Technical Specification

of One (1) Set

# of 500-MHz Superconducting RF Modules

for the Taiwan Photon Source, TPS, at NSRRC

1. General

1.1 Background (Information Only)

The Taiwan Photon Source (TPS) at National Synchrotron Radiation Research Center (NSRRC) requires **three (3)** sets of 500-MHz superconducting RF accelerating modules (cavities) for the TPS storage ring. The TPS is designed to be operated at maximum beam current 400 mA (eventually being upgraded to a maximum beam current 500 mA) and machine energy 3 GeV. Routine operation of TPS requires compensation for the loss of beam energy to synchrotron light in the dipoles and insertion devices, as well as parasitic energy loss that is coupled through the storage-ring impedances and dissipated in the walls of the vacuum chambers. A constant transfer of RF power to the electron beam is thus required for routine operation. The maximum beam power required for TPS will eventually be 720 kW at a maximum beam current 400 mA, strongly dependent on the number of high-field superconducting insertion devices to be installed. The 500-MHz superconducting RF accelerating modules are therefore selected both to compensate losses of beam energy and to ensure beam stability and adequate beam lifetime at an operating beam current 400 mA. Two (2) sets of RF transmitters, each with maximum RF output power 300 kW, CW, at RF frequency 500 MHz are under construction at present. One (1) set of 500-MHz superconducting RF accelerating modules shall thus be required to be capable of delivering the radiation beam power up to at least 250 kW. Three (3) sets of 500-MHz superconducting RF accelerating modules will be ordered by NSRRC. Among them, two (2) modules will be routinely operated after the TPS is commissioned in 2013, and one (1) module will serve as a spare accelerating module at the beginning of the machine operation.

Advanced synchrotron light sources pursue a great machine reliability to fulfill the experimental requirements of its users of a storage ring as a light source. An RF system with an ultra-small trip rate is essential for successful operation of a modern light source. The operating machine, Taiwan Light Source (TLS) at NSRRC, is routinely operated with a mean time between failures (MTBF) greater than 100 h and with a MTBF of the RF system greater than 200 h. The individual 500-MHz superconducting RF accelerating modules operated at TPS are expected also to have a MTBF greater than 200 h considering the need of TPS for at least two storage-ring RF plants for accelerator operation in its initial operational phase. To fulfill this operational requirement, our major concerns are the following.

First, the capability of maximum handling of RF power of the individual 500-MHz superconducting RF accelerating module is a critical consideration to achieve system reliability. The 500-MHz superconducting RF accelerating module used for TLS is currently operated with a maximum RF power smaller than 70 kW, but the required maximum RF power of the individual 500-MHz superconducting RF accelerating modules for the TPS shall be 300 kW, CW, in its final operational phase – the RF transmitter has a maximum RF output power 300 kW.

Second, the radiation beam power required to operate the TPS at its commissioning and in the initial operational phase is expected to be much less than 300 kW for individual 500-MHz superconducting RF accelerating modules, because the operational beam current might not be increased to its design value 400 mA in the first operational years and the RF-power-consuming insertion devices will be installed year by year according to budget constraints. This condition requires the coupling coefficients or external quality factors Q_{ext} of the 500-MHz superconducting RF accelerating modules to be <u>readily adjustable</u> so as to optimize the Touschek beam lifetime (total voltage between 2.8-3.5 MV for TPS) under varied operational requirements at various operational stages, but to minimize the standing-wave maximum voltage and to avoid an enhancement of the multipacting strength inside the high-power input coupler. More specifically, the adjustment of the coupling coefficients or external quality factors Q_{ext} of the individual 500-MHz superconducting RF accelerating modules to optimize the machine operational parameters shall be free of risk of coupler arcing or overloading on the ceramic RF windows.

Third, high-power multipacting or discharging inside the high-power input coupler of the 500-MHz superconducting RF accelerating module is a major cause of RF trips for the SRF module operated at high RF power. The design of the high-power input coupler for the 500-MHz superconducting RF accelerating module shall be equipped with an effective weapon against multipacting whenever it is coincident with the operational conditions of the machine, and a discharge at the high-power input coupler shall be avoided within any operational range of the external quality factor Q_{ext} up to a maximum RF power rating 300 kW.

Therefore, NSRRC selected the 500-MHz/*508-MHz SRF Modules of KEKB design* for the 500-MHz superconducting RF accelerating modules for TPS (hereafter named as ***500-MHz SRF Modules for TPS***) because of their highly reliable track record[1] of operation at KEKB at an RF power rating greater than 300 kW and because of the tunability of external quality factor (Q_{ext}) from 1.5x10^5 to 5x10^4 to fulfill the performance of 500-MHz superconducting RF accelerating modules required for TPS.

1.2 Agreement between KEK and NSRRC on the development and integration of the 500 MHz Superconducting RF for a high current application (named as *Technology Transfer from KEK to NSRRC* hereafter):

Nine (9) sets of *508-MHz SRF Modules of KEKB design* were designed and integrated by KEK, of which eight (8) modules are routinely operated at KEK with RF power up to 350 kW, CW, and with the world's smallest trip rates. Another two (2) sets of *500-MHz SRF Modules of KEKB design* were produced for Beijing Electron Positron Collider (BEPC-II) at Institute of High Energy Physics (IHEP) in China through technology transfer from KEK to IHEP. The production of these SRF modules of KEKB design is described as follows.

1. The design concept and the blueprint of the SRF module were developed by KEK.
2. The mechanical components and parts of the SRF module such as a niobium cavity, a coupler with great input power, a liquid-helium cryostat, HOM dampers, cryostat support, associated vacuum beam-line components etc., were produced by a qualified mechanical manufacturer selected by KEK. The contracted mechanical manufacturer assumed the responsibility for

---

[1] Y. Morita et al., "Status of KEK Superconducting Cavities and Study for Future SKEKB," Proceedings of SRF2009, Berlin, Germany.

mechanical construction and performance including detailed manufacturing drawings and for cryostat assembly including testing of Maximum Allowable Operating Pressure (MAOP) at room temperature but not for the RF and cryogenic performances.

3. System integration of the SRF module was undertaken at KEK with the assistance of manpower from the contracted mechanical manufacturer. The system integration work included
    a) surface treatment and water rinsing of the niobium cavities,
    b) vertical tests of the surface-treated and water-rinsed cavities,
    c) high-power RF tests/conditioning of the HOM dampers and high-power input couplers,
    d) insertion of the cleaned niobium cavities into the liquid-helium cryostats, and
    e) preparation work for various performance tests at room and cryogenic temperatures.

NSRRC seeks to take full advantage of a reliable SRF design and operation at an RF-power rating 300 kW or greater per SRF module. NSRRC is eager to have three (3) sets of 500-MHz superconducting RF accelerating modules of KEKB design for the accelerator operation at TPS. After signing the Agreement of Technology Transfer from KEK to NSRRC, the production of the 500-MHz superconducting RF accelerating modules of KEKB design for TPS (*500-MHz SRF Modules for TPS*) will conform to the production procedure adopted at KEK as well as the previous scheme of technology transfer from KEK to IHEP, and is summarized as follows.

1. The existing design of the 500-MHz/508-MHz SRF Module developed by KEK will be adopted with minor modifications to fit the specific interface requirements of TPS. Under the supervision of KEK, NSRRC takes the responsibility for the design change.
2. NSRRC will invite bidding from qualified mechanical manufacturers with experience in mechanical production of SRF modules for KEK. The successful bidder becomes the *Supplier* to NSRRC to supply the *500-MHz SRF Modules for TPS*.
3. The surface treatment, RF processing and system integration will be done by KEK and NSRRC staff at KEK with the assistance of the *Supplier* of the SRF modules. The tasks mentioned above will be conducted under supervision of KEK.

Whenever the RF or cryogenic performance of the manufactured *500-MHz SRF Modules for TPS* becomes unsuccessful in satisfying the performance required for accelerator operation at TPS, additional treatment or processing or system integration will be undertaken by KEK, NSRRC, and its *Supplier*. NSRRC agrees to provide compensation to its *Supplier*, if not due to that *Supplier*'s fault in manufacturing, for the extra work. KEK will undertake arbitration for any dispute between NSRRC and its *Supplier* of the *500-MHz SRF modules for TPS*.

Therefore, the production of the *500-MHz SRF module for TPS* shall be separated into five distinct phases.

Phase I: The *Supplier* as mechanical manufacturer shall be responsible for converting the design concept and sketch by KEK to its own manufacturing drawings and mechanical products. The *Supplier* assumes the responsibility for mechanical construction including detailed manufacturing drawings but not for the RF and cryogenic performances after its system integration done at KEK under supervision of KEK.

Phase II: System integration of the liquid-helium cryostat of the *500-MHz SRF module for TPS* with the surface-treated and clean niobium cavity will be undertaken at KEK by NSRRC and KEK under supervision of KEK. The *Supplier* shall provide the assistance of manpower for the system integration. The system integration work includes, but is not limited to,

i. surface treatment and water rinsing of the niobium cavities,
ii. vertical tests of the surface-treated and water-rinsed cavities,
iii. high-power RF conditioning of the HOM dampers and high-power input couplers,
iv. insertion of the cleaned niobium cavities into the cryostats, and
v. preparation work for various performance tests at room and cryogenic temperatures.

