TENERIFE Program : High Temperature Experiments On A 4 Tons UF_6 Container

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I - INTRODUCTION

Over the past few years, the International Atomic Energy Agency has been working on establishing regulation for UF_6 transportation which should take into account chemical and radiological hazards. This action took a concrete form with the guide TEC - DOC 587-2 published by the IAEA in 1989 and which will serve as a basis for the next issue of the IAEA regulation for the transport of radiactive materials (Safety Series n°6), planned for 1995.

This guide specifically provides that packagings for the transport of non-fissile products (enrichissment less than 1%), such as the type 48Y cylinder, must be able to resist in the fire conditions identical to these related to containers for radioactive materials of type B, 800°C for half an hour.

Since the capacity of a 48Y container to withstand fire cannot be guaranteed by calculations, an experiment (TENERIFE project) was defined and integrated into a wider IAEA research programme. The main purpose of these tests is to verify the resistance to fire of 48Y containers. The contract to cover the collaboration between Japan and France was signed in October 1991.

II - OBJECTIVES

To know the input of the future thermo-mechanical code, we have to get a better understanding of the thermo-physical evolution of the UF_6 which pressurizes the container. This evolution is function of :

a) the heat transfer rate from the fire to the container
b) the UF_6 behaviour in the container.

The first point may proceed from the type B regulation requirements (about 54 kW/m^2) or real heat flux during experimental fire (120 kW/m^2 in J.J. Gregory 1989). Though this external boundary conditions are not specific to UF_6, it is a very important unknown of the problem.

The actual main incertitude is more related to the second point which concerns heat transfer itself inside the cylinder depending on the phenomenology of UF_6 liquefaction and vaporization.

Malett experiments (A.J. Malett, 1966) are the only UF_6 heating in a fire. Computer models for determining the moment when the 48Y type container ruptures (12 tonnes UF_6) on exposure to hydrocarbon fire have been developed at the CEA, at the CRIEPI and abroad. It has only been possible to partially validate them since the existing tests (USA and Japan) were only executed on smaller containers (maximum 100 kg UF_6) and at lower simulated fire temperatures (400°C).

The analysis and extrapolation to a 48Y container in fire during 30 minutes gives a great scattering in the results in terms of fire and cause of rupture :

Williams (Williams, 1988) : **28 mn hydraulic rupture**
Park (Park) : **22 mn** rupture due to vapor pressure
Shiomi and al. (Yamakawa and Shiomi, 1988 ; Abe, 1989) : **no rupture**
Duret (Duret and Bonnard, 1983 ; Duret and Warniez 1988) : **no rupture** (hydraulic rupture at 40 mn).

This dispersion comes from the scale effect from 100 kg of UF_6 to 12 tons.

It is the main reason we decide to respect two important parameters in the TENERIFE experiment :

a) external temperature level,
b) realistic internal diameter.

a) External temperature level :

At the beginning the heat transfer to UF_6 material is limited by a presence of a gap between the steel wall and the UF_6. In order to get a picture of the events we will make use of a calculation based on our model developed for a 48Y container (Duret and Warniez, 1988). These calculations indicate that the steel temperature is higher than 500°C.

The transfer will come from conduction heat transfer (unknown : the contact surface) and also radiation (unknown : the internal emissivity).

On a other hand, this temperature level is much higher than the critical temperature of UF_6 : thus the liquid UF_6 should not wet the hot steel and a vapour film may separate the liquid UF_6 from the steel surface. If this vapour film is stable, this film acts as a thermal resistance and will delay the heating up and the melting of UF_6. Thus the time to rupture would be increased. If not, the heat transfer to UF_6 should be increased, which reduces the time to rupture.

