BURSTING TESTS ON TYPE 48Y CONTAINERS FOR URANIUM HEXAFLUORIDE

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SUMMARY

In order to conform to the new requirements from the IAEA, it is necessary for the large-scale UF6 containers to comply with the fire resistance requirement imposed for type B packages. The thermohydraulic characteristics of UF6, which now are defined, and the calculation models, which are validated, have revealed major risks of rupture of the container. The purpose of the present programme is to define the strength limits of the materials at the moment of rupture of the wall under the conditions of the fire test.

Three industrial containers, of different grades, are heated after being previously equipped and insulated, and are pressurised by the injection of nitrogen until rupture takes place. Two of the containers are filled with dry sand. After preliminary tests performed to validate the measurement chains and the data acquisition system, the 3 tests are carried out in a large open area which affords the required safety against the effects of the bursting of the cylinder.

CONTEXT

The IAEA recommends that the fire resistance requirement already imposed on packages of fissile materials and on "type B" packages be extended to cover transportation containers of UF6. In order therefore to be approved unilaterally, these containers should be resistant to an enveloping flame of 800°C for 30 minutes, the representative conditions of a severe hydrocarbon fire. These new regulations should come into force in 2001, but in the present state of knowledge, it is not possible to guarantee the fire resistance of such packages.

As part of a previous programme (the TENERIFE programme), IPSN conducted a series of experiments to determine, with greater accuracy, the thermohydraulic behaviour of the UF6 in large-scale transportation containers when they are subjected to a fire. The tests carried out in the course of this programme faithfully simulated the conditions of an external fire and disclosed the principal phenomena which determine the heat transference in this type of container. These phenomena are associated in particular with the boiling of the UF6 in contact with an overheated steel wall, the simultaneous existence of three phases - liquid, solid and vapour - and the heat transfer through the porosity in the solid UF6. The results obtained enabled computer models to be validated, which will be used to confirm that the containers satisfy the requirements of the future regulations.

The calculations of the behaviour of the containers, using the new numerical model, revealed that there is a serious risk of rupture of the container wall, whatever grade of steel is used. This risk is even greater if other configurations exist (for example, by varying the filling rate, the orientation of the package, or the thickness of the steel to take into account defects or corrosion effects), which would result in an increase in the risk of rupture. The TENERIFE programme also makes it possible to state that the conformance of the 48Y containers to the new IAEA requirements can be guaranteed if such containers are provided with thermal insulation at the ends.

It thus appeared to be necessary to define the strength limits of the materials at the moment of rupture of the container wall under the conditions of the fire test prescribed by the IAEA.

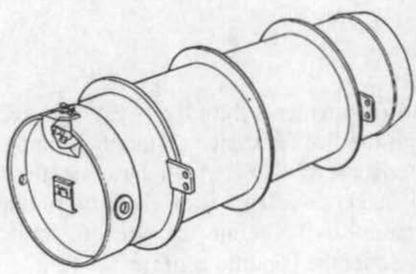

Figure 1 : The 48Y container

PURPOSE OF THE TEST PROGRAMME

Calculation models for determining the instant of rupture of a 48Y container (12 tonnes of UF6) when exposed to a hydrocarbon fuel fire have been developed at the IPSN and abroad. In these models, the evaluation of the mechanical behaviour of the steel incorporates a law of elasto-plastic behaviour and a rupture criterion obtained from tests carried out on small-scale specimens, whose steel was not subjected to the same manufacturing operations and whose mechanical properties are not necessarily representative of the true behaviour of the container, notably in the region of discontinuities (welding heat-affected zones, stress concentrations due to geometrical discontinuities, etc). This new programme should confirm or refine the law for the mechanical behaviour at temperature on actual 48Y containers.

The proposed tests are carried out on industrial containers strictly identical to those which normally contain uranium hexafluoride. Each test consists of heating and pressurising a 48Y container (without UF6) until rupture takes place. In addition, the containers are made from steel covering a fairly wide range of grades. To take account of their different performances, three new containers manufactured from steel of two different grades are tested.