The *Supplier* shall specify the scope and cost of assistance to be provided for the work at KEK mentioned above in terms of content of assistance per process (with estimated process working hours) in its Quotation. NSRRC shall check the process results after completeness of assistance process. Provided that either (1) NSRRC or KEK requires a better process results by asking the *Supplier* to repeat or add any of the process or (2) the actually total assistance working hours are more than 10% of the estimated total working hours given by the *Supplier* due to fault, delay or prolongation of NSRRC or KEK, these additional cost and expenses shall be paid by NSRRC to the *Supplier* according to the scope and cost of assistance task provided by the *Supplier* in its contracted Quotation for the *500-MHz SRF Modules for TPS* to NSRRC.

Phase III: The associated vacuum-beam pipes (including vacuum beam-line tapers, vacuum beam-line bellows etc.), HOM dampers, and their mechanical supports will be manufactured by the *Supplier* and then shipped to NSRRC by the *Supplier* for assembly by NSRRC.

Phase IV: The *Supplier* is responsible to ship the liquid-helium-tested liquid-helium cryostat and its mechanical support for the *500-MHz SRF Module for TPS* to NSRRC.

Phase V: After receiving the liquid-helium cryostat from the *Supplier*, NSRRC will attach the assembled beam-line components (done in Phase III) and the vacuum gate valves (provided by NSRRC) to the liquid-helium cryostat (done in Phase II). After that, the *500-MHz SRF module for TPS* will be tested under high-power RF at NSRRC with help from KEK experts and with the assistance from the *Supplier*.

The *Supplier* shall specify the scope and cost of assistance to be provided for the work at NSRRC mentioned above in terms of content of assistance per process (with estimated process working hours) in its Quotation.

NSRRC shall check the process results after completeness of assistance process. Provided that either (1) NSRRC or KEK requires a better process results by asking the *Supplier* to repeat or add any of the process or (2) the actually total assistance working hours are more than 10% of the estimated total working hours given by the *Supplier* due to fault, delay or prolongation of NSRRC or KEK, these additional cost and expenses shall be paid by NSRRC to the *Supplier* according to the scope and cost of assistance task provided by the *Supplier* in its contracted Quotation for the *500-MHz SRF Modules for TPS* to NSRRC.

1.3 Scope of *Supplier*

The *Supplier* shall deliver **three (3)** sets of *500-MHz SRF Modules for TPS* and each module shall fulfill the requirements of this *Technical Specification*, including providing the spare parts as default described in this *Technical Specification*. The *Supplier* shall supervise various assembled works and performance tests described in this *Technical Specification* for the *500-MHz SRF Modules for TPS* at KEK and at NSRRC.

This *Technical Specification* below defines the technical requirements for **each** set of *500-MHz SRF Module for TPS* to be used as a 500-MHz superconducting RF accelerating module at the TPS at NSRRC in Hsinchu, Taiwan. The *Supplier* is fully responsible to produce the *500-MHz SRF Module for TPS* completely fulfilling this *Technical Specification*. Without agreement by the authorized representative of NSRRC in writing, the production of the *500-MHz SRF Module for TPS* shall exactly follow this *Technical Specification*. Any mutual agreement on modification of the technical details during production of the *500-MHz SRF Module for TPS* shall be officially recorded in the *Technical Modification Form* (shown in Table I) with the signatures of authorized representatives of the *Supplier* and NSRRC

The original design and procedures of production, assembly and test developed by KEK for the *500 MHz/508 MHz SRF Modules of KEKB* *design* shall be followed by the *Supplier* as closely as possible.

The *Supplier* shall take full responsibility for its personnel safety when they are working on any fabrication or test for the *500-MHz SRF Modules for TPS* either at KEK or at NSRRC.

Table I: *Technical Modification Form* for the *500-MHz SRF Module for TPS*

<table>
<tr><td>NSRRC Procurement #</td><td colspan="3"></td></tr>
<tr><td>Supplier Project #</td><td colspan="3"></td></tr>
<tr><td>SRF Module #</td><td colspan="3"></td></tr>
<tr><td>Modification #</td><td colspan="3"></td></tr>
<tr><td>Date</td><td colspan="3"></td></tr>
<tr><td colspan="4">Relevant Technical Requirements before Modification</td></tr>
<tr><td colspan="4"></td></tr>
<tr><td colspan="4">Technical Reason for Modification</td></tr>
<tr><td colspan="4"></td></tr>
<tr><td colspan="4">Relevant Technical Requirements after Modification</td></tr>
<tr><td colspan="4"></td></tr>
<tr><td colspan="4">Impacts on SRF Module Production (Delivery Schedule and Cost)</td></tr>
<tr><td colspan="4"></td></tr>
<tr><td colspan="4">Technical Comment/Suggestion from KEK</td></tr>
<tr><td colspan="4"></td></tr>
<tr><td>Supplier Authorized Representative</td><td></td><td>NSRRC Authorized Representative</td><td></td></tr>
</table>

1.4 Conceptual Drawing of the *500-MHz SRF Module for TPS* is shown in Fig. 1.

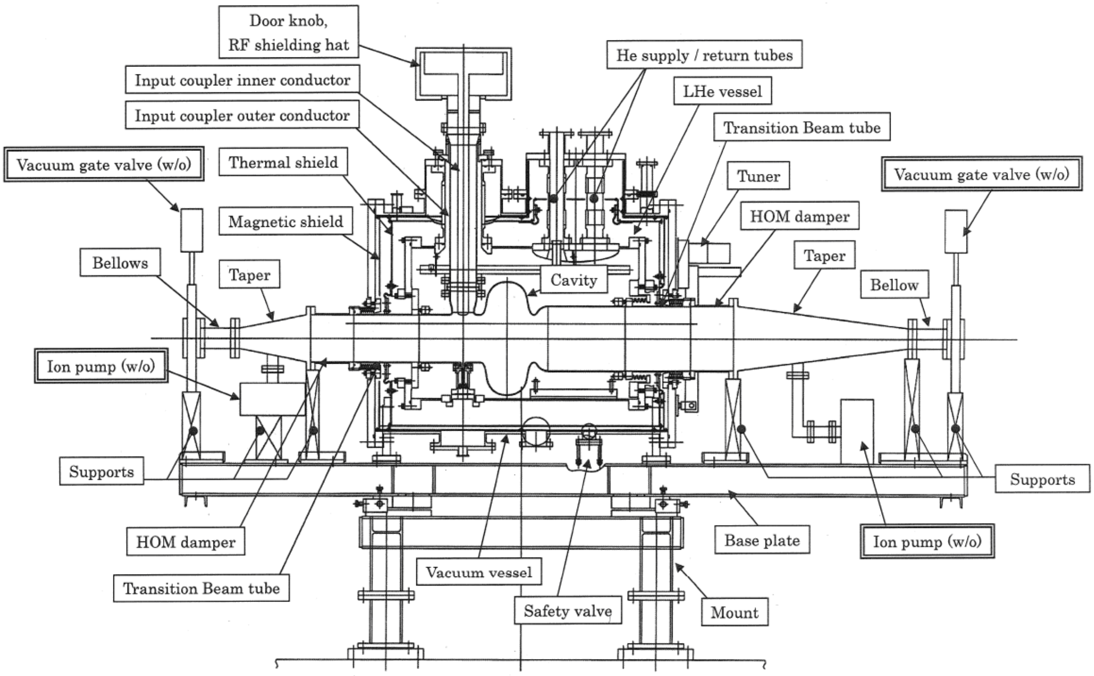

Figure 1: Conceptual Drawing of the *500-MHz SRF Module for TPS.*

2. Niobium Cavity

2.1 The *Supplier* shall supply the niobium cavity for the *500-MHz SRF Module for TPS* for a target electrical performance of cavity as follows.

2.1.1 The operating accelerating RF gap voltage (V_c) exceeds 2.4 MV, CW, at its TM010-like resonance frequency 499.66 MHz with an ohmic quality factor (Q_0) greater than 5.0x10^8 at V_c = 2.4 MV, CW.

2.1.2 The RF loss is less than 30 W at V_c = 1.6 MV, CW, with $Q_0 \geqq$ 1.0x10^9.

2.1.3 The RF loss is less than 135 W at V_c = 2.4 MV, CW, with $Q_0 \geqq$ 5x10^8.

2.2 Niobium sheets for production of the niobium cavity:

2.2.1 The specification of the niobium material shall follow the requirements adopted for production of the niobium cavity for the *508-MHz SRF Module for KEKB.*

2.2.2 The material of the cavity is ultra-pure niobium (with purity 99.85 % or greater) with Residual Resistivity Ratio (RRR) about 200 or greater. The niobium flanges could be produced from reactor-grade niobium (with RRR about 50).

2.2.3 The thicknesses of the niobium sheets for production of the niobium cavity for the *500-MHz SRF Module for TPS* shall be designed by the *Supplier* according to his analysis results for the various operational load conditions. The *Supplier* shall report to NSRRC his analysis conditions and results in sufficient detail before or at the *Engineering Review Meeting*.

2.2.4 The *Supplier* shall visually inspect the received niobium sheets from its material supplier for obvious surface defects such as scratches, voids, cracks etc. In the event of any such findings the niobium sheets shall be rejected or the area shall be ground, slightly etched and inspected again. The *Supplier* shall report to NSRRC its results of material inspection within two (2) months after receiving the niobium material.

