to lift and position them. (See Fig. 6.) The two lift actuators raise the head to the top of the track, the two positioning actuators push the head into position where the clamps can engage and seal them against the bulkhead flange.

After the heads are in their closed position and seated, the plenum volume is vented to the atmosphere and conditioned for personnel entry.

Conditioning the plenum is accomplished by circulating dry air through the volume to bring the oxygen constituency and temperature of the gas to an acceptable working level. It should be noted that of the activities which must be performed to isolate and condition the plenum, elevation of the temperature of the space requires the most time. The mass of the metal structure of the test section serves as a large heat sink which requires considerable time to heat. When the required level of oxygen and temperature are reached, the large doors in the plenum pressure shell (Fig. 7) are opened, so that personnel can enter the plenum to perform their work assignments. Oxygen monitors provide a safety alarm in the event that for any reason the oxygen level drops below a specified lower limit.

The plenum doors are locked and seated on the pressure seal by motor-driven eccentrics. When they are unlocked, they can be moved on motor-driven wheels into an insulated pocket to clear the doorway.

To return the plenum to the operational mode, the plenum doors are closed, and a bypass system is opened which allows the pressure to equalize across the plenum bulkheads. Once the pressure is equalized, the closure heads are unclamped and returned to their stored position. The contraction and high speed diffuser structures are then brought back to their operating position and secured in place. The facility is then ready for test work. A schematic of the plenum vent, purge and conditioning system is shown on figure 8.

Model Access System.

The model access system requires the plenum pressure to be atmospheric. It does not, however, require that gaseous nitrogen be purged from the plenum volume or that the temperature in the plenum be elevated.

The model access system is composed of two large rectangular tubes, each 2.1 m by 3.0 m in cross section and 4.9 m in length with doors at the outboard ends. (See Fig. 9.) When the model access system is being used, these tubes are normally seated in the door frames external to the plenum with the outboard doors closed as indicated in the upper view of the figure. When model access is required, the plenum pressure is brought to atmospheric, the side walls of the test section are lowered, and the 2.7 m x 3.7 m doors in the plenum shell are opened by unseating them and translating them horizontally into the stored position. The access tubes are then slowly inserted until they meet (see the lower configuration on figure 9). When they meet, a seal around the perimeter of the open ends of the tubes and around the model sting seals the model within the tube. (See Fig. 10.) The tube volume is then purged with dry air to raise the oxygen and temperature to the desired level. Heating for the model surface is provided as required to avoid condensation, and the doors at the outboard ends of the tubes are opened to provide a complete through-passage around the model for service.

Details of Access Tubes.

The model access tubes (Fig. 11) are rectangular in cross section and are constructed of aluminum. A fiberous glass insulation is inserted between the inner and outer skins of the structural shell to insulate the working space inside the tube from the cold gas which surrounds it. The motion of the tube in the insertion process is actuated by a cable-wench arrangement driven by an electric motor. Parallel rails embedded in the floor outside the tunnel align and guide the motion. Two sets of rollers support the tubes as they are inserted into the plenum. The pressure differential across the plenum pressure shell is required to be near zero to minimize nitrogen leaks across the seals. Because of the very small pressure differential, a wiper type seal is used at the door to prevent large leakage of cold nitrogen. Any nitrogen that escapes around the seal is scavenged with an exhaust system and pumped to a release point above the roof of the building.

The seal at the interface of the two tubes is a braided teflon cord contained in a groove around the perimeter of the tube end (Fig. 11). Alignment of the seating surface is achieved by the engagement of wedge type pins or ramps at five locations around the perimeter (Fig. 11).

The seal around the model sting is contained in a sting adapter plate which is a removable portion of the tube (also Fig. 11). The plate is sized to allow different sting geometries to be sealed by the tubes.

When the tubes meet and seal, a lock is required for safety. This lock is interlocked with locks on the end doors (Fig. 10) and is activated from outside the access tube. The lock is positive and cannot be released until the exterior doors are closed and locked when work on the model is completed.