In order to refine the law of the behaviour to rupture at temperature, the tests are carried out, simulating the temperature and pressure ranges which result from the preliminary evaluations. On the other hand, it is not thought necessary to simulate exactly all the transient thermal and mechanical effects of the reference fire conditions, firstly because they vary with the configuration of the package, secondly because the law of the mechanical behaviour is smooth and may be extrapolated to other configurations on the basis of all the experimental results available.

The test parameters are determined by preliminary thermal and electrical studies.

CONDUCT OF THE TESTS

Three tests are carried out. For each test, the aim is to achieve a temperature distribution in the steel in the same range as the calculated results obtained in the case of a fire on a full 48Y.

For tests A and B , the aim of which is to simulate the extended regulatory fire test of the IAEA, a circumferential thermal gradient is obtained which approximates to that calculated, whereupon an internal pressure change is introduced. For each of these tests, a rate of pressure rise with respect to time is simulated which is close to that calculated for a 48Y cylinder exposed to the extended regulatory fire test of the IAEA in accordance with the numerical simulation made by CEA/DTP.

In test C on a grade 70 steel, the aim of which is to confirm the failure condition, a rupture criterion is reached at a slower speed, with no thermal gradient. For this, the container is uniformly preheated, then the internal pressure is gradually increased. This test should confirm the two others , with the objective of a better control over the temperature of the failure area, by the use of temperature steps.

The steel is maintained at high temperature for a time as short as possible, to avoid its becoming annealed.

The test programme may be summarised as follows :

Test N°	Grade of steel	Temperature of the steel	Pressure
A	SA 516 Grade 60	Lower surface : ambient	Rate of increase of the pressure simulated until rupture
B	SA 516 Grade 70	Upper surface : 650°C max.	
C	SA 516 Grade 70	Constant-temperature periods at 500-600-650°C etc	Constant-pressure periods at 40-45-50 bar etc

TEST CONTAINERS

An investigation carried out on the steel materials of which the 48Y containers are made revealed that materials A516 grades 55, 60 and 70 actually exist in numerous units among the approximate 10 000 French containers. As the grade 55 steel is not available, one container in grade 60 and two containers in grade 70 are procured.