2.2.5 The *Supplier* shall select the niobium sheets with required mechanical properties (tensile strength, 0.2 % yield strength etc.) according to his analysis results for various operational load conditions on the cavity.

2.2.5.1 Deleted.

2.2.5.2 Deleted.

2.3 Deleted.

2.4 After the production of the cavity, the niobium cavity shall have inner surfaces free of scratches, blemishes and inclusions. In the event of any such findings the inner surfaces of niobium cavity shall be carefully ground, slightly etched and inspected again.

2.5 Manufacturing tolerance:

2.5.1 The major dimensions of the cavity profile shall be within the tolerances required for the niobium cavity for the *508-MHz SRF Module for KEKB.*

2.5.2 The minimum thickness of the niobium cavity after its production shall be within the tolerances acceptable for the niobium cavity for the *508-MHz SRF Module for KEKB.*

2.6 The *Supplier* shall guarantee the vacuum leak rate and pressure of the niobium cavity for the *500-MHz SRF Module for TPS* as follows:

2.6.1 The rate of leakage of the cavity at room temperature shall be less than $5 \cdot 10^{-9}$ mbar-L/s just before and after the first *High-pressure Test* in the *Supplier*'s factory and before and after the second *High-pressure Test* at KEK.

2.6.2 The pressure of the cavity vacuum at room temperature shall be in the range 10^{-8} mbar or less at the *Vertical Test*.

2.7 The *Supplier* shall NOT guarantee the electric performance (achievable accelerating voltage, resonance frequency, ohmic quality factor, and RF loss) of the niobium cavity at cryogenic helium temperature except the resonance frequency at room temperature.

2.7.1 No material defect and scratch on the inner surfaces of the niobium cavity that affects its electric performance shall be allowed.

2.7.2 The *Supplier* is fully responsible to avoid either any material inclusions or defects inside the niobium cavity caused by the production of a sheet material or any material defect of the niobium cavity during machining and production. The *Supplier* is fully responsible whenever the failure to achieve the target electrical performance of the niobium cavity is due to a material defect of the niobium cavity.

2.7.3 Cavity fabrication by electron-beam welding of half-cells is a delicate procedure, requiring immediate cleaning steps and a careful choice of the weld parameters to achieve full penetration of the joints. Particularly critical are the equator welds, which are made from the outside, and a reliable method shall be developed to obtain a smoothly welded seam at the inner cavity surface. Contamination of the niobium cavity during welding and assembly shall be avoided; otherwise, the equator e-beam welding might become the cause of a limitation on the achievable accelerating voltage. The iris e-beam welding shall ensure a smooth surface and avoidance of an enhanced geometric electric field. The *Supplier* is fully responsible whenever the target electrical performance of the niobium cavity cannot be achieved because of the poor quality of electron-beam welding.

2.8 The *Supplier* shall guarantee the resonance frequency of the TM010-like mode of the niobium cavity at room temperature and atmosphere pressure.

2.8.1 The design of the niobium cavity shall be the same as that for the *508-MHz SRF Module for KEKB* except that the cavity profile shall be modified for a target operational frequency at a resonance frequency 499.66 MHz in the TM010-like mode for the *500-MHz SRF Module for TPS* at the cryogenic temperature between 4.4 - 4.5 K.

2.8.2 NSRRC will give the *Supplier* the cavity profile that will be similar or identical to the cavity profile of the *500-MHz SRF Module of KEKB design for IHEP (China)*, i.e. the length of the straight section of the cavity equator is about 23.5 mm greater than that for the *508-MHz SRF Module for KEKB*. This extra length is absorbed on decreasing the length of the large beam-pipe correspondingly to maintain the size of the liquid-helium cryostat for the 5*00-MHz SRF Module for TPS* identical to that for the *508-MHz SRF Module for KEKB*. The exact profile will be given before approval of the manufacturing drawing.

2.8.3 NSRRC will decide the target frequency of the niobium cavity at room temperature and atmosphere pressure after the *Supplier* notifies NSRRC of the Hooke's spring parameter of the e-beam-welded niobium cavity.

2.8.4 The *Supplier* shall pre-tune the resonance frequency of the niobium cavity to a range within ±20 kHz of the target frequency at room temperature and atmospheric pressure.

2.8.5 The pre-tuning equipment will be borrowed from KEK by NSRRC for the usage of the *Supplier*.

2.8.6 The *Supplier* shall guarantee the pre-tuning of the niobium cavity for the *500-MHz SRF Module for TPS* under the technical support of KEK. The pre-tuning of the resonance frequency of the niobium cavity shall follow the procedure adopted for the *508-MHz SRF Module for KEKB*.

2.8.7 The *Supplier* shall provide NSRRC with the results of measurements within one (1) month after the completion of the frequency pre-tuning.

2.9 The *Supplier* shall report to NSRRC the results of production of the niobium cavity for the *500-MHz SRF Module for TPS* within one (1) month after its completion.

2.10 Protection and diagnosis:

2.10.1 The niobium cavity shall be implemented with sufficient pin photo diodes for protection and diagnosis. These diodes will be attached on the equator every 90^o, top and bottom flanges of the cavity, outer coaxial port of the niobium cavity, etc. These pin photo diodes will be provided by NSRRC.

2.10.2 The niobium cavity shall be implemented with sufficient temperature sensors for protection and diagnosis. These sensors will be attached on the equator every 90^o, etc. These temperature sensors will be provided by NSRRC.

3. Surface Treatment of Cavity and *Vertical Test* at KEK

3.1 Surface treatment at KEK

3.1.1 The surface treatment of the niobium cavity for the *500-MHz SRF Module for TPS* is premised on the use of KEK's electric polishing facility under the supervision of KEK.

3.1.2 The *Supplier* shall NOT guarantee the results of surface treatment (electro-polishing 1 and 2) at KEK.

3.1.3 The exchange or replacement of the electro-polishing solution shall follow the instructions given by KEK experts. NSRRC shall reimburse the cost of consumables for electro-polishing to KEK directly (not to go thought the *Supplier*).

3.1.4 The *Supplier* shall pay the one-time fee for the annealing for cavity and supporting manpower for the surface treatment without electro-polishing per cavity.

3.2 Annealing of niobium cavity:

3.2.1 The *Supplier* shall guarantee the process of annealing of the niobium cavity for the *500-MHz SRF Module for TPS* under the technical support of NSRRC.

3.2.2 The *Supplier* shall NOT guarantee the niobium cavity to be free of Q-virus or Q-disease because of a large concentration of hydrogen inside the niobium material (Refer to Item 3.3.3 of this *Technical Specification*.)

3.2.3 The *Supplier* shall avoid diffusing impurities into, or contaminating, the niobium cavity during annealing. The *Supplier* shall follow the preparation procedure suggested by NSRRC.

3.2.4 The annealing shall be undertaken under the following conditions:

3.2.4.1 temperature: 700 ^{o}C

3.2.4.2 vacuum pressure: 10^{-4}-10^{-6} mbar

3.2.4.3 duration: 1.5 h

3.2.4.4 tools: The titanium box used for the *508-MHz SRF Module for KEKB* will be borrowed from KEK.

3.2.4.5 measurement: The outgassing from the niobium cavity shall be measured with Q-MASS.

3.3 *Vertical Test*:

3.3.1 The *Vertical Test* of the niobium cavity will be undertaken at KEK under the supervision of KEK experts.

3.3.2 The target electrical performance for the *Vertical Test* of the niobium cavity must achieve an operating accelerating RF gap voltage (V_c) greater than 2.4 MV, CW, at its TM010-like resonance frequency about 499.66 MHz with an ohmic quality factor (Q_0) greater than 1.0x10^9. The cavity is completely immersed in a liquid-helium bath at temperature 4.2 K or 4.5 K.

3.3.3 The niobium cavity shall not be accepted for system integration whenever the cavity is not free of the Q-virus. Whether the niobium cavity is immune to the Q-virus shall be experimentally verified during the *Vertical Test* on applying a sufficiently slow rate of cooling between 150 K and 120 K more than 6 h. Providing that the niobium cavity has the Q-virus, NSRRC will ask the *Supplier* to repeat the annealing related processes and pay the *Supplier* extra cost according to the price breakdown for the *Supplier* provided assistant work given in the contracted Quotation for the *500-MHz SRF Modules for TPS* to NSRRC. (Refer to Item 3.2.2 of this *Technical Specification*.)

3.3.4 The resonance frequency of the niobium cavity during *Vertical Test* at 4.2 K or 4.5 K shall be measured and be expected to lie within an acceptable frequency range to fulfill the requirements of the RF operational frequency at 499.66 MHz of the *500-MHz SRF Module for TPS*.

3.4 The *Supplier* shall provide sufficient (referring to Item 1.2 of this *Technical Specification*) manpower to support the following operation at KEK:

3.4.1 Surface treatment of the niobium cavity (surface treatment by electropolishing excluded)

3.4.2 Baking of the niobium cavity

3.4.3 *Vertical Test* of the niobium cavity

3.4.4 Vacuum leakage test

4. High-Power Input Coupler

4.1 The *Supplier* shall supply the high-power input coupler for a target electrical performance capable of long-term operation at an RF power rating up to 300 kW, CW, or more in the full-reflection standing wave, at warm (room) and at cold temperatures. The design of the high-power input coupler shall be the same as that for the *508-MHz SRF Module for KEKB*.