The tubes contain their own power distribution system for light and outlets for electrical hand tools as well as utility air supply. As mentioned earlier, the tubes also provide electrical power for heating the model as required. Oxygen monitors are provided in the work area near the tube joint to provide alarm if oxygen level exceeds a specified lower limit. The oxygen monitor also issues a permissive signal to allow the external doors to be opened after the tube is purged.

Dry Air Supply Systems.

There are two air supply systems associated with the model access (Fig. 8). One system supplies dry air to purge the plenum volume to permit personnel access. It also supplies dry air to purge the access tubes when they are used. The other system supplies air in the plenum while personnel are working there to assure a continuing supply of air for breathing. Both purge processes are designed to avoid the introduction of moisture into the cold test section. It should be noted that the bypass system for pressure equalization includes a double isolation valve with a vent in between to assure the safety of personnel working in the plenum. The same arrangement is incorporated in the purge air supply which has a high flow capacity. The personnel air is controlled by flow rate and is of limited flow capacity so that it cannot produce a hazard.

Operating Times.

As mentioned earlier, the objective of the model and plenum access system described above is to enhance productivity and minimize operating cost. One objective, therefore, was to keep the time used for access at a minimum acceptable interval. The projected time intervals for the different activities required for personnel access to the plenum volume are shown in figure 12. In the case of plenum access, the temperature rise of the internal structures controls the time required for the total process. If the structures are warmed to room temperature, the process can require up to five hours because the permissible rate of temperature change is limited by thermal stress in certain parts of the structure. In general, plenum access will be required only for model installation or for correcting instrument malfunction. These kinds of activities are expected to be infrequent.

On the other hand, model access required for configuration changes to models during a test program is expected to be frequent. The expected time intervals for the activities required for personnel access to the model are shown on figure 13. The model access tubes permit the model to be available for service without purging the plenum or warming the internal structures. As a consequence, the time required for access is limited only by the time required to perform the necessary activities, purge, and warm the model. The cold environment influenced the selection of methods used for actuation of the motions of the large structures. Hydraulic cylinders as actuators would have been somewhat faster than the electro-mechanical system selected. The hydraulic fluid and seals, however, were not generally compatible with the cold environment, and the potential for hydraulic oil leaks and continuing maintenance problems led to the selection of the slower, but generally more trouble-free electric-driven actuators. The actuators are housed in thermally-controlled enclosures to keep lubrication from freezing and thereby preventing operation. This control would have been provided for the hydraulic actuators as well. However, the hydraulic piping would have required elaborate thermal control and monitoring.

The time interval for model access in this cryogenic tunnel is somewhat longer than for some more conventional air tunnels. As mentioned previously, this is largely due to the requirement to purge and warm the working space.

The model access system design, as presented, will permit nominal model service and return to operation in less than a two-hour period which satisfies the productivity goals for the tunnel.

Concluding Remarks.

An access system for personnel entry to the test region and to the model for service and configuration changes has been described. The system was designed to minimize the loss of nitrogen (test gas) and time considering the operating environment and constraints and productivity criteria established for the National Transonic Facility. The system is believed to be functionally acceptable and free of hazards.

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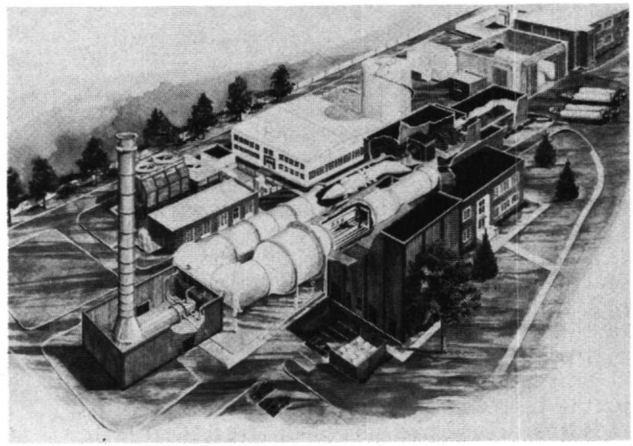