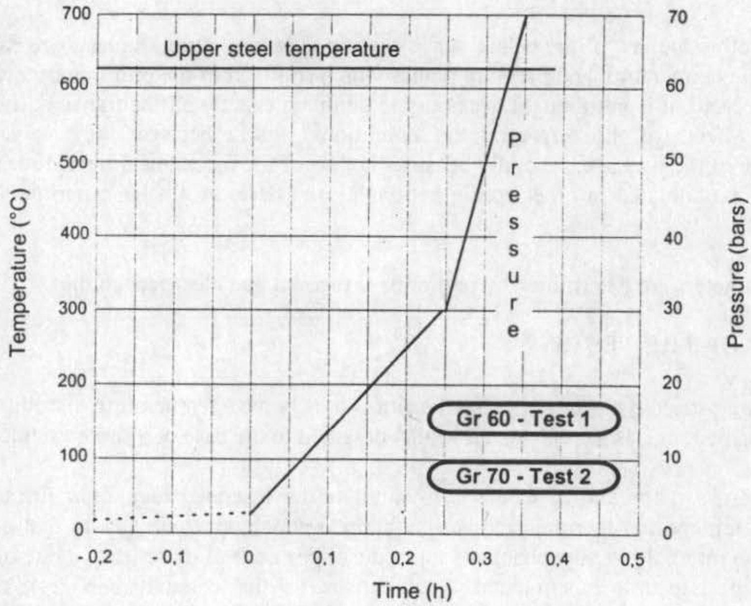

Figure 2 : Tests A and B, limiting conditions

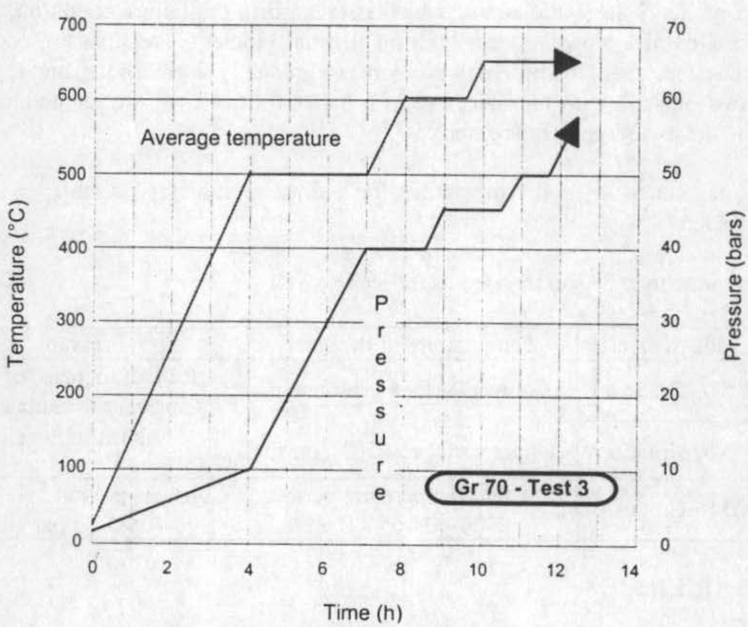

Figure 3 : Test C, limiting conditions

The containers are new to avoid any contamination of the test site. No change is made to their structural integrity (no welding, no additional tappings), but the plug is welded to its sleeve to avoid any leakage around the fusible thread protection deposit. Similarly, the pressurisation system, which takes the place of the valve, is welded to the second sleeve and then connected to the control device. In addition to the manufacturing file in accordance with the current Standard, an additional measurement check by ultrasound is carried out on each container, to confirm the absence of defects and to obtain accurate figures for the thickness of the steel shell.

Each container is placed inside a chassis. For the test, it is chocked as for transport and secured only by the handling lugs.

To begin with, each container is equipped with heating elements, some forty measurement sensors (strain gauges, thermocouples, etc) and external thermal insulation. It is provided with an outlet tube for the pressurisation.

The inlet tube fitted to one of the two ports and the plug blanking off the other is made of steel and secured to the wall by welding compatible with the test conditions (650°C and 60 bar or 6MPa). The quality of the welding is ensured by the approval of the welding process, by the qualification of the welder and by its inspection by an approved organisation.

FILLING OF THE CONTAINERS

The two containers A and B are filled with dry sand, a solid insulant whose purpose is to reduce the internal volume and the consequences of the rupture and the resultant pressure release. The filling will take place on the test site, to a level 0,25 to 0,30 m above the centre-line of the cylinder and with a controlled horizontal distribution. The third test will be performed with an empty container C. The weight of the sand will be approximately 4,5 t and that of the container 2,6 t ; the volume of the container will be 4 m^3.

The guarantee, that the filling is to the correct level and horizontal, is ensured by conformance with three criteria determined by means of tests on a model : the quality of the sand in terms of grain size and moisture content, filling from a calibrated vessel giving the weight of sand to be introduced and following an execution procedure for levelling.

PRESSURISATION OF THE CONTAINERS

The pressurisation of the container is achieved from an array of compressed nitrogen cylinders. This gas is preferred to air in order not to engender any significant deterioration of the materials, either chemically or by structural change, by any temperature effect on the steel of the wall.

The gas is introduced without any preheating system and with a flow rate which may vary from one test to another. The dimensions of the nitrogen supply circuit is such as to provide a flow rate which can reach 200 Nm^3/hr during the pressure rise. The nitrogen is supplied from an array of cylinders inflated to 200 bar (20 MPa). The gas pressure is measured by a sensor with a signal feedback and it is controlled by a valve with a pressure setting which can be remotely controlled and can be varied with respect to time. A pressure relief circuit is installed to avoid the overpressures liable to appear during the heating (caused by the moisture in the sand, for example).

TEST EQUIPMENT

A preliminary analysis of the risks associated with these tests has revealed that the bursting of a container could generate a shock wave equivalent to that produced by 2 kg of TNT, for a container filled with sand, or 10 kg of TNT, for an empty container. A burst could thus result in fragments forming projectiles with an estimated velocity an initial calculation has put at 170 m/sec and an estimated range of 500 m. The test site has been thus chosen bearing these results in mind.