4.1.1 The *Supplier* shall supply the inner conductor with ceramic RF window.

4.1.1.1 The surface of the ceramic RF window on the vacuum side shall be properly coated with TiN_xO_y to decrease the coefficient of secondary-electron emission.

4.1.2 The high-power input coupler shall be provided with monitoring ports capable of measuring discharge light (arcing), multipacting electron current and vacuum pressure.

4.1.3 Deleted.

4.1.4 The high-power input coupler shall be implemented with sufficient pin photo diodes for protection and diagnosis. The pin photo diodes will be provided by NSRRC.

4.1.5 The high-power input coupler shall be implemented with sufficient temperature sensors for protection and diagnosis. The temperature sensors will be provided by NSRRC.

4.1.6 The high-power input coupler shall be implemented with LVDT or a dial gauge for protection and diagnosis. The LVDT or dial gauge will be provided by NSRRC.

4.1.7 The *Supplier* shall supply a high-voltage bias-type doorknob transition with RF shielding hat.

4.1.7.1 The VSWR of the doorknob transition shall be optimized for operation at 499.66 MHz.

4.1.7.2 The doorknob transition shall be capable of delivering an RF power greater than 300 kW, CW.

4.1.7.3 The doorknob transition shall be capable of applying a bias voltage up to ±2000 V, DC.

4.1.7.4 The doorknob transition shall be effective on one side to connect to WR1500 standard waveguide and on the other side to the inner conductor (coaxial) of the high-power input coupler.

4.1.7.5 NSRRC will provide the WR1500 semi-soft waveguide bellows between the waveguide port of the doorknob transition and the standard waveguide.

4.1.8 The *Supplier* will install the cooling fan, DC power supply for bias-voltage, vacuum-pressure gauge, thermocouples and arc detector that will be provided by NSRRC.

4.1.9 NSRRC will supply the cooling-water system for the high-power input coupler.

4.1.10 The *Supplier* will install the heater for the high-power input coupler. The heater will be provided by NSRRC.

4.2 NSRRC will decide the target external quality factor (Q_{ext}) of the *500-MHz SRF Module for TPS*.

4.3 Deleted.

4.4 The major dimensions of the high-power input coupler of the *500-MHz SRF Module for TPS* shall be within the tolerances required for the high-power input coupler of the *508-MHz SRF Module for KEKB*.

4.5 The *Supplier* shall guarantee the vacuum pressure and leak rate of the high-power input coupler for the *500-MHz SRF Module for TPS* as follows:

4.5.1 The vacuum pressure of the high-power input coupler shall be in the range 10^{-8} mbar or less after high-power RF processing and after its assembly into the liquid-helium cryostat of the *500-MHz SRF Module for TPS.*

4.5.2 The rate of leakage of the high-power input coupler shall be less than $5 \cdot 10^{-9}$ mbar-L/s at room temperature after high-power RF processing and after its assembly into the liquid-helium cryostat of the *500-MHz SRF Module for TPS.*

4.6 High-power RF processing at KEK (to be undertaken by NSRRC staff supervised by KEK experts):

4.6.1 The high-power RF processing of the high-power input coupler shall be undertaken in a coupler test stand, <u>first</u> without application of a bias-voltage and <u>then</u> with application of a bias voltage to the inner conductor (coaxial) of the high-power input coupler up to ±2000 V, DC, in step ±100 V or smaller, for multipacting suppression and excitation, both with RF power, up to 300 kW, CW, at 500 MHz or 508 MHz in a traveling wave and in a totally reflected standing wave with the RF phase varying over a half wavelength.

4.6.2 After the high-power RF processing of the high-power input coupler at the coupler test-power stand, the RF performance of the high-power input coupler shall be verified on continuous operation at 300 kW, CW, at 500 MHz or 508 MHz in a traveling wave and in a totally reflected standing wave more than 4 h, with no trip for any cause. Otherwise, the high-power RF processing shall be repeated. The vacuum of the RF window shall be better than $1 \cdot 10^{-7}$ mbar during this performance verification.

4.7 The *Supplier* shall NOT guarantee the electric performance of the high-power input coupler.

4.7.1 Neither material defect nor scratch on the inner surfaces of the outer coaxial and outer surfaces of the inner coaxial of the high-power input coupler that affects the performance shall be allowed.

4.7.2 The mechanical design of the high-power input coupler shall allow the *500-MHz SRF Module for TPS* to be operated with Q_{ext} within the range from $5 \cdot 10^4$ to $1.5 \cdot 10^5$ on replacing the gasket thickness of the Conflex vacuum sealing. The required coupler length and gasket thickness will be provided by NSRRC.

4.8 The *Supplier* shall send sufficient (referring to Item 1.2 of this *Technical Specification*) manpower to support the following operations at KEK:

4.8.1 rinsing of the high-power input coupler

4.8.2 baking of the high-power input coupler

4.8.3 high-power RF processing at KEK

4.8.4 vacuum leakage test before and after the high-power RF processing at KEK

4.8.5 supervision of re-installation of the high-power input coupler at NSRRC, and

4.8.6 supervision of vacuum leakage test at NSRRC

4.9 The *Supplier* shall report to NSRRC the results of production of the high-power input coupler for the *500-MHz SRF Module for TPS* within one (1) month of its completion.

5. Liquid-helium Cryostat

5.1 The *Supplier* shall supply the liquid-helium cryostat for the *500-MHz SRF Module for TPS.*

5.1.1 The design of the liquid-helium cryostat for the *500-MHz SRF Module for TPS* shall follow the conceptual design of the liquid-helium cryostat for the *508-MHz SRF Module for KEKB*.

5.1.2 The liquid-helium cryostat for the *500-MHz SRF Module for TPS* shall provide the functionality required for the liquid-helium cryostat for the *508-MHz SRF Module for KEKB.*

5.1.3 The major dimensions of the liquid-helium cryostat for the *500-MHz SRF Module for TPS* shall be within the tolerances required for the liquid-helium cryostat for the *508-MHz SRF Module for KEKB.*

5.1.4 The materials selected for the liquid-helium cryostat for the *500-MHz SRF Module for TPS* shall follow the selection for the *508-MHz SRF Module for KEKB*. Otherwise, the *Supplier* shall make a proposal to NSRRC and obtain technical agreement from KEK.

5.1.5 Deleted.

5.2 The *Supplier* shall supply the following items:

5.2.1 liquid-helium vessel with its suspension system (liquid-helium vessel support);

5.2.2 vacuum vessel;

5.2.3 thermal-transition beam tubes (large and small);

5.2.4 superinsulation for liquid-nitrogen and liquid-helium temperatures, each with at least 20 layers;

5.2.5 thermal shield with liquid nitrogen;

5.2.6 magnetic shield;

5.2.7 internal cryogenic tubing for the liquid-helium supply and the return of cold gaseous helium with external cryogenic connectors;

5.2.8 internal cryogenic tubing for the liquid-nitrogen supply and return with external cryogenic connectors, and

5.2.9 cryogenic safety-relief valves.

5.2.10 The *Supplier* shall NOT supply the vacuum gate valves of the vacuum vessel, vacuum pumps and gauges.

5.3 The *Supplier* shall properly install the following items that will be supplied by NSRRC:

5.3.1 monitoring transducers for liquid-helium levels (one set for normal operation and the other one set as spare in situ);

5.3.2 cryostat heaters (120 V, 200 W, 60 Hz) inside the liquid helium (one set for normal operation and the other one set as spare in situ);

5.3.3 heaters (120 V, 25 W or greater, 60 Hz) for the outer coaxial of the high-power input coupler (one set for normal operation and the other one set as spare in situ);

5.3.4 monitoring transducers for cryogenic temperatures (spares in situ for all cryogenic-temperature sensors related to control of the rate of cooling);

5.3.5 pin photo diodes for radiation monitoring.

5.4 The *500-MHz SRF Module for TPS* shall be implemented with LVDT or dial gauges to monitor the variation of the length of the niobium cavity and the thermal-transition beam-pipes during cooling or warming of the liquid-helium cryostat. The LVDT or dial gauges will be provided by NSRRC.

5.5 The *Supplier* shall guarantee the vacuum performance of the liquid-helium cryostat for the *500-MHz SRF Module for TPS* as follows:

5.5.1 The *Supplier* shall be fully responsible for the vacuum tightness of the liquid-helium cryostat (including its internal cryogenic piping and connection) for the *500-MHz SRF Module for TPS* operating at cryogenic temperature or after thermal cycling whenever the vacuum sealing was done by the *Supplier* <u>(neither by KEK nor by NSRRC)</u>.

5.5.2 Thermal shocks using liquid nitrogen and measurements of leak tightness shall be performed at least three times for all extensible and flexional tubes of the liquid-helium cryostat before assembly, if thermal shocks can be applied.

5.5.3 The rate of leakage of the niobium cavity (to ambient, to the liquid-helium vessel, and to the vacuum vessel) at room temperature shall be less than $5 \cdot 10^{-9}$ mbar-L/s after assembly in the *Supplier*'s factory.

5.5.4 The rate of leakage of the liquid-helium vessel and the tubing for the helium supply and return of the liquid-helium cryostat and the warm return line through the outer coaxial of the high-power input coupler (to ambient, to cavity, and to the vacuum vessel) at room temperature shall be less than $5 \cdot 10^{-9}$ mbar-L/s after assembly.