Figure 1. Artist Perspective of the National Transonic Facility Site

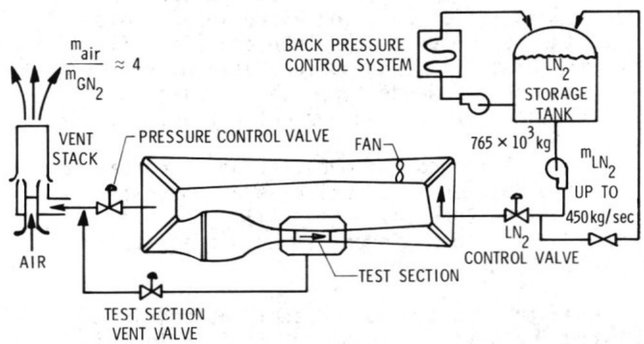

Figure 2. Simple Schematic of the Nitrogen Supply and Vent System for the National Transonic Facility

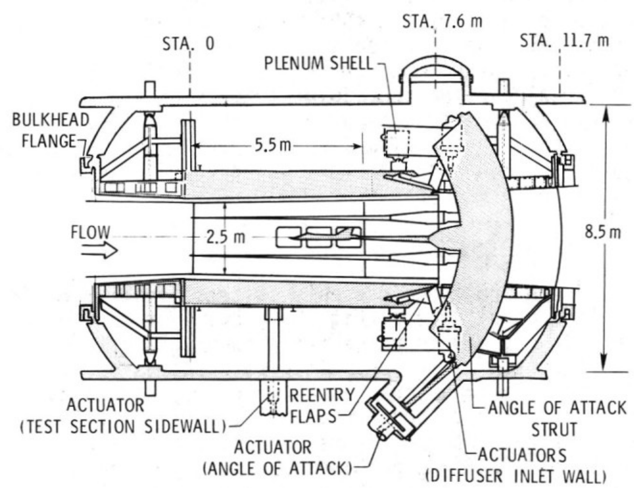

Figure 3. Prcfile of the Test Section of the National Transonic Facility Showing Some of the Pertinent Features