The stability of this film will, in fact, depend on the time at which UF_6 will really start to melt. This will depend on the quality of heat transfer in the solid UF_6. If transverse conduction in the solid UF_6 is taken into account, the temperature distribution in the solid will not be uniform and the melting temperature will be reached near the steel wall sooner as precalculated with the assumption of uniform temperature distribution (which is in the model we developed).

b) Realistic internal diameter :

Solid UF_6 is porous and UF_6 has a high vapour pressure ; therefore heat transverse exchange in solid UF_6 is related not only to conduction but also to vapour convection (evaporation in hot sites and condensation in cold sites). It is a matter of fact that the experiments give "equivalent conductivities" which are much higher than the conductivity of the pure solid.

But what is the validity of the known "equivalent conductivity" derived from low temperatures low diameter experiments when real cases (high steel temperatures, high diameters) are considered ? It is possible that phenomena like porosity occlusions may appear for high diameters which may not exist for lower diameters.

III - DESCRIPTION OF THE EXPERIMENTAL PLANT

III.1 Working principle

These tests are essentially analytical at simulated fire temperatures of between 800 and 1000°C. They use a representative mass of UF_6 (around 4 tons). The tests will not seek to rupture the test container which has a diameter equal to the 48Y container, but shorter length.

These tests carried out in realistic conditions (typical thermal gradient at the wall, characteristic period for UF_6 internal mass transfer) should make possible to improve knowledge of two fundamental phenomena :

- vaporisation of UF_6 on contact with the heated wall (around 400°C), a phenomenon which controls the container internal pressurization kinetic,
- the equivalent conductivity of solid UF_6, a phenomenon which is linked to the heat transfer by UF_6 vaporisation-condensation through the solid's porosities and which depends on the diameter of the container.

In addition, they will allow the influence of other parameters to be studied, such as UF_6 container filling mode or the mechanical characteristics of the container material.

A UF_6 container fitted with instruments (wall temperature, UF_6 temperature, pressure) is heated by a rapid heat transient in a radiating furnace where the temperature and thermal power supplied can be measured.

The test continues until pre-established thresholds have been reached :

- strain threshold measured on the container surface (strain gauges positioned on the outside),
- maximum temperature threshold of UF_6,
- container internal pressure threshold.

In order to take into account the effects of inertia (transfer of accumulated heat in the steel to the UF_6 for instance), the tests will be undertaken progressively (by increasing the duration of exposure to high temperature).

To prevent any risk of environmental contamination, three containments are provided :

- the container envelope,
- a leaktight vessel housing the furnage-container assembly which is large enough to contain all the UF_6 on accidental rupture of the container,
- an external barrier consisting of a leaktight building (Caisson J).

III.2 Experimental container

The container corresponds to a section of the 48Y container so that the thermal exchanges can be properly reproduced. The diameter, thickness, materials and fabrication process are identical, but the container is shorter (around 1/3) to limit the quantity of UF_6 to around 4 tons.

The experimental container is used for filling, emptying, transport of UF_6, and for carrying out the thermal tests. It is planned to use one container for each thermal test, each of them will be placed inside the experimental furnace where it is secured by its bottom jackets. The container will be fabricated and checked as for the last edition of ANSI N 14-1 1990 (American National Standard Institute Inc : Packaging of Uranium Hexafluoride for Transport).

The experimental container consists of a cylindrical sleeve and of pressed ends (large radius cross section), both made of steel A 516 grade 70. The thickness is equal to 16 mm. Its minimal capacity is 1400 litres. Its external walls undergo the same surface treatment (sand blasting and painting) as for 48Y containers. Its dimensions are :

- inside diameter : 1218 mm,
- length : 1.560 mm (excluding flanges and curved faces jackets).

The container (see Figure 1) is equipped with :

- bottom jackets, in which holes are provided for handling,
- two protection hoods for instrumentation devices and valves during handling and transport,
- a flange on one of the two curved faces, for thermocouple crossing,
- two flanges for pressure measurements,
- one valve for filling and one plug for emptying and cleaning.

The maximal relative pressure is 14 bars and the calculated temperatures are + 120°C and - 40°C. The proof pressure is 28 bars.

III.3 Conditionning operation

Each flange are closed, brazed or soldered before the UF_6 filling, but special procedures are necessary for the following points. The gas over the UF_6 must be only the UF_6 gas, but on an other hand we need to remove the "superior" valve because tightness system based on a low temperature alloy.

From the maker (see Figure 2 Stage 1) we inspect the internal instrumentation (temperature sensors), and external instrumentation (strain gauges and thermocouples). Then UF_6 is filled in conventional and reproductible conditions for all containers (weight check, calculated proportionally to the measured internal volume and indicated on the container) using a classical system (Stage 2). After an usual cooling (as one of a 48Y type container), several operations will be performed (Stage 3 to 7) : inspection of pressure sensors, visualisation of solid UF_6 with a endoscope, setting of a special plug in place of the valve.

III.4 Furnace

The furnace is able to produce flows characteristic of a fuel fire at 800°C (around 60 kW/m²) on the external walls of the container (shell and heads). It works under vacuum atmosphere, its thermal inertia produces a rapid temperature transient (increase to 800°C in around 4 min).

The total electrical power requirements is 660 kW which will be independently regulated for each of the four zones by means of one or more sensitive probes for each zone.

Following the supposed UF_6 solid distribution, the heating cylinder is divided in four heating zones (Figure 3) :

. zone 1 or upper cylindrical part, P = 153 kW
. zone 2 or medium part, P = 76 kW
. zone 3 or lower cylindrical part of the container, P = 229 kW
. zone 4 or front face and back face, P = 203 kW.

The furnace is positioned horizontally and consists of two half-shells which are fitted together along a median horizontal plane (Figure 3). Its dimensions are : outside diameter : 1800 mm, length : 1975 mm.

The external insulation use a special multisheet bases on a stack of 30 radiative screens (Figure 4). Gas flow can be directed inside the space between container and furnace by mean of the cooling system, at the end of the test.

A calibration test will be performed to know the most precisely as possible the external heat flow coming from the furnace. For this, a special container will be constructed. Similar to the UF_6 container, externally painted, but empty, it will be simply rigged with about twenty thermocouples in the thickness of the wall. After that, it will be putted through different thermal conditions in the furnace.

From each thermocouple, the temperature increasing measurements will give the heat flow with following method :

- T_e is the regulation temperature of the furnace, F_p the local heat flow at the point p depends on T_e and T_p the steel temperature at p

$F_p = r * Cp * e * dT_p/dt$ with e : steel thickness
r,Cp : density and thermal capacity.

- the transient measurements of T_p and dT_p/dt will permit to obtain the external heat flow, which we will write eventually as :

$$F_p = E_{eq} * \sigma * ((T_e+273)^4 - (T_p+273)^4)$$

where E_{eq} (equivalent emissivity) is adjusted in order to reproduce the measured heat flow (if we establish that E_{eq} stays constant, or may be a function of T_p).

For inner emissivity, it seems necessary that the wall has been in contact with UF_6 in order to create the normal fluorure coating. We propose to cut a steel piece after a test with UF_6 and perform a classical emissivity measurement on the sample at different temperatures.

III.5 Instrumentation

Experimental measurements include those which are performed on the container to control the strain level and to measure temperature inside UF_6 mass.

The number and position of the different measuring devices are as follows :

- 10 strain gauges and 10 thermocouples placed at locations on the external surface of the container (strain gauges in quarter of a bridge) according to the results of a structural analysis,
- 2 pressure gauges connected to the flanges in the upper part of the container by mean of heated tubes in order to avoid solidification of UF_6 inside (measuring range : 0 - 100 psia to 0 - 250 psia),
- 40 thermocouples located inside the container as indicated on the figure :
  * 24 thermocouples (circles on Figure 5) positioned on the middle right section of the container to measure temperature gradients near the wall and inside UF_6,
  * 16 thermocouples (arrows on Figure 5) positioned against the wall to verify heating homogeneity.

Thermocouples will be positioned in the container before welding of the last bottom. In order to avoid any deformation during melting of UF_6 they will be held vertically by mean of combs and grooved tubes, where two systems are studied (Figure 6).