5.5.5 The rate of leakage of the nitrogen supply and return tubes of the liquid- helium cryostat (to ambient and to the vacuum vessel) at room temperature shall be less than $5 \cdot 10^{-9}$ mbar-L/s after assembly.

5.5.6 The rate of leakage of the vacuum vessel of the liquid-helium cryostat (to ambient, to the liquid-helium vessel, and to internal cryogenic piping) at room temperature shall be less than $5 \cdot 10^{-8}$ mbar-L/s after assembly.

5.5.7 The vacuum vessel shall be installed with an RGA for monitoring of vacuum leakage. The RGA will be provided by NSRRC.

5.5.8 The pressure in the vacuum vessel of the liquid-helium cryostat at room temperature shall be in the range 10^{-4} mbar or less after assembly.

5.6 The terrestrial and ambient magnetic shielding of the liquid-helium cryostat shall be experimentally verified before the assembly of the niobium cavity into the liquid-helium vessel but with the liquid-helium vessel inside the liquid-helium cryostat of the *500-MHz SRF Module for TPS*. The liquid-helium cryostat shall be positioned horizontally during the performance measurements of the terrestrial and ambient magnetic shielding. The axial (beam) axis of the liquid-helium cryostat shall be aligned parallel to the orientation with the maximum strength of the terrestrial and ambient magnetic field at the measurement location. The measured residual magnetic field shall be less than 50 mG at the geometric center of the niobium cavity. The *Supplier* shall provide NSRRC with the results of measurements within one (1) month after the completion of experimental verification of the magnetic shielding.

5.6.1 The terrestrial and ambient magnetic shielding was implemented using a vacuum vessel made of soft iron of sufficient thickness for the liquid-helium cryostat of the *508-MHz SRF Module for KEKB*. Alternatively, the terrestrial and ambient magnetic shielding can be implemented using μ-metal layers inside the vacuum vessel of the liquid-helium cryostat. The *Supplier* shall count the degradation of permeability of μ-metal when it operates at cryogenic temperature (for example ADMU80) and μ-metal of a different kind shall be implemented for the liquid-helium vessel (for example Cryoperm). In addition, the μ-metal shall have sufficient thickness for effective magnetic shielding.

5.7 The static cryogenic loss to liquid helium shall be 35 W or less at the cryogenic liquid-helium test at KEK and at the high-power test at NSRRC.

5.8 The joint between the *500-MHz SRF Module for TPS* and the cryogenic transfer-lines shall be bayonet joints of the same design as for KEK. The *Supplier* shall supply two sets of all pairs of (male and female) bayonet joints for each *500-MHz SRF Module for TPS*. The *Supplier* shall assemble the female or male (female one upward) joint into the *500-MHz SRF Module for TPS*. NSRRC shall weld the male or female (female one upward) joints to the cryogenic transfer-lines to the SRF valve box.

5.9 The *Supplier* shall report to NSRRC the results of production of the liquid-helium cryostat for the *500-MHz SRF Module for TPS* within one (1) month of its completion.

6. Assembly of the Liquid-helium Cryostat at the *Supplier*'s Factory

6.1 The *Supplier* shall assemble the liquid-helium cryostat with the niobium cavity for the *500-MHz SRF Module for TPS* (to be discussed).

6.2 The *Supplier* shall allow the Representatives of NSRRC to witness the assembly of the liquid-helium cryostat (with the suspension system, cryogenic piping, liquid-helium vessel, niobium cavity etc.) in the *Supplier*'s factory.

7. Factory Acceptance Test and High-pressure Tests

7.1 A *Factory Acceptance Test* for the niobium cavity shall be undertaken in the *Supplier*'s factory.

7.1.1 The inside surface shall be inspected optically, especially the quality of the weld.

7.1.2 The resonance frequency of the niobium cavity at room temperature and atmosphere pressure shall be measured.

7.1.3 *High-pressure Tests* are part of the *Factory Acceptance Test*.

7.2 A *Factory Acceptance Test* for the assembled liquid-helium cryostat shall be undertaken in the *Supplier*'s factory.

7.2.1 The *Supplier* shall demonstrate to the Representatives of NSRRC the performance of magnetic shielding for the liquid-helium cryostat.

7.2.2 The *Supplier* shall demonstrate to the Representatives of NSRRC the success of tests of vacuum leakage for the assembled liquid-helium cryostat.

7.2.3 The *Supplier* shall demonstrate to the Representatives of NSRRC the success of the *High-pressure Test* for the assembled liquid-helium cryostat including liquid-helium supply and gas-helium return pipes.

7.2.4 The *Supplier* shall demonstrate to the Representatives of NSRRC the success of the *High-pressure Test* for the liquid nitrogen supply and return pipes.

7.3 The niobium cavity and the liquid-helium cryostat of the *500-MHz SRF Module for TPS* shall be tested at high pressure either separately or together during the *Factory Acceptance Test*. This (first) *High-pressure Test* for the liquid-helium cryostat may be done using gaseous nitrogen or water.

7.3.1 The maximum allowed operational pressure of the *500-MHz SRF Module for TPS* is 1.313 bara. The maximum testing pressure during the first *High-pressure Test* is 125% of the maximum allowed operational pressure, 1.64 bara.

7.3.2 Neither buckling nor observable creep nor inelastic deformation shall be allowed during the first *High-pressure Test*.

7.3.3 The rate of vacuum leakage shall be measured before and after the first *High-pressure Test*. The vacuum leakage shall NOT be observed.

7.3.4 The cavity resonance frequency shall be measured before and after the first *High-pressure Test*. Drift of the cavity resonance frequency not more than 10 kHz shall be observed.

7.4 *High-pressure Test* for the nitrogen supply and return pipes:

7.4.1 The maximum allowed operational pressure of the nitrogen supply and return pipes for the *500-MHz SRF Module for TPS* is 6.0 bara. The maximum testing pressure during the *High-pressure Test* is 125 % of the maximum allowed operational pressure, 7.5 bara.

7.5 *High-pressure Test* for the cooling-water channels for the inner coaxial of the high-power input coupler, the HOM dampers, and radiation masks on the vacuum beam-line tapers.

7.5.1 The maximum allowed operational pressure of the water-cooling channels is 7.0 bara for the HOM dampers and radiation masks on the vacuum beam-line tapers, and 3 bara for the inner coaxial of the high-power input coupler. The maximum testing pressure during the *High-pressure Test* is 125 % of the maximum allowed operational pressure, 8.75 bara for the HOM dampers and radiation masks on the vacuum beam-line tapers, and 3.0 ~~3.75~~ bara (100 % of the maximum allowed operational pressure) for the inner coaxial of the high-power input coupler.

7.6 Deleted.

8. Higher-order-mode Dampers

8.1 The *Supplier* shall supply the higher-order-mode (HOM) dampers for the *500-MHz SRF Module for TPS* for a target electrical performance of the power-handling capacity **each** up to 10 kW, CW, or more of beam power. The design, manufacture and high-power RF tests of these HOM dampers shall be the same as that for the *508-MHz SRF Module for KEKB*.

8.1.1 The *Supplier* shall order the HOM dampers as soon as the *Engineering Review Meeting* is finished, or even earlier.

8.2 The production of HOM dampers for the *500-MHz SRF Module* for TPS shall follow mostly its original design for the *508-MHz SRF Module for KEKB*, except that the water-cooling channels for the HOM dampers shall be doubled to increase the cooling capacity. NSRRC will provide the drawing.

8.2.1 Deleted.

8.2.2 An ultrasonic scan shall be applied to the HOM dampers to verify that the ferrite layers are free of crack or bubble after their manufacture. Otherwise, the production of the HOM dampers is unsuccessful.

8.2.3 The *Supplier* shall NOT guarantee the electrical performance of HOM dampers for the *500-MHz SRF Module for TPS*.

8.3 Each *500-MHz SRF Module for TPS* has two HOM dampers: large beam-pipe HOM damper and small beam-pipe HOM damper.

8.4 The nominal thickness of the ferrite layer of each HOM damper is 4 mm.

8.5 The *Supplier* shall supply the local water manifold for cooling of HOM dampers.

8.6 The HOM dampers will be implemented with surface and cooling-water temperature sensors that will be provided by NSRRC.

8.7 After ultrasonic scan, the baking of the HOM dampers for the *500-MHz SRF Module for TPS* will be undertaken by NSRRC under supervision of KEK experts at KEK. The outgassing rate will be measured.

8.8 The *Supplier* shall guarantee the vacuum pressure and leak rate of HOM dampers for the *500-MHz SRF Module for TPS* as follows:

8.8.1 The pressure of each HOM dampers shall be in the range 10^{-8} mbar or less after high-power RF tests and baking at KEK.

8.8.2 The rate of leakage of each HOM damper shall be less than $5 \cdot 10^{-9}$ mbar-L/s at room temperature after the high-power RF tests and baking at KEK.

8.9 The *Supplier* shall send sufficient (referring to Item 1.2 of this *Technical Specification*) manpower to support the following operation at KEK:

8.9.1 high-power RF tests;

8.9.1.1 A high-power RF test up to 5 kW in CW mode at 2450 MHz with duration 30 min or more shall be applied to the full-size HOM dampers. The high-power RF test may be done in air.

8.9.1.2 The full-size HOM dampers shall be successfully tested with high RF power up to 10 kW at 500-MHz or 508-MHz with duration 30 min or more. The outgassing rate will be measured if the high RF power test is done in vacuum.