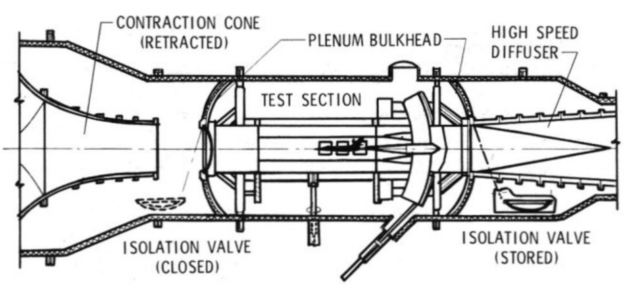

Figure 4. Sketch of Plenum Isolation System for the National Transonic Facility

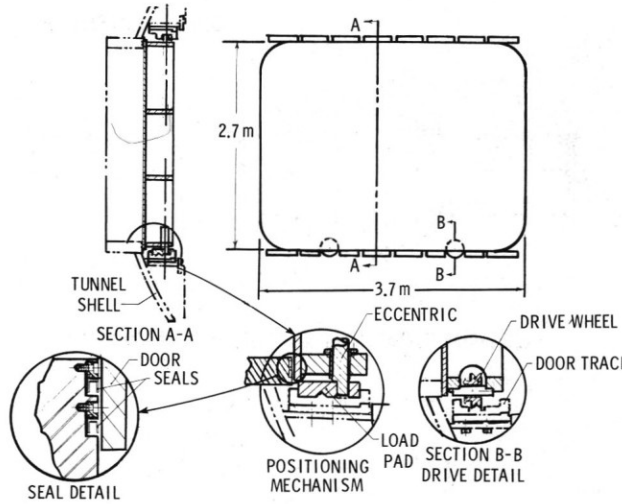

Figure 7. Plenum Access Door Details

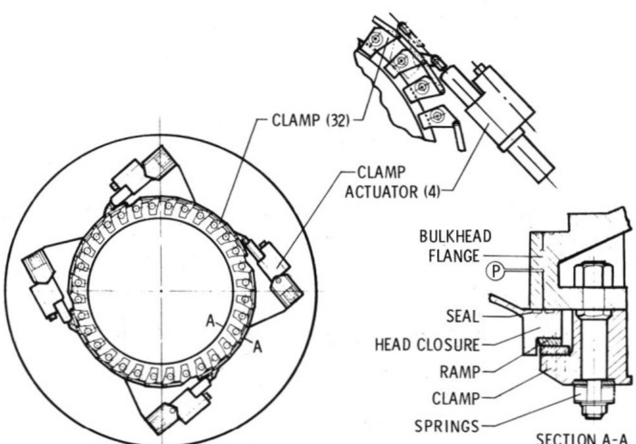

Figure 5. Sketch Showing Details of the Plenum Bulkhead Clamping System and Flange Seals

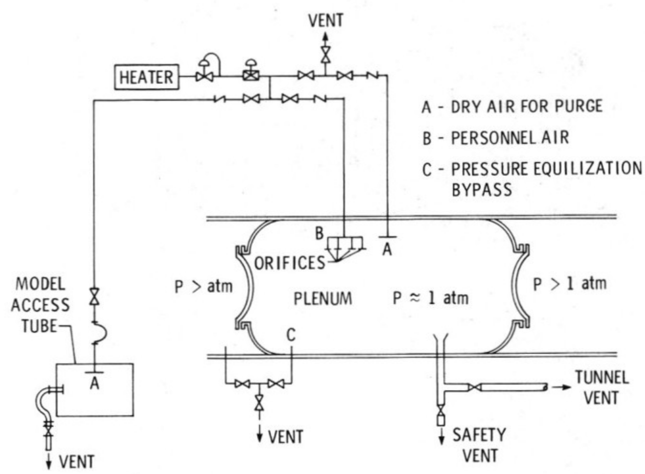

Figure 8. Simple Schematic of the Dry Air Supply System for the Plenum and Access Tube Purge and Breathing Air Supply