Inside thermocouples come out of the container through a small diameter tube where they are brazed. There are connected, with the outside thermocouples, stain gauges and pressure gauges, on a connecting cabinet.

Additional measurement devices are needed for plant thermodynamic state monitoring and for running the tests. These will include :

- thermocouples to control furnace operation,
- thermocouples dispershed in the free atmosphere inside the vessel,
- pressure gauges connected to the internal vessel volume.

During the UF_6 filling of each container the previous thermocouples will be used, on an other hand the internal UF_6 aspect and the level will be vilualized with a fiberscope after the cooling and also after every test in the furnace.

III.6 Experimental vessel

Its function is to maintain UF_6 confined in the case of a container leak. It is a plain steel vessel, 3.85 m long and 3.00 m in diameter, consisting of a horizontal cylindrical sleeve and two curved ends ; its internal volume is about 21 m^3 (figure 7).

The cover, consisting of one of the curved ends, can be dismantled and is movable. Moving the cover involves completely opening the vessel to insert the experimental container and upper half-shell of furnace, and extracting them out between tests.

The vessel is designed to withstand an absolute pressure of 7 bars, reached in case of container rupture, and a primary vacuum of between 5.10^{-2} and 5.10^{-3} torrs, required during thermal tests, and to support wall temperatures up to 200°C.

Measurements devices for plant thermodynamic state monitoring and running the tests, include thermocouples located in the free atmosphere inside the vessel, wall probes on the outside wall of the vessel, pressure gauges connected to the internal volume and a α detector connected with the vessel volume.

III.7 Caisson J

This experimental room, reinforced concrete made, can withstand wall temperature equal to 130°C and an overpressure equal to 1 bar. Its walls are 1 meter thick and the dimensions are : 20 m x 15 m x 12 m = 3600 m^3.

For thermal tests planned, ventilation circuits which include very high efficiency filter boxes, are used to maintain an under-pressure of a few millibars inside the room. Gas temperature, pressure are measured inside the caisson ; α detection devices are located inside the room and on the outlet circuit.

III.8 UF_6 recovery

Container burst with dispersion of all the UF_6 quantity inside the experimental vessel or UF_6 smaller leak are detected by pressure increase or by means of an α detector. For the recovery of UF_6, two principles are applied :

- UF_6 gaseous transfer by hot point cold point method, from the vessel to the 48Y container which is kept at about 15°C ;
- residual UF_6 hydrolysis with a large quantity of water ; after which, gas and liquid effluents are neutralized with a potassium carbonate solution.

It is constituted of two parts (figure 8) :

- a 48Y container, connected to the vessel by means of a heating pipe with adjustment or shut off valves,
- an hydrolysis circuit with, above the vessel, wet air supply system, and below the vessel, released gas treatment and liquid effluents recovery.

These facilities will not be used during normal operation of the rig. However, as they are connected with the vessel, some of its components are taken into account during operation of the rig for the thermal tests.

III.9 Plant control and monitoring system

Test remote control and measurement recording are performed by means of a data recorder, which is situated in the monitor room of caisson J, and of mimic boards of the plant.

There are 192 readings including 150 temperatures, 10 strains and 5 pressures. Experimental readings are recorded at time intervals less than or equal to 1 second.

On the test mimic board , monitoring of test parameters are displayed :

- strain and associated temperature measured on the container surface, temperature in UF_6 mass, the pressure inside the container,
- furnace temperature of each zone with the characteristics of the electrical power supply,
- temperature and pressure inside the experimental vessel,
- the signal from UF_6 detection system inside the vessel.