8.9.1.3 Moved to Item 8.2.2.

8.9.2 Moved to Item 8.7.

8.10 The *Supplier* shall report to NSRRC the results of production of the HOM dampers within one (1) month of their completion.

9. Associated Vacuum Beam-Line Components

9.1 The *Supplier* shall supply the associated vacuum beam-line components for the *500-MHz SRF Module for TPS* including two thermal-transition beam-pipes (parts of liquid-helium cryostat), two vacuum beam-line bellows, and two vacuum beam-line tapers including water-cooled radiation masks.

9.2 The *Supplier* shall supply the mechanical supports for the associated vacuum beam-line components (large and small pipes) and for the liquid-helium cryostat for the *500-MHz SRF Module for TPS*.

9.2.1 The design, manufacture, surface treatment and baking of these associated vacuum beam-line components shall be the same as those for the *508-MHz SRF Module for KEKB* except that each vacuum beam-line taper shall be equipped with one pair of radiation masks and four e-bpms (or HOM probes) in addition.

9.2.2 Design of the RF contacts for the individual vacuum beam-line components shall follow the KEKB design.

9.3 Thermal-transition beam-pipes:

9.3.1 The thermal-transition beam-pipes shall be equipped with thermal intercepts at liquid-nitrogen temperature from copper brazed onto their stainless-steel pipes. The anchoring locations shall follow the design for the *508-MHz SRF Module for KEKB*.

9.3.2 Electric heating wires shall be implemented around the warm ends of the thermal-transition beam-pipes to avoid condensation of water. The heating capacity of the electric heating wires will be optimized such that the surface temperatures are about 20 ^{o}C at the far ends of the thermal-transition beam-pipe. NSRRC will supply the electric heating wires for these thermal-transition beam-pipes.

9.4 Vacuum beam-line tapers:

9.4.1 Each vacuum beam-line taper shall include water-cooled radiation masks, four orthogonal (±45^{o} tilted from the horizontal plane) RF pick-up / HOM probes (with SMA connectors) as e-bpm in service as electron-beam position monitors or for measurement of higher-order modes, and vacuum pumping ports with screen shielding for ion pumps. The electronics for the beam-position monitoring will be provided by NSRRC.

9.4.2 NSRRC will provide the conceptual design for the radiation masks and four orthogonal RF pick-up / HOM probes on the vacuum beam-line tapers. The *Supplier* shall provide NSRRC the production drawings for reconfirmation.

9.4.3 Deleted.

9.5 Vacuum beam-line bellows:

9.5.1 The design of vacuum beam-line bellows on the side of the large beam-pipe shall be able to accommodate the variation of the internal axial length of the *500-MHz SRF Module for TPS* to produce a frequency tuning up to 1 MHz centered at 499.66 MHz when the niobium cavity is at liquid-helium temperature.

9.5.2 The vacuum beam-line bellows shall be produced from stainless steel.

9.5.3 The internal RF shielding for the vacuum beam-line bellows shall follow the KEKB design.

9.6 NSRRC will supply the all-metal vacuum gate valves of the vacuum beam-line components.

9.7 The *Supplier* shall guarantee the mechanical performance of the individual vacuum beam-line components for the *500-MHz SRF Module for TPS.*

9.8 The *Supplier* shall guarantee the vacuum performance of the individual vacuum beam-line components for the *500-MHz SRF Module for TPS* as follows:

9.8.1 The pressure of each vacuum beam-line component shall be in the range 10^{-8} mbar or less after baking.

9.8.1.1 The surface treatment of the associated vacuum beam-line components (except the vacuum beam-line tapers) shall follow the KEKB standard procedures.

9.8.1.2 The *Supplier* shall be responsible to perform the standard surface treatment/cleaning for the stainless-steel beam-line tapers and copper radiation masks of the vacuum beam-line tapers before vacuum brazing. Chemical surface treatment/cleaning of different types shall be adopted for the stainless-steel[2] part and the copper part[3]. The *Supplier* shall avoid contamination of the vacuum beam-line tapers during vacuum brazing. No extra surface treatment/cleaning will be required after vacuum brazing.

9.8.1.3 The baking of the associated vacuum beam-line components will be undertaken by NSRRC.

9.8.2 The rate of leakage of each vacuum beam-line component shall be less than $5 \cdot 10^{-9}$ mbar-L/s at room temperature.

9.8.3 One of the associated vacuum beam-line components shall be installed with a high-vacuum type RGA for monitoring of vacuum leakage. The RGA will be provided by NSRRC.

[2] Example of surface treatment/cleaning procedure for components made of stainless steel (developed by APS): Step #1: ultrasonic washing at full power level, using the solution of 2% RIDOLINE at 65.5℃ or 150F, circulating more than 10 min; Step #2: rinsing with flowing ultrapure water at cold, 6 GPM supply, more than 20 min; Step #3: drying with hot nitrogen gas at 37.8℃ or 100F or greater, until dry.

[3] Example of surface treatment/cleaning procedure for components made of copper (developed by APS): Step #1: ultrasonic washing at full power level, using the solution of 2% CITRANOX at 60℃ or 140F, circulating more than 10 min; Step #2: rinsing with flowing ultrapure water at 37.8℃ or 100F, 6 GPM (1gal=3.785 liter) supply, more than 20 min or shorter (oxidation shall be avoide); Step #3: drying with hot nitrogen gas at 37.8℃ or 100F or greater, until dry.

9.9 The *Supplier* shall send the HOM dampers, vacuum beam-line tapers, vacuum beam-line bellows, and their mechanical supports to NSRRC before the deadline specified in the *Contract*. They will be assembled by NSRRC at NSRRC. The *Supplier* shall supervise the assembly when the complete sets of associated vacuum beam-line components (named as pre-assembled units) are to be attached to the liquid-helium-tested liquid-helium cryostat of the *500-MHz SRF Module for TPS*.

10. Survey and Alignment

10.1 The design of the liquid-helium cryostat and associated vacuum beam-line components for the *500-MHz SRF Module for TP*S shall follow the functional requirements for the *508-MHz SRF Module for KEKB* to fulfill the need for survey and alignment.

10.2 The survey and alignment procedure for the niobium cavity and liquid-helium cryostat for the *500-MHz SRF Module for TP*S shall follow the functional requirements for the *508-MHz SRF Module for KEKB* to fulfill the need for survey and alignment.

10.3 The exterior of the liquid-helium cryostat of the *500-MHz SRF Module* shall have no less than six (6) fiducial points, including two (2) fiducial points located on the top of the liquid-helium cryostat (upstream and downstream) and two (2) more on each side of the liquid-helium cryostat at the level of the beam (cavity) axis. It shall be convenient for a laser tracker to work at these six (6) fiducial points.

10.4 The exterior of the vacuum beam-line components of the *500-MHz SRF Module for TPS* shall have no less than eight (8) fiducial points located on the circumferences (spacing per 90^{o}) of two outside flanges of some upstream and downstream vacuum beam-line components of the *500-MHz SRF Module for TPS*. During the assembly of the *500-MHz SRF Module for TPS*, the beam (cavity) axis will be determined relative to these fiducial points and reported to NSRRC for alignment. The details will be discussed after signing the *Contract*. This procedure shall be approved by NSRRC. NSRRC shall determine the position of the outside flanges relative to the reference marks and align the *500-MHz SRF Modul*e *for TPS* with the use of a laser tracker.

10.5 Fiducial sockets shall be welded or holed in place and have internal diameter $6.35^{+0.02}_{-0.00}$ mm, depth 12 mm, and external diameter 28 mm.

10.6 The *Supplier* shall provide data to relate the position of the niobium cavity to the fiducial points on the exterior of the *500-MHz SRF Module for TPS.*

10.7 The *Supplier* shall provide a reference plane (table) on the top of the *500-MHz SRF Module for TPS* of size 100 mm x 100 mm for use of a bubble inclinometer.

10.8 NSRRC will provide the fiducial sockets and the *Supplier* shall be responsible either to weld the fiducial sockets in place for purpose of survey and alignment, or to provide the holes for installation of the fiducial sockets in place by NSRRC.

10.9 The final survey and alignment shall be performed by NSRRC at NSRRC.

10.10 The details of the survey and alignment procedure for the *500-MHz SRF Module for TPS* shall be concluded at the *Engineering Review Meeting*.

11. Frequency Tuner

11.1 The *Supplier* shall supply the frequency tuner. The design of the frequency tuner for the *500-MHz SRF Module for TPS* shall be the same as that for the *508-MHz SRF Module for KEKB.*

11.1.1 The frequency tuner shall effect a mechanical tuning of the cavity-resonance frequency in a range ±2 mm, corresponding to ±400 kHz.

11.1.2 The frequency tuner shall effect a slow electrical tuning of the cavity-resonance frequency in a range ±1 mm, corresponding to ±200 kHz or more with a stepping motor.

11.1.3 The frequency tuner shall be implemented with a piezo-tuner for a tuning range of at least ±30 μm, corresponding to ±6 kHz. The piezo actuator and its power supply will be provided by NSRRC to the *Supplier*.

11.2 Accessories:

11.2.1 The *Supplier* shall supply the tuner, limiting switches, mechanical hard stops, stepping motor with its power supply (driver). The strength of the mechanical hard stops shall be over-designed. The power supply is effective for power according to the line voltage 120 V, AC, 60 Hz.