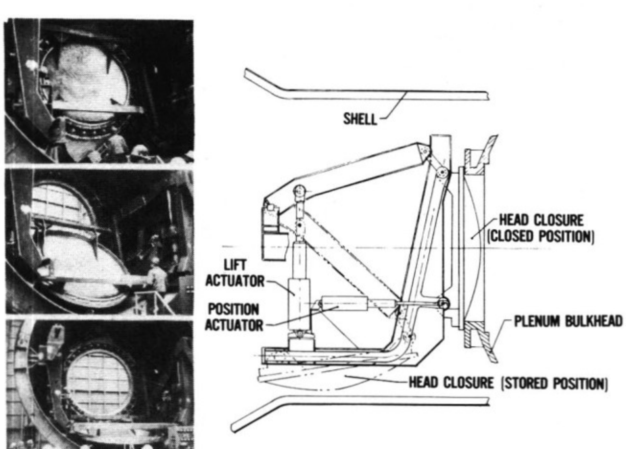

Figure 6. Position System for the Dished Head Closures

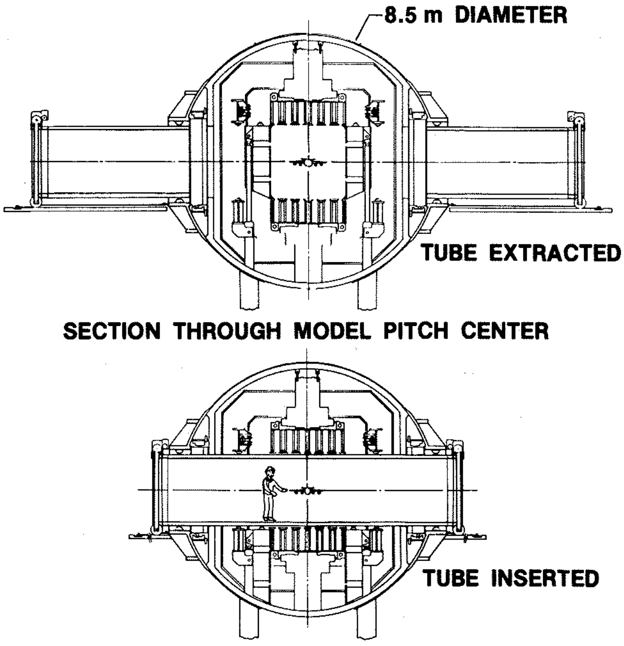

Figure 9. Model Access System

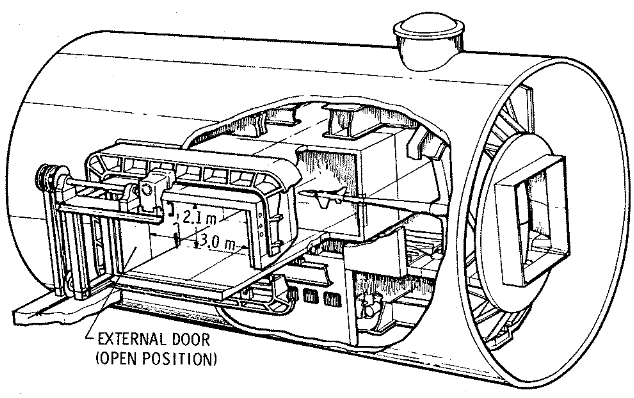

Figure 10. Isometric View of Model Access System in the Inserted Position

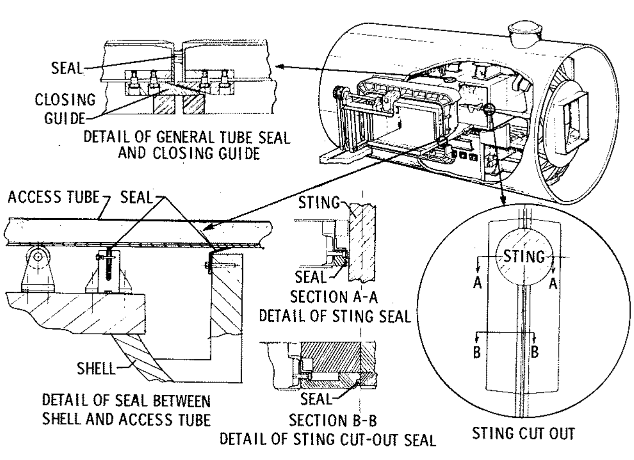

Figure 11. Details of the Model Access Tube Alignment Mechanism and Seals

COMPONENT/PROCESS	MOTION	ACTUATION TIME	METHOD
CONTRACTION/DIFFUSER	CLAMP/UNCLAMP TRANSLATE	3.5 min	ELECTRO-MECHANICAL ACTUATORS
BULKHEAD CLOSURE	POSITION & CLAMP	9.5 min	ELECTRO-MECHANICAL ACTUATORS
PLENUM VENTING	BLOWDOWN	3.0 min	
TEST SECTION DOOR LOCKS	ENGAGE/DISENGAGE	0.1 min*	ELECTRO-MECHANICAL ACTUATORS
MODEL ANGLE LOCK	ENGAGE/DISENGAGE	0.5 min*	ELECTRO-MECHANICAL ACTUATORS
CORNER FILLETS	DISENGAGE/STORE	0.5 min*	ELECTRO-MECHANICAL ACTUATORS
TEST SECTION DOOR	RAISE/LOWER	1.0 min*	HYDRAULIC ACTUATORS
PLENUM CONDITIONING	INBLEED DRY AIR	30.0 min	
PLENUM DOORS	TRANSLATE	2.0 min	ELECTRO-MECHANICAL ACTUATORS

* CAN BE ACCOMPLISHED DURING VENTING OR FILLING

Figure 12. Actuating Times for the Different Processes Leading to Plenum Access

FUNCTION	TIME
CONDITION PLENUM	18 min
INSERT TUBES	3 min
CONDITION TUBES/WARM MODEL	37 min
CHANGE/SERVICE MODEL	VARIABLE
PREPARE FOR TUBE EXTRACTION	5 min
RETRACT TUBES	3 min
RETURN TO OPERATING CONDITIONS	18 min
TOTAL	84 min + VARIABLE

Figure 13. Actuating Times for the Different Processes Leading to Model Access