III.10 test matrix

Test matrix (table 1) includes six tests :

- the first test is a calibration one with an empty cylinder which aims to determine the heat flux received by the experimental cylinder,
- the second test aims to investigate the general behavior of the experimental container fed with liquid UF_6 with total surface heating at 800°C, with special attention paid to "overshoot" effect at the end of heating time ; it consists of several separate heating phases with increasing duration ;
- two tests are performed with a container fed with liquid UF_6, with total surface heating at 800°C ; heating durations are determined from second test results analysis ;
- one test aims to analyse the "end" effect and is performed with a container fed with liquid UF_6, with cylindric surface heating at 800°C and with insulated curved ends ;
- one test is carried out with a container equipped with japanese protective cover.

Optional tests are considered to investigate :

- behavior of the valve,
- the effect of filling with gaseous UF_6 which changes initial distribution of matter inside the container,
- the effect of the filling rate.

Tests at higher temperature (1000°C) would also be possible.

Detailed studies of the project began in 1991 ; realization of the experimental facilities will last two years and the first test will be performed at the beginning of 1994.

Table 1 Test matrix

Test number	Furnace temperature °C	Heating Duration minutes	type of filling	heated surface	remark
1			empty container		calibration test
2	800	5 10 15 X	liquid	total	
3	800	X/2	liquid	total	
4	800	X	liquid	total	
5	800	X	liquid	cylindric	
6	800	X	liquid	total	with japanese protective covers

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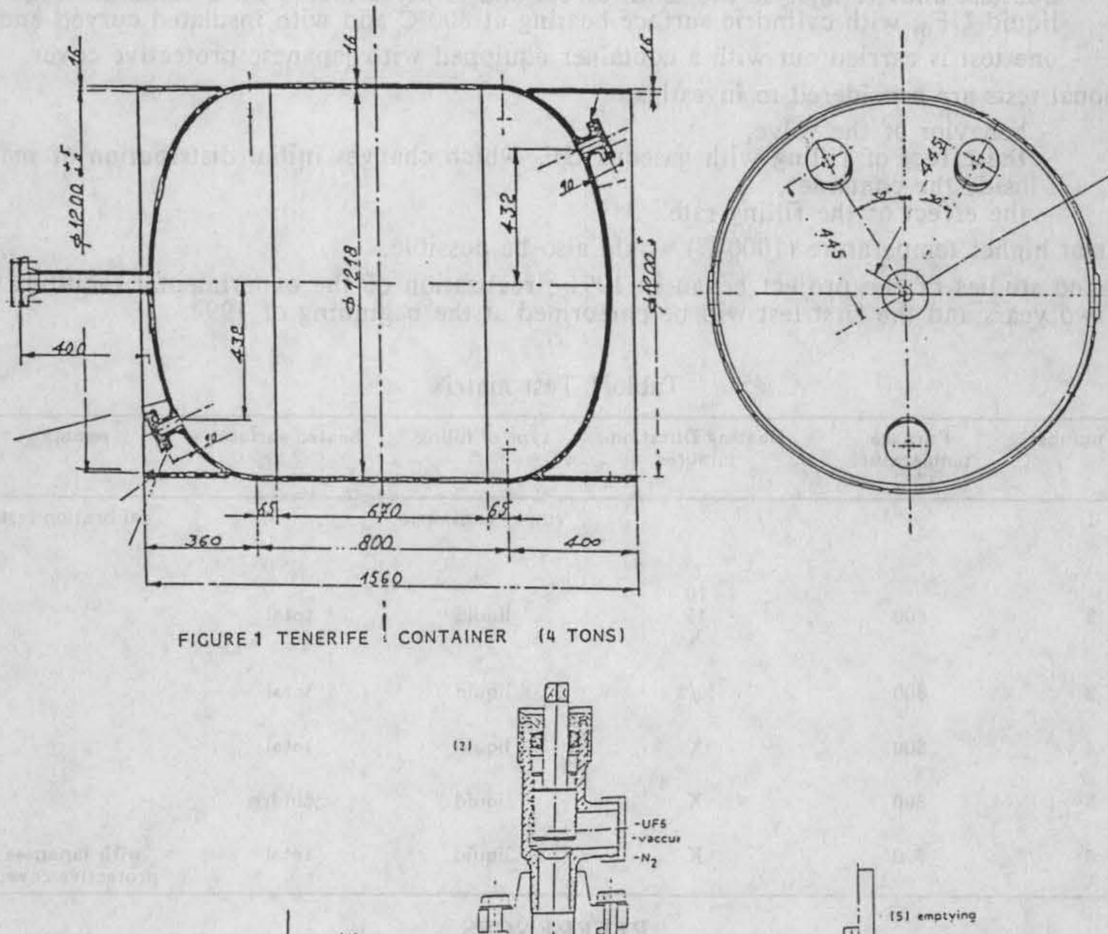


FIGURE 1 TENERIFE CONTAINER (4 TONS)

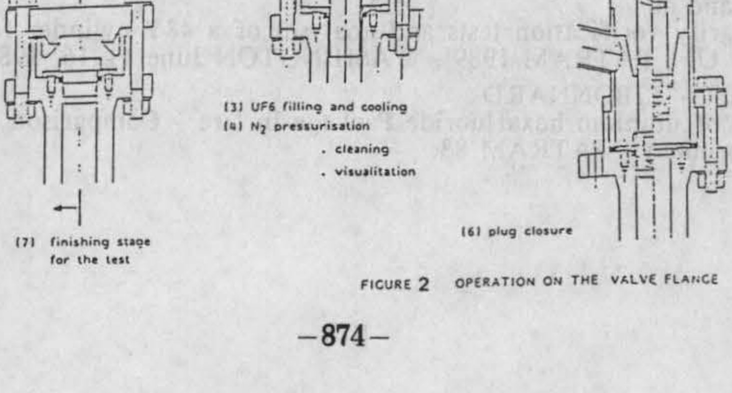


FIGURE 2 OPERATION ON THE VALVE FLANGE

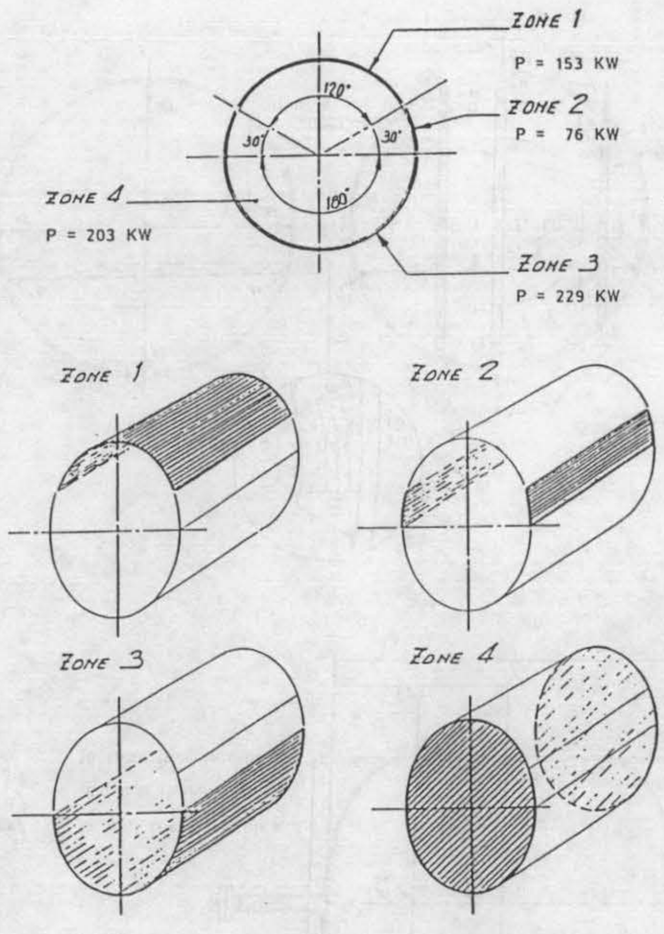


FIGURE 3 HEATING ZONES REPARTITION

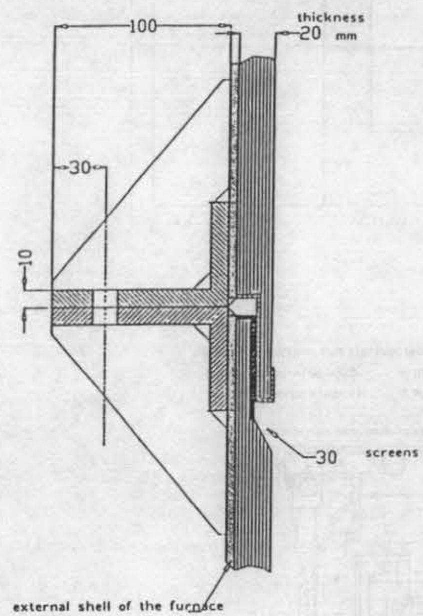


FIGURE 4 MULTISHEET INSULATION

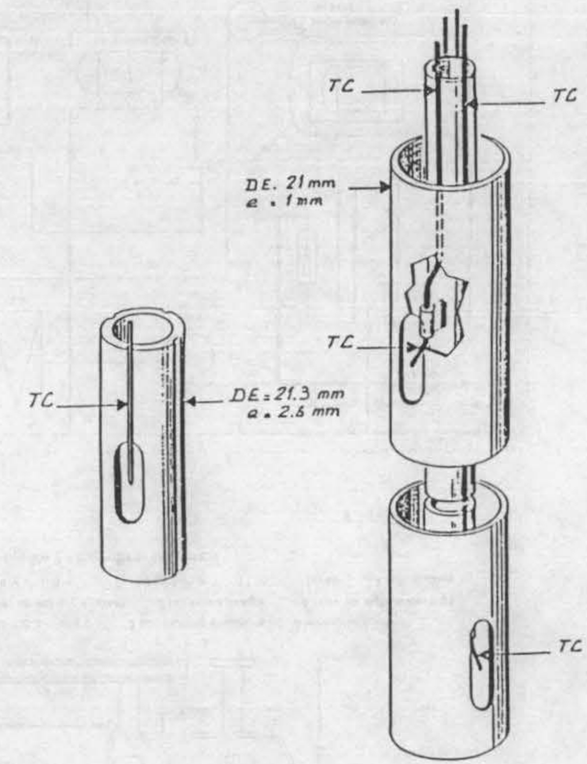