11.2.2 The *Supplier* shall NOT supply the micro-stepping driver of the stepping motor.

11.2.3 The design of the frequency tuner shall NOT include the dynamic pressure compensator.

11.2.4 The frequency tuner shall be implemented by the *Supplier* with load cells (x2), tuner LVDT (x2), cavity LVDT (x2), potentiometer that are provided by NSRRC to the *Supplier*.

11.3 Movement of the frequency tuner:

11.3.1 The movement of the frequency tuner shall be smooth within the tuning ranges mentioned above.

11.3.2 The movement of the frequency tuner shall be carefully adjusted and aligned such that the frequency tuner will not move along a zigzag path or with a tilted angle with respect to the nominal path of the beam flight.

11.3.3 The movement of the frequency tuner with backlash or jumping within the tuning range shall be avoided.

11.3.4 The movement of the frequency tuner shall not cause inhomogeneous deformation of the vacuum beam-line bellows.

12. 15D RF monitor antenna (pick-up)

12.1 15D RF monitor antenna (pick-up) on the niobium cavity for measurement of the transmitted cavity field.

12.1.1 The *Supplier* shall supply the 15D RF monitor antenna (pick-up) for the niobium cavity and its RF cables inside the liquid-helium cryostat with SMA connectors.

12.1.2 The design of the 15D RF monitor antenna (pick-up) for the *500-MHz SRF Module for TPS* shall be identical to the one used for the *508-MHz SRF Module for KEKB*.

12.1.3 The antenna length of 15D RF monitor antenna (pick-up) shall be provided by NSRRC such that the external quality factor (Q_{tran}) of the 15D RF monitor antenna of the niobium cavity shall be in the range between $5\text{x}10^{10}$ and $2\text{x}10^{11}$. Consequently, the detected RF power is in the range 10^2 mW at 1.6 MV.

12.1.4 The rate of leakage of the 15D RF monitor antenna (pick-up) shall be less than $5 \cdot 10^{-9}$ mbar-L/s at room temperature.

12.2 The *Supplier* shall send sufficient manpower to support the installation of 15D RF monitor antenna into the niobium cavity and the liquid-helium cryostat at KEK.

12.3 Deleted.

13. Instrumentation for Monitoring, Protection, and Diagnosis

13.1 The design of the instrumentation monitoring system for monitoring, protection and diagnosis of the *500-MHz SRF Module for TPS* shall follow the design of the *508-MHz SRF Module for KEKB* as default.

13.2 The liquid-helium vessel, the niobium cavity, the high-power input coupler, the large and small thermal transition beam pipes, and the inlet and outlet pipes for liquid nitrogen should be implemented with sufficient (referring to Table II) temperature sensors.

13.3 Sufficient (referring to Table II) temperature sensors will be positioned near the heaters for the liquid-helium vessel and for the high-power input coupler.

13.4 Sufficient (referring to Table II) pin photo diodes shall be implemented on the outer surfaces of the niobium cavity, high-power input coupler, and liquid-helium vessel.

13.5 Sufficient (referring to Table II) heaters for the liquid-helium vessel and the high-power input coupler shall be implemented.

13.6 Sufficient (referring to Table II) vacuum pressure monitoring ports for the cavity, high-power input coupler, and vacuum vessel of the liquid-helium cryostat shall be available.

13.7 Sufficient (referring to Table II) ports for monitoring the pressure of helium gas for the liquid-helium vessel shall be available.

13.8 Sufficient (referring to Table III) ports for monitoring the water pressure, temperature and flow rate for the cooling water of the high-power input coupler, HOM dampers (x2), and vacuum beam-line tapers (x2) shall be available.

13.9 Sufficient (referring to Table II and Table III) liquid-helium level sensors (including in-situ spare) for the *500-MHz SRF Module for TPS* shall be implemented.

13.10 Sufficient amounts (not less than 6 sets) of feedthroughs (hermetic seal connector with at least 22 pins each) for interconnection of the wires and cables used for the *500-MHz SRF Module for TPS* to its exterior SRF electronics system (provided by NSRRC) shall be provided by the *Supplier* to match the port design. The *Supplier* shall provide a complete pair of feedthroughs, i.e. the male (female) ones will be implemented on the liquid-helium cryostat and the female (male) ones shall be delivered to NSRRC for external cabling.

13.11 NSRRC may request to enhance or to modify the instrumentation-monitoring system by equipping more or spare sensors, but the quantity of enhanced sensors shall not be more than 1 feedthrough and 10% of the total amount of sensors already requested in this *Technical Specification*. Otherwise, the *Supplier* is allowed to claim extra cost (overheads and profit) and time for *Supplier* to install these spare sensors.

13.12 Deleted.

13.13 The installation and wiring of these instrumentation sensors and devices can be undertaken by NSRRC under supervision of the *Supplier*. The *Supplier* shall notice NSRRC at least four weeks before the installation work is to be done. Refer to Items 20.1, 20.2, and 20.3 of this *Technical Specification*.

Table II-1: Monitoring list for the *500-MHz SRF Module for TPS* (Connector No.1 on liquid helium cryostat)

					Length(m)	Design by
Pin No.	Signal Item		Sensor	Lead wire	Sensor Lead wire	
A	Cavity heater in LHe vessel		Kapton heater 100 V x 300 W	ETFE filmed lead twist pair wire	3	KEK
B					3	
C	Cavity heater in LHe vessel(spare)		Kapton heater 100 V x 300 W	ETFE filmed lead twist pair wire	3	KEK
D					3	
E	no use					
F	no use					
G	Coupler heater 1		Kapton heater 100 V x **100 W**	ETFE filmed lead twist pair wire	3	KEK
H					3	
J	Coupler heater 2 (spare)		Kapton heater 100 V x **100 W**	ETFE filmed lead twist pair wire	3	KEK
K					3	
L	No use					
M	No use					
N	Coupler temp. 1 (middle)	CC+	CC JIS C1602-95 T class-2		3	KEK
P	Coupler temp. 1 (middle)	CC-				
R	Cavity heater temp.	CC+	CC JIS C1602-95 T class-2		3	KEK
S	Cavity heater temp.	CC-				
T	Cavity heater temp. (spare)	CC+	CC JIS C1602-95 T class-2		3	KEK
U	Cavity heater temp. (spare)	CC-				
V	Coupler Heater temp.	CC+	CC JIS C1602-95 T class-2		3	KEK
W	Coupler Heater temp.	CC-				
X	Coupler Heater temp. (spare)	CC+	CC JIS C1602-95 T class-2		3	KEK
Y	Coupler Heater temp. (spare)	CC-				

Table II-2: Monitoring list for the *500-MHz SRF Module for TPS* (Connector No.2 on liquid helium cryostat.)

				Length(m)		Design by
Pin No.	Signal Item	Sensor	Lead wire	Sensor	Lead wire	
A	PtCo1 Cryostat bottom temp.1 (near to LBP) 1 I+	PtCo Alloy resistance thermometer	ETFE filmed lead twist pair wire	1	3	KEK
B	2 I-			1	3	
C	3 V+		ETFE filmed lead twist pair wire	1	3	
D	4 V-			1	3	
E	PtCo2 Cryostat bottom temp.2 (near to SBP) 1 I+	PtCo Alloy resistance thermometer	ETFE filmed lead twist pair wire	1	3	KEK
F	2 I-			1	3	
G	3 V+		ETFE filmed lead twist pair wire	1	3	
H	4 V-			1	3	
J	PtCo3 Cryostat bottom temp.3 (near to SBP) (spare) 1 I+	PtCo Alloy resistance thermometer	ETFE filmed lead twist pair wire	1	3	KEK
K	2 I-			1	3	
L	3 V+		ETFE filmed lead twist pair wire	1	3	
M	4 V-			1	3	
N	PtCo4 Cavity top temp.1 1 I+	PtCo Alloy resistance thermometer	ETFE filmed lead twist pair wire	1	3	KEK
P	2 I-			1	3	
R	3 V+		ETFE filmed lead twist pair wire	1	3	
S	4 V-			1	3	
T	PtCo5 Cavity top temp.2 (spare) 1 I+	PtCo Alloy resistance thermometer	ETFE filmed lead twist pair wire	1	3	KEK
U	2 I-			1	3	
V	3 V+		ETFE filmed lead twist pair wire	1	3	
W	4 V-			1	3	
X	No use					
Y	No use					

Table II-3: Monitoring list for the *500-MHz SRF Module for TPS* (Connector No.3 on liquid helium cryostat.)

				Length(m)		Design by
Pin No.	Signal Item	Sensor	Lead wire	Sensor	Lead wire	
A	PtCo6 Cavity middle temp.1 1 I+	PtCo Alloy resistance thermometer	ETFE filmed lead twist pair wire	1	3	NSRRC
B	2 I-			1	3	
C	3 V+		ETFE filmed lead twist pair wire	1	3	
D	4 V-			1	3	
E	PtCo7 Cavity middle temp.2 (spare) 1 I+	PtCo Alloy resistance thermometer	ETFE filmed lead twist pair wire	1	3	NSRRC
F	2 I-			1	3	
G	3 V+		ETFE filmed lead twist pair wire	1	3	
H	4 V-			1	3	
J	PtCo8 Cavity bottom temp.1 1 I+	PtCo Alloy resistance thermometer	ETFE filmed lead twist pair wire	1	3	NSRRC
K	2 I-			1	3	
L	3 V+		ETFE filmed lead twist pair wire	1	3	
M	4 V-			1	3	
N	PtCo9 Cavity bottom temp.2 (spare) 1 I+	PtCo Alloy resistance thermometer	ETFE filmed lead twist pair wire	1	3	NSRRC
P	2 I-			1	3	
R	3 V+		ETFE filmed lead twist pair wire	1	3	
S	4 V-			1	3	
T	PtCo10 Coupler temp. down 1 1 I+	PtCo Alloy resistance thermometer	ETFE filmed lead twist pair wire	1	3	KEK
U	2 I-			1	3	
V	3 V+		ETFE filmed lead twist pair wire	1	3	
W	4 V-			1	3	
X	No use					
Y	No use					

Table II-4: Monitoring list for the *500-MHz SRF Module for TPS* (Connector No.4 on liquid helium cryostat.)

Pin No.	Signal Item		Sensor	Lead wire	Length(m) Sensor	Length(m) Lead wire	Design by
A	PtCo11 Coupler temp. down 2 (spare)	1 I+	PtCo Alloy resistance thermometer	ETFE filmed lead twist pair wire	1	3	NSRRC
B		2 I-			1	3	
C		3 V+		ETFE filmed lead twist pair wire	1	3	
D		4 V-			1	3	
E	PtCo12 Cryostat bottom temp.4 (near to LBP) (spare)	1 I+	PtCo Alloy resistance thermometer	ETFE filmed lead twist pair wire	1	3	NSRRC
F		2 I-			1	3	
G		3 V+		ETFE filmed lead twist pair wire	1	3	
H		4 V-			1	3	
J	LHe level meter 1	A I+	Liquid Helium Level Sensor	ETFE filmed lead twist pair wire		3	KEK
K		B I-				3	
L		C V+		ETFE filmed lead twist pair wire		3	
M		D V-				3	
N	LHe level meter 1 (spare)	A I+	Liquid Helium Level Sensor	ETFE filmed lead twist pair wire		3	KEK
P		B I-				3	
R		C V+		ETFE filmed lead twist pair wire		3	
S		D V-				3	
T	Coupler temp. (middle 1)	CC+	CC JIS C1602-95 T class-2		3.5		KEK
U		CC-					
V	Coupler temp. (middle 1) (spare)	CC+	CC JIS C1602-95 T class-2		3.5		NSRRC
W		CC-					
X	No use						
Y	No use						

Table II-5: Monitoring list for the *500-MHz SRF Module for TPS* (Connector No.5 on liquid helium cryostat.)

Pin No.	Signal Item		Sensor	Lead wire	Length(m) Sensor	Length(m) Lead wire	Design by
A	PtCo13 Cryostat bottom temp.5 (near to LBP) (spare)	1 I+	PtCo Alloy resistance thermometer	ETFE filmed lead twist pair wire	1	3	NSRRC
B		2 I-					
C		3 V+		ETFE filmed lead twist pair wire	1	3	
D		4 V-					
E	PtCo14 Cryostat top temp.1 (near to LBP)	1 I+	PtCo Alloy resistance thermometer	ETFE filmed lead twist pair wire	1	3	NSRRC
F		2 I-					
G		3 V+		ETFE filmed lead twist pair wire	1	3	
H		4 V-					
J	PtCo14 Cryostat top temp.2 (near to SBP)	1 I+	PtCo Alloy resistance thermometer	ETFE filmed lead twist pair wire	1	3	NSRRC
K		2 I-					
L		3 V+		ETFE filmed lead twist pair wire	1	3	
M		4 V-					
N	PIN 1	+	Si PIN photo diode	ETFE filmed lead twist pair wire	3		KEK
P		-					
R	PIN 2	+	Si PIN photo diode	ETFE filmed lead twist pair wire	3		KEK
S		-					
T	PIN 3	+	Si PIN photo diode	ETFE filmed lead twist pair wire	3		KEK
U		-					
V	PIN 4	+	Si PIN photo diode	ETFE filmed lead twist pair wire	3		KEK
W							
X	No use						
Y	No use						

Table II-6: Monitoring list for the *500-MHz SRF Module for TPS* (Connector No.6 on liquid helium cryostat.)

Pin No.	Signal Item		Sensor	Lead wire	Length(m) Sensor Lead wire	Design by
A	LN2 IN temp. 1	CC+	CC JIS C1602-95 T class-2		3	KEK
B		CC-				
C	LN2 IN temp.2 (spare)	CC+	CC JIS C1602-95 T class-2		3	NSRRC
D		CC-				
E	LN2 OUT temp. 1	CC+	CC JIS C1602-95 T class-2		3	KEK
F		CC-				
G	LN2 OUT temp. 2 (spare)	CC+	CC JIS C1602-95 T class-2		3	NSRRC
H		CC-				
J	Vacuum vessel LBP temp 1(near cavity)	CC+	CC JIS C1602-95 T class-2		3	NSRRC
K		CC-				
L	Vacuum vessel LBP temp 2(far cavity)	CC+	CC JIS C1602-95 T class-2		3	KEK
M		CC-				
N	Vacuum vessel SBP temp 1(near cavity)	CC+	CC JIS C1602-95 T class-2		3	NSRRC
P		CC-				
R	Vacuum vessel SBP temp 1(far cavity)	CC+	CC JIS C1602-95 T class-2		3	KEK
S		CC-				
T						
U						
V						
W						
X						
Y						

Table III-1: Monitoring list for the *500-MHz SRF Module for TPS* (instrumentation sensors and devices outside the liquid helium cryostat.)

Items	Sub-items	Signal Item	Type	Provider	Quantity
1		**Cavity Tuner**			
	1-1	Stepper motor	Stepper motor	Supplier	1
	1-2	Stepper motor driver		Supplier	1
	1-3	Tuner force (left & right side)	Load Cell	NSRRC	2
	1-4	Tuner LVDT	linear variable differential transformer (LVDT)	NSRRC	1
	1-5	Cavity LVDT	linear variable differential transformer (LVDT)	NSRRC	1
	1-6	Limit switch		Supplier	2
	1-7	Piezo-tuner		NSRRC	1
	1-8	Piezo-tuner power supply		NSRRC	1
	1-9	Potentiometer		NSRRC	1
2		**Cooling Water**			
	2-1	HOM outlet flow rate	water flow sensor	NSRRC	KEKB design
	2-2	RF coupler water outlet flow rate	water flow sensor	NSRRC	KEKB design
	2-3	Beam line taper water outlet flow rate	water flow sensor	NSRRC	2
	2-4	LBT HOM water inlet temperature	T-type Thermocouple	NSRRC	KEKB design
	2-5	LBT HOM water outlet temperature	T-type Thermocouple	NSRRC	KEKB design
	2-6	SBT HOM water inlet temperature	T-type Thermocouple	NSRRC	KEKB design
	2-7	SBT HOM water outlet temperature	T-type Thermocouple	NSRRC	KEKB design
	2-8	RF coupler water inlet temperature	T-type Thermocouple	NSRRC	KEKB design
	2-9	RF coupler water outlet temperature	T-type Thermocouple	NSRRC	KEKB design
	2-10	Vacuum beam line taper water inlet temp.	T-type Thermocouple	NSRRC	2
	2-11	Vacuum beam line taper water outlet temp.	T-type Thermocouple	NSRRC	2

Table III-2: Monitoring list for the *500-MHz SRF Module for TPS* (instrumentation sensors and devices outside the liquid helium cryostat.)

Items	Sub-items	Signal Item	Type	Provider	Quantity
	2-12	HOM water pressure	0-10 bara	NSRRC	KEKB design
	2-13	RF coupler water pressure	0-10 bara	NSRRC	KEKB design
	2-14	Beam line taper water pressure	0-10 bara	NSRRC	2
3		**Surface Temperature**			
	3-1	Gate valves (left & right)	T-type Thermocouple	NSRRC	2
	3-2	Beam-line tapers (left & right)	T-type Thermocouple	NSRRC	4
	3-3	Taper flanges	T-type Thermocouple	NSRRC	2
4		**Helium Pressure**			
	4-1	Helium vessel bath pressure	0-30 psia	NSRRC	2
	4-2	Helium vessel bath pressure (manometer)	0-1000 torr,abs	NSRRC	1
	4-3	Helium vessel bath pressure switch	0-15 psig	NSRRC	1
	4-4	RF coupler helium gas pressure	0-15 psig	NSRRC	2
	4-5	RF coupler helium gas pressure switch	0-15 psig	NSRRC	1
5		**LN2 Pressure**			
	5-1	LN2 Pressure	0-6 barg	NSRRC	2
6		**Helium gas flow meter**			KEKB design
7		**Coupler arc detector**			KEKB design
8		**Accessories**			
		ETFE insulated lead wire	ETFE Insulated lead wire	NSRRC	KEKB design

14. Mechanical Supports

14.1 The *Supplier* shall supply the mechanical supports for the *500-MHz SRF Module for TPS* including two mechanical supports of the HOM dampers, vacuum beam-line tapers, vacuum pumps on tapers and vacuum gate valves of the vacuum beam-line components.

14.2 The design of the mechanical supports for the *500-MHz SRF Module for TPS* shall follow their original design for the *508-MHz SRF Module for KEKB* but with modifