TECHNICAL NOTE RELATED TO THE MARKET SURVEY OF
THE SF6 GAS HANDLING AND STORAGE PLANT

Abstract

This document is the Technical Note related to the Market Survey in preparation of the calls for tenders for the “SF6 gas handling and storage plant” (GHSP) for MITICA (Megavolt ITer Injector & Concept Advancement) and SPIDER (Source for Production of Ion of Deuterium Extracted from Radio frequency plasma) experiments that will be hosted in a facility called PRIMA (Padova Research on Injector Megavolt Accelerated).

PRIMA is a test facility located in Padova (Italy) aiming at testing and qualifying at full scale the Heating and Current Drive Neutral Beam Injector before installation in the near-term International Thermonuclear Experimental Reactor (ITER) in Cadarache (France). The PRIMA Test Facility will be conducted by CONSORZIO RFX (Padova) under Management and Funding from Fusion for Energy (F4E).

This document provides general information, as well as procurement schedule. Information is preliminary and subject to change.
1. SCOPE OF THIS DOCUMENT

This document describes SF6 Gas Handling and Storage Plant (GHSP) of the MITICA experiment, the scope of the supply, the main requirements and the approximate schedule of the project.

1.1 SCOPE OF THE SUPPLY

The Gas Handling and Storage Plant includes all the components necessary to handle and store the SF6 insulating gas of the High voltage transmission line for the MITICA experiment. The GHSP scope is composed of:

- The Gas Handling Systems (GHS) to manage the overall SF6 gas present in the MITICA plant
- The necessary Gas Storage Tanks
- Pipes and valves to connect the GHS to the MITICA plant and to the Gas Storage Tanks
- Local Control Unit of the GHS complete of HMI
- Measuring instruments to check the SF6 quality and quantity
- The SF6 gas
- Design, manufacturing, testing and installation of the plant.
- Documentation (QA activities management).

1.2 OVERVIEW OF THE PRIMA SITE AND THE MITICA EXPERIMENT

The ITER project aims to build a fusion device, twice the size of the largest current devices, with the goal of demonstrating the scientific and technical feasibility of fusion power. It is a joint project among the European Union, China, India, Japan, South Korea, the Russian Federation and the USA. ITER will be constructed in Europe, at Cadarache in the south of France.

In this framework F4E, together with the Japanese and Indian Domestic Agencies and Consorzio RFX, is developing a test facility named PRIMA (Padova Research on Injector Megavolt Accelerated). It is located near the premises of Consorzio RFX, in the CNR area in Padova, Italy, and will host the prototype of the Neutral Beam Injector, called MITICA (Megavolt ITer Injector & Concept Advancement), one of the heating systems of the ITER machine. One of the major components of MITICA is the power supply system, working at 1 Megavolt.

The SF6 GHS equipment will be dedicated to this MITICA experiment, in particular to service the high voltage equipment provided by the Japanese Domestic Agency.
Figure 1.1 General overview of the CNR site in Padova

Figure 1.2 Drawing of the PRIMA site close to Consorzio RFX.
2. GHSP TECHNICAL REQUIREMENTS

2.1. MAIN SPECIFICATIONS

The main functions of the SF$_6$ GHS of MITICA are the following:

- Evacuation of air from the gas compartments;
- Filling of SF$_6$ in the gas compartments;
- Recovery of SF$_6$ from the gas compartments;
- Storage and filtering of SF$_6$;
- Flooding of the gas compartment with ambient air.

The intervention of SF$_6$ handling plant will be required:

1. For the first gas filling and during the life of the experiment.
2. In case of scheduled maintenance or extraordinary intervention (fault occurrence) during lifetime.
3. To fill the beam vessel at suitable pressure (maximum 1.4 bar at 20°C) to allow the execution of integrated tests on the NBI.
All operations shall be performed in accordance with the updated procedures for safe and environmental compatible gas handling described in the standards CIGRE 276 and IEC/TR 62271-4. SF₆ handling plant shall be provided with its own local control system.