FIGURE 6 THERMOCOUPLE SUPPORT IN UF6
(THERMOCOUPLE CHROMEL ALUMEL Ø 1 mm

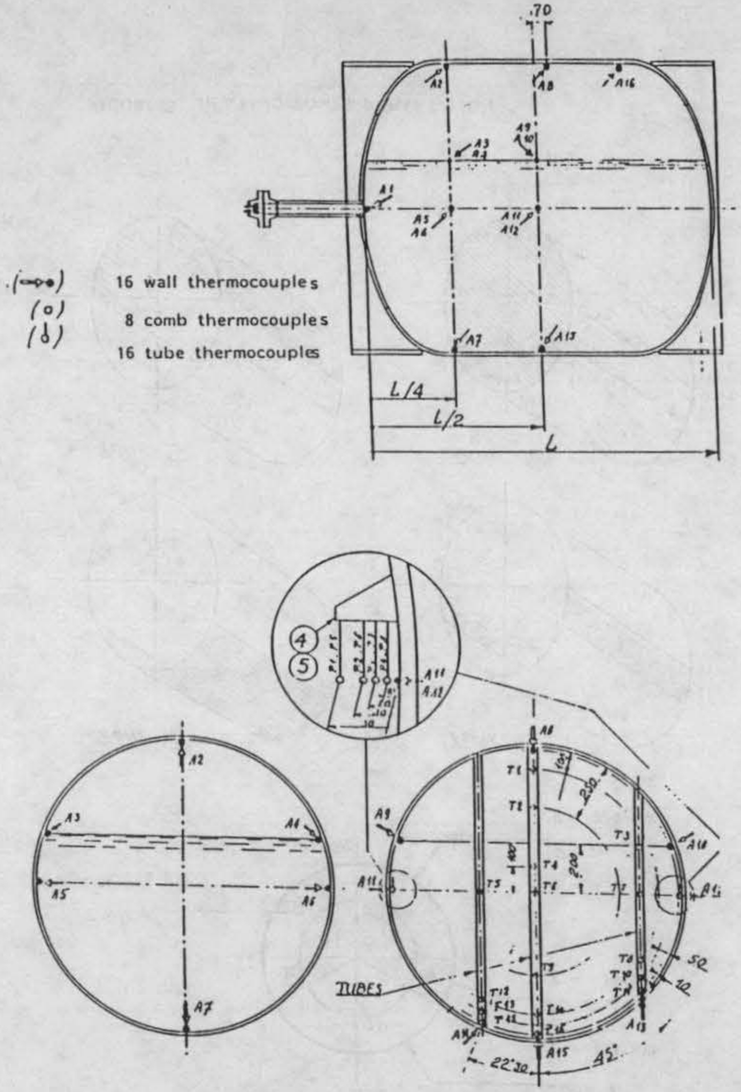
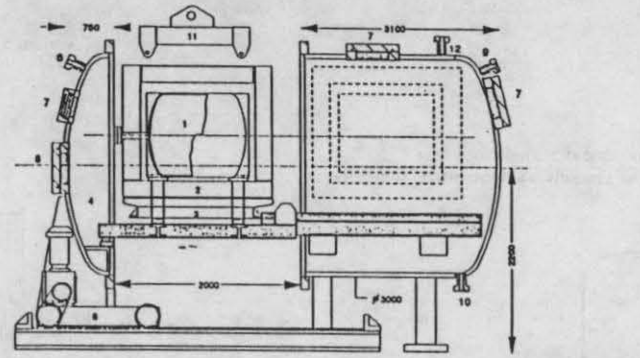


FIGURE 5 MEASUREMENT LOCATION



1 experimental container 2 electrical furnace 3 supporting structure 4 movable cover
5 truck for cover moving 6 to wet air supply system 7 reserved flange 8 tape for tight crossings
9 to 48Y container and effluents recovery circuit 10 to pump 11 rocking lever 12 safety valve

Figure 7 - Experimental vessel

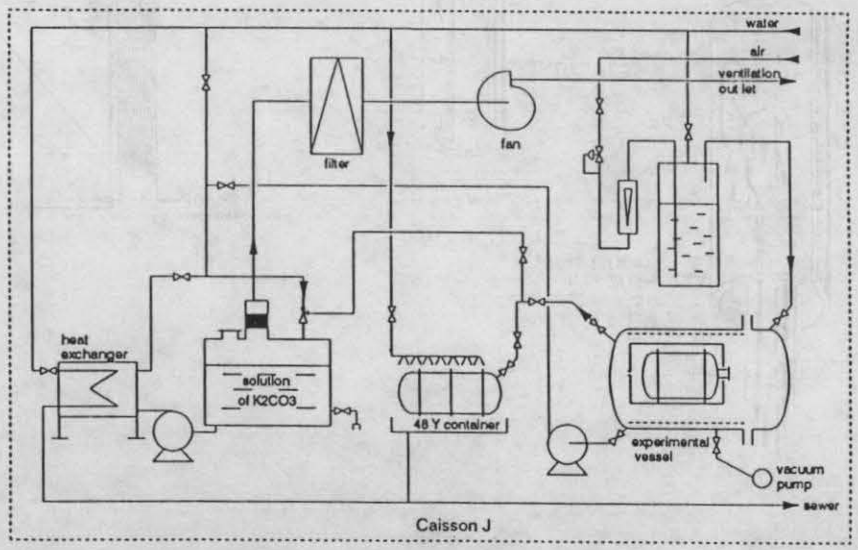


Figure 8 - Schematic of experimental facilities