The tests are carried out on an area made available in a test centre localised in the south-west of France. The test zone allows the bursting of the 48Y containers to take place, its area ensuring, by the introduction of a safety radius of 1 km, that the effects of the bursting of the cylinder will be contained within the Centre's boundaries (both with regard to the blast effect and with regard to the projection of splinters) and the existing infrastructure possesses a capacity for resistance greater than the effects of potential intrusions.

The package is transported and placed in position by mobile equipment and a structure for protecting it against the weather is erected. The test zone is equipped with the necessary lighting and pylons for photography.

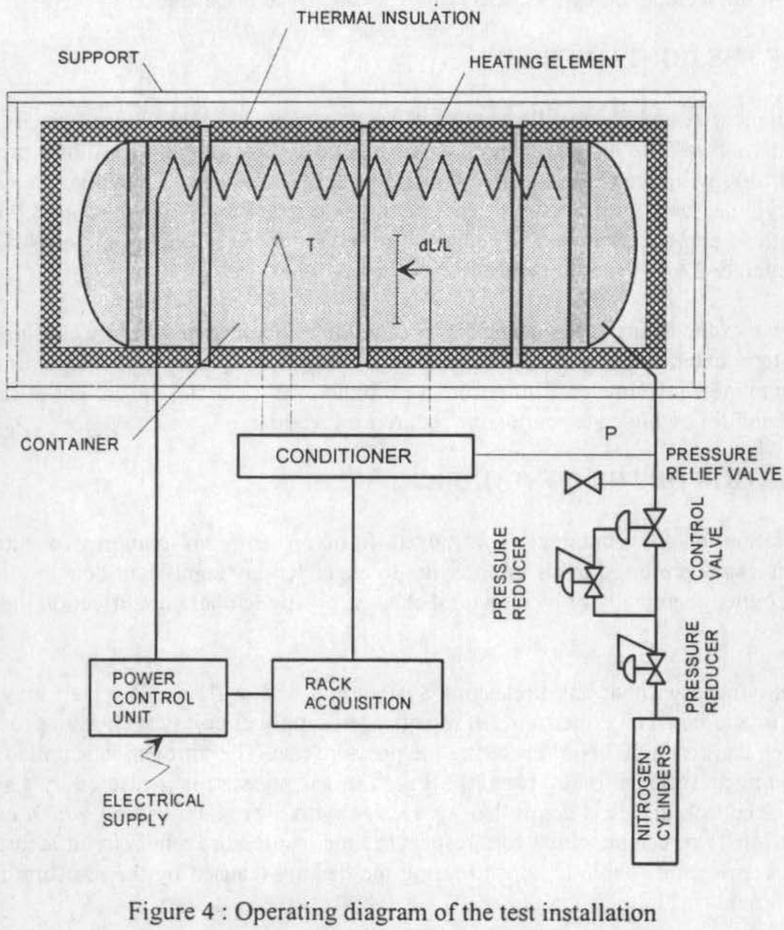

Figure 4 : Operating diagram of the test installation

A building in the immediate vicinity of the test area provides shelter for the control panel, the measurement conditioners and the nitrogen array. A few metres from that building, a reinforced measurement shelter houses the test personnel, who has a direct view of the test container. This building is equipped with electrical racks and a measurement acquisition system. The remainder of the personnel present is withdrawn to the control position situated outside the range of any projectiles.

EXECUTION OF THE TESTS

The 3 tests are carried out between the beginning of December 1997 and the end of March 1998. The period between two tests is decided by the time required for the instrumentation for the next test and the assimilation of knowledge from the preceding test.

After the preparatory work (handling, filling with sand, installation and protection of the electrical supply and the measurement circuits, installation of the pressurisation and connection circuit) and prior to each test, preliminary tests are carried out (operating check, pressurisation test, heating test) in order to validate the measurement chains and the data acquisition system.

The tests are performed in accordance with a Quality Assurance System. At the end of the tests, a test report is compiled; it includes a summary of the measurements and an analysis of the results.

The whole of the programme is covered by still photographs and the tests are filmed with a video camera.

FIRST RESULTS

The first test, test A, took place on the 9 December 1997.

On that day, heating was started at full power, with a temperature rise of 3°C per minute. 3 hr 30 min after heating was started, the temperature of all the zones had stabilised at the set value, i.e. 620°C. Once this constant temperature had been reached, pressurisation was started, firstly at a rate of 1,7 bar/min for 200 seconds and then at a rate of 3 bar/min until failure. After 20 min of pressurisation, failure occurred at a pressure of 52 bar. The pressure immediately decayed.

At the moment failure took place and for a very brief duration, a plume of gas mixed with sand was observed escaping from the upper area of the container (the zone opposite to the nitrogen injection). When the upper part of the heat insulation was removed, it could be seen that large plastic distortions had taken place on the upper shell in zone 4 (see figure 5) and that the last stiffener had fractured at the butt-weld, causing the shell to tear by a longitudinal crack. The width of the opening was 4 cm at the base of the stiffener and 7 cm at its end, the length of the tear being approximately 20 cm.

The initial findings were as follows :

- the temperature of the skirt on the nitrogen inlet side, the temperatures of the rings and even those of their bases remained below 600°C.
- as more nitrogen was injected, zone 3 experienced significant cooling.

- at the moment of failure, the distortion of the shell was such that it brought about an electrical defect of a loss of insulation of one of the heating cables for zone 4.
- the values given by the displacement sensors at the moment of failure indicate distortions of the shell of up to 13% (with the radius length as reference).

Due to programming constraints, test C had to be carried out before test B.

Test C was carried out on the 20 January 1998.

The heating and the pressurisation of the container were applied in parallel, with the rates of increase of pressure and temperature on the curve in figure 3 being strictly adhered to. Failure occurred 8 hr 30 min after the start of the test, during the second constant-temperature level of 600°C and just after the first constant-pressure level of 40 bar.

On this occasion also, major distortions of the shell were noted (from 10 to 15 cm, which resulted in the rupture of the bands holding the heat insulation), together with the failure of the central stiffener, in the same manner as for the first test container. The dimensions of the tear were however smaller : approximately 1 cm wide and 10 cm long.

From these first tests, two conclusions could be drawn for the last test :

- the temperature drop observed during the injection of nitrogen is due holding in suspension by the incoming gas jet of the hot surface layer of sand, thus exposing the cold mass. For test B, a calming device will be installed to remedy this defect.
- the stiffeners constitute areas of weakness of the 48Y containers, which are due to welding defects, observed visually on the fractured stiffeners and confirmed by X-rays carried out on the intact stiffeners of container A (after test) and container B (before test). It was decided to repair the welding of the three stiffeners of container B and to X-ray them.

The last test is scheduled for the end of March and the completion of the test interpretation phase for July 1998. It should provide comparative data concerning the behaviour of 48Y cylinders according to the quality of the stiffener butt-welds.

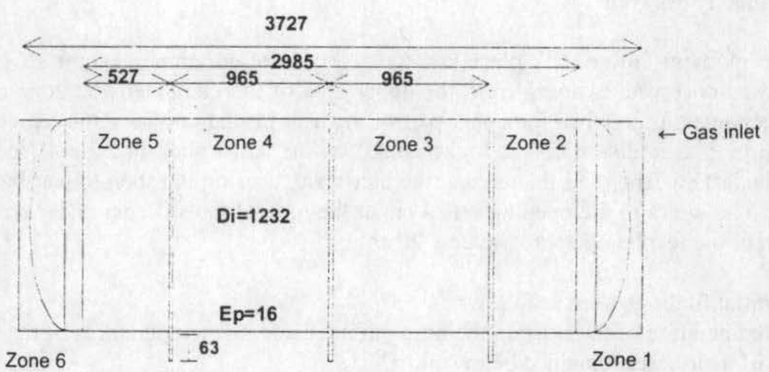

Figure 5 : Heating zones

SESSION 2.3

Back-End and Spent Fuel