2.2. NBI & TRANSMISSION LINE GAS COMPARTMENTS

MITICA experimental facilities include several high voltage equipment insulated in SF₆. Referring to the figure 2.1, the compartments to be filled with SF₆ can be distinguished:

1. The compartment of the -1MV Rectifier diodes tanks.
2. The compartment of the -800kV Rectifier diodes tanks.
3. The compartment of the -600kV Rectifier diodes tanks.
4. The compartment of the -400kV Rectifier diodes tanks.
5. The compartment of the -200kV Rectifier diodes tanks.
6. The compartment of the HV filter tank,
7. The compartment formed by the Transmission Line 1 (TL1), the Transmission Line 2 (TL2) and the connection to the HVD1 bushing; the SF₆ volume is confined at the two ends of the TL assembly by disk insulator. (TL1 and TL2 are partially installed under Building 8). The testing Power Supply (TPS, not represented) will be connected during the NBI power supply integrated tests.
8. The compartment formed by the Transmission Line 3 (TL3) and the HVD2 (Installed in Building 1)
9. The compartment formed by the MITICA vessel; this compartment will be filled only during the initial integrated tests (Installed in Building 1)

Figure 2.1: 3D view of the transmission line and power supplies to be filled with SF₆
Figure 2.2: Plant view of the transmission line scheme with indicative overall dimension.

Figure 2.3: Detail view of the MITICA vessel
All the previously described devices will be filled with a rated SF$_6$ pressure of 6 bar absolute referred to 20°C ambient temperature (except for the MITICA vessel, which will be filled at 1.4 bar absolute). Referring to currently available project data and deriving the gas density from related vapour pressure gas curve, the quantitative of SF$_6$ required to fill the overall plant can be estimated as reported in Table 2.1.

### Table 2.1: Compartments volume and SF$_6$ quantity estimation

<table>
<thead>
<tr>
<th>Figure</th>
<th>Compartment</th>
<th>Component</th>
<th>Volume [m$^3$]</th>
<th>SF6 weight [t]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-1MV Rectifier diode tank</td>
<td>85.3</td>
<td>3.3</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>-800kV Rectifier diode tank</td>
<td>85.4</td>
<td>3.3</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>-600kV Rectifier diode tank</td>
<td>41.2</td>
<td>1.6</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>-400kV Rectifier diode tank</td>
<td>41.4</td>
<td>1.6</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>-200kV Rectifier diode tank</td>
<td>39.3</td>
<td>1.5</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>HV Filter tank</td>
<td>112.2</td>
<td>4.4</td>
<td></td>
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<table>
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<tr>
<td>7</td>
<td>TL1</td>
<td>71.4</td>
<td>2.8</td>
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<tr>
<td></td>
<td>TL2</td>
<td>150.2</td>
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<td></td>
<td>HVD1-TL bushing</td>
<td>8</td>
<td>0.3</td>
</tr>
<tr>
<td></td>
<td>TPS (including connection pipe)</td>
<td>29.8</td>
<td>1.2</td>
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<tr>
<th></th>
<th>Sub Total</th>
<th>229.6</th>
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<tbody>
<tr>
<td>8</td>
<td>TL3</td>
<td>61</td>
</tr>
<tr>
<td></td>
<td>HVD2</td>
<td>39</td>
</tr>
<tr>
<td></td>
<td>HV bushing</td>
<td>21.5</td>
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<table>
<thead>
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<th>121.5</th>
<th>4.7</th>
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<tr>
<td>9</td>
<td>Beam Source vessel</td>
<td>80</td>
<td>0.7</td>
</tr>
<tr>
<td></td>
<td>Beam Line vessel</td>
<td>113.5</td>
<td>1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Sub Total</th>
<th>193.5</th>
<th>1.7</th>
</tr>
</thead>
</table>

|   | Grand Total | 979.2 | 32.2 |

(mod. QA-236 F4E_D_22GTTD)
2.3. OPERATING REQUIREMENTS

The procedure to access inside the gas compartments in a safe condition, and to avoid mechanical loads on the internal membranes (e.g. disk bushing) foresees the following phases:

1. Evacuate the SF6 gas from all the compartments from 6 to 1 bar.
2. In the compartment which needs access, the SF6 pressure will be reduced down to 1 mbar
3. The compartment will be then flood with fresh air
4. After the intervention in the compartment, it will be closed and the air will be evacuated. The remaining air pressure to be a maximum of 1 mbar.
5. SF6 is backfilled initially by natural flow from the storage vessels in all compartments using the pressure difference whenever possible (avoids the usage of compressors), the GHS should be provided with appropriated heating elements to heat the expanding gas,
6. Use compressors to increase the pressure to 6 bar of all compartments.

The performance required is being assessed, as an indication the complete handling operation (phases 1 to 6) shall not take longer than **6.5 days** in the worst case, to access any of the compartments.

By-passes will be provided to avoid differential pressure between compartments 6/7 and 7/8, because of the presence of brittle elements in the disk bushings.

The most frequent operation scenario is that to access is only required to the MITICA Beam Vessel (Access inside compartment 9). To access the MITICA vessel it is foreseen to only perform phases 1, 5 and 6.

The evacuation of the compartment 8 to a pressure lower than atmospheric one shall be allowed only if the Beam vessel is in vacuum condition, to avoid applying a pressure in the wrong direction. An operating procedure need to assure the correct operating sequence (i.e. possibility to apply interlock that automatic stops GHS operation).

The number and size of Gas Handling Systems will be chosen on the basis of the number of compartments, of the maximum volume of the compartments and of the other requirements.

The required volume of the SF6 storage tanks shall be chosen based on the total quantity reported in the table 2.1 considering storing the SF6 at the liquid state. The optimal pressure (residual pressure) on the storage tanks when the compartments are full of gas, has to be defined.
2.4. SF₆ CHARACTERISTICS

The NBI plant must be filled for the first time with new SF₆ gas which meets prescription given in related standard IEC 60376 [1] for technical grade SF₆. Due to the maximum impurity levels that can be present in SF₆ (see Table 2.2), the SF₆ amount in a container (measured in the liquid phase), shall be higher than 99.7 % in weight.

SF₆ persists in the atmosphere for a long time and has a high Global Warming Potential (22,200 times higher than carbon dioxide global warming potential). Therefore gas recovering, reclaiming and recycling have fundamental importance in order to keep the gas permanently in a closed cycle, avoiding any deliberate release and preserving the environment. The GHSP shall comply with limits given in relevant regulations and standards (e.g. Regulation No 517/2014 of 16 April 2014 of the European Parliament and of the council on fluorinated greenhouse gases).

<table>
<thead>
<tr>
<th>Content</th>
<th>Specification</th>
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<tbody>
<tr>
<td>Air</td>
<td>2 g/kg</td>
</tr>
<tr>
<td>CF₄</td>
<td>2400 mg/kg</td>
</tr>
<tr>
<td>H₂O</td>
<td>25 mg/kg</td>
</tr>
<tr>
<td>Mineral Oil</td>
<td>10 mg/kg</td>
</tr>
<tr>
<td>Total acidity expressed in HF</td>
<td>1 mg/kg</td>
</tr>
</tbody>
</table>

3. CONCEPTUAL DESIGN

The following is a description of a typical system that could be used for the GHSP, with the characteristics of the main component. The supplier shall develop a detailed design taking into account the specific requirement of the application.

The MITICA SF6 GHS, pipe lines and recipients to recover the gas shall be designed to fit within the space constrains as proposed in figure 3.1.
3.1. INTERCONNECTION PIPE

This pipe runs along the transmission lines as schematically represented in the figure 3.1. It will be connected at one side to the gas storage tanks. Intermediately it will be connected with the GHS. The SF6 gas will be transferred as a liquid inside the pipe at most of the time. The pressure can be up to 50 bar. The inner diameter of the pipe will be at least 40 mm and will be made from stainless steel.

3.2. STORAGE TANKS

To store the recovered gas, a number of storage tanks will be installed in the area indicated in fig. 3.1. A space of 12 m x 6 m is allocated for this purpose. This area is outdoors and un-covered.

The tanks shall be equipped:

- isolation valve, in order to be selectively accessible for example in case of maintenance
- pressure relief valves and necessary certification.
- manometers / pressure sensors routed to the central control system of MITICA for monitoring in the control room.
- Protective painting, if necessary, should be applied to the tanks.
- Weight measurement equipment.
3.3. GAS HANDLING SYSTEM

The conceptual design proposal estimates that a configuration consisting of 3 GHS units, each one installed on a chassis that is easily movable on wheels or can be handled by a forklift truck. Each GHS unit can have the following characteristics:

- Compressor ≥ 50 m³/h, 50 bar.
- Oil free vacuum pump for SF6 evacuation ≥100 m³/h, capable of evacuate to a final pressure < 1 mbar
- Vacuum pump for air evacuation ≥100 m³/h, capable of evacuate to a final pressure <1 mbar

The approximated overall dimensions of each unit shall be L= 3m, W=1,5m, H=1,5m. The connections will be done by means of flexible pipes with a dimension of at least DN40. For a proper functionality, the length of the pipe that will connect the GHS with the compartments should be contained in 15m.

To access the compartment 8 it might be necessary to include an additional pipe from the compartment to the ground level, as this compartment is in a higher level and inside the MITICA neutron shield and therefore difficult to reach with a hose from the GHS.

Other solutions with different configuration or customized proposal (i.e. different number of units, different pump characteristics, fixed position units) could be considered given the case of a more convenient cost / performance relation.

Small mobile units will have the advantage of convenient storage indoor when not used, and the possibility to be used in different configurations (e.g. 2 units connected to one single compartment) when needed.

![Figure 3.3: Basic functional scheme of the SF₆ GHS](mod. QA-236 F4E_D_22GT TD)
3.3.1 GHS Component description

It can be framed in CIGRE 276, the main characteristics are reported here:

- **Pre-filtering unit**
  A pre-filtering unit, either stand-alone or internal, is required to recover both normally and arced SF₆. The reactive gaseous decomposition products are acid compounds and could damage the gas reclaimer or the gas storage container. The requirements of the pre-filtering unit are basically the same as those of the filtering units installed in the gas handling device, but the pre-filtering capacity could be considerably higher.

- **Filtering unit**
  Filtering units are required to remove the reactive gaseous decomposition products before they are stored—hence allowing for the re-use of SF₆. These filtering units are installed in the SF₆ reclaimer. Typical filter types used during SF₆ reclaiming are particle filter, and gas/moisture filter (to adsorb moisture and reactive gaseous decomposition products)
  In consideration of intentional absence of electric arcs inside MITICA plant, some of pre-mentioned filters can be omitted or performance requirements relaxed with respect to a gas reclaimer system which typically operates close to a switching device.

- **Vacuum pump**
  The vacuum pump is used to evacuate the gas compartment from air. The residual pressure at the inlet of the vacuum pump should be typically lower than 100 Pa.
  The capacity of the vacuum pump should be suitable for the volume of the gas compartment and the evacuation time. The connecting diameter should be appropriate in order to avoid extend the evacuation process.

- **Compressor**
  When the SF₆ pressure in the gas compartment is higher than the pressure in the storage container, it is quicker to allow direct gas expansion. In all other cases, a compressor is required to recover the gas.

- **Storage containers**
  Commercial pressure vessels or special storage containers for used SF₆ are available as storage containers.
  The local regulations for the operation of pressure vessels shall be observed. In order to reduce the required volume, the gas should be stored in liquid phase at max. 50 bar.
• Evaporator/heater
If SF6 is stored in liquid form and used as a gas, icing/frosting of the storage container takes place when large gas quantities are handled in a short time. It will be evaluated whether the use of heaters or evaporators is necessary.

• Gas and hose connections
The reclaimer, the gas storage container and the electric power equipment are connected via flexible hose connections. Care should be exercised to avoid the presence of air or other compounds inside the hoses in order to reduce the possibility of contaminating the gas. For this reason, hose connections with both self-closing and vacuum tight couplings are required.

• Gas piping and pipe junctions
Gas piping and pipe junctions shall be designed to avoid leaks and corrosion. For that purpose, stainless steel, copper and brass are typically used. The design of both piping and connections shall take into account vibration so that periodical operations such as re-tightening of fittings are not required.

• Safety valves
Safety valves shall be used in the SF6 cycle for pressure relief. Local safety regulations shall be followed. Safety valves which do not directly release SF6 to the atmosphere are recommended.

• Control and monitoring system system ( see also point 3.5 )

3.4. INTERFACE REQUIREMENTS

The MITICA SF6 GHSP is interfaced with the following systems:
- The PRIMA buildings as in fig 1.3
- The compartments of the HV equipment insulated by SF6 gas
- 400 Vac auxiliary power supply
- The MITICA Vessel ( only for on-site integrated tests of the NBI )

3.4.1 Compartments

Each compartment shall be connected with its GHS by means of one pipe with nominal diameter 40 mm or higher (DN80 flange will be provided). The type of coupling shall be agreed. All removable stretches of pipes shall be provided with tight valve at both ends to avoid SF6 release in atmosphere when disconnected. It shall be remarked that the compartments will be electrically insulated from the ground. Therefore, if permanently connected to the compartment, the insulation of the related pipe shall be coordinated.
3.4.1 400 V Power Supply

In the PRIMA Site the following auxiliary power supplies will be available to feed the GHSP:

- 400 V AC, three phase plus neutral, interruptible
- 400 V AC, three phase plus neutral, uninterruptible

In Table 3.4 are reported the main characteristics of the 400 V Auxiliary power supply.

<table>
<thead>
<tr>
<th>Table 3.4 – 400 V Auxiliary power supply characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal Voltage</td>
</tr>
<tr>
<td>230/400 V 3-ph, 4-w</td>
</tr>
<tr>
<td>Limits of the voltage variations</td>
</tr>
<tr>
<td>± 10%</td>
</tr>
<tr>
<td>Nominal ac voltage frequency</td>
</tr>
<tr>
<td>50 Hz</td>
</tr>
</tbody>
</table>

The PRIMA Organisation will arrange a 400 V distribution board close to the GHSP areas, equipped with protection breakers. The connection will be done by removable connector.

3.4.2 MITICA Vessel

The MITICA vessel is provided with a flange for the handling of the SF6. The procurement must also consider the possibility to include a safety release valve to be attached on the rupture disc on the vessel.

3.5. INSTRUMENTATION AND CONTROL

3.4.3 Local Control Specification

A dedicated local control unit complete with human machine interface must be used for all operating conditions of the gas handling equipment. No remote operation or integration with the experiment control system is foreseen.

3.4.4 Control instruments

The SF6 quality and quantity in the compartments (purity level, water vapour content and density) shall be periodically checked by means of specific instruments to be used for monitoring from MITICA central control system. The measurement instruments shall be part of this procurement, and allocated in different points along the HV transmission line. There will be provided a number of ports on the HVTL to install the measurement instrumentation.

3.5. SITE CONDITION

The installation activities on site will be managed according to the safety regulation for temporary working site (construction yard) (Italian Law decree 81/2008). Special provision will be indicated to coordinate the work with other supplier performing the installation of the electrical components.
4. TESTING

The SF₆ system is basically assembled by off the shelf components. For all the components belonging to the SF₆ system i.e. the Gas Handling System (GHS), the storage tanks, the pipes and the valves to connect the GHS to the MITICA plant – the Supplying Company shall provide the conformity certificates. The correspondence between the delivered components to the required ones has to be checked and demonstrated before delivery to site.

Furthermore, for gas storage tanks the visual inspection, dimensional (volume) verifications, material and conformity certificates, welding certificates and procedures have to be verified at the Supplier site. Pressure tests, where required, have to be carried out in order to satisfy the conformity to Standard and PED requirements as well as Italian regulation for pressure vessels as applicable. In particular for the GHS, the overall functionality of the complete system, operated directly by its control system, will be performed at the Supplying Firm premises.

After the complete installation of the SF₆ Gas Handling and Storage System, the following acceptance tests shall be performed:

- Pressure tests
- Leak detection tests of the overall system
- Performance tests
- Non-destructive controls of the welded junctions performed on the Site

5. SCHEDULE

Tentative schedule for the procurement of the SF₆ gas handling plant in the following table:

<table>
<thead>
<tr>
<th>MILESTONE</th>
<th>DATE</th>
</tr>
</thead>
<tbody>
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<td>CALL FOR TENDER PUBLISHED</td>
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<td>Oct-15</td>
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<td>DESIGN COMPLETED</td>
<td>Apr-16</td>
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<td>MANUFACTURING AND FACTORY TEST COMPLETE D</td>
<td>Oct-16</td>
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<tr>
<td>DELIVERY TO PADOVA SITE</td>
<td>Nov-16</td>
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<tr>
<td>ON SITE INSTALLATION AND TESTING COMPLETED AND ACCEPTED</td>
<td>Feb-17</td>
</tr>
<tr>
<td>SF6 HANDLING PLANT ACCEPTED</td>
<td>Mar-17</td>
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</table>
6. APPLICABLE STANDARDS AND LEGISLATION

All components used for this system shall be designed, manufactured and tested in conformity with:

- CE directives
- Applicable legislation at the place of execution of the works
- the latest issues of the Standards and Recommendations published by IEC and CIGRE.

An indicative list is reported below.

<table>
<thead>
<tr>
<th>Document tag</th>
<th>Title</th>
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<tr>
<td>[10] IEC 60331-21 (1999-04)</td>
<td>Tests for electric cables under fire conditions - Circuit integrity - Part 21: Procedures and requirements - Cables of rated voltage up to and including 0,6/1,0 kV</td>
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<tr>
<td>[17] Law decree 22/01/2008, n. 37</td>
<td>Law decree concerning plant installation</td>
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7. QA

As a part of the F4E QA activities, this procurement will be managed within a quality plan prepared by the supplying company in accordance with the provisions of Supplier Quality Requirements (F4E-QA-115, F4E_D_22F8BJ v3.2), graded according to the quality class indicated by F4E.

Conclusion and Market Survey

You have now the possibility to answer to the F4E Market Survey. You can access the survey by clicking on this link:

F4E Market Survey on SF6 GAS HANDLING AND STORAGE PLANT

You can also access the F4E Model Contract by clicking this link:

F4E Model Contracts

(please note that there is one optional question of the survey that is related to the model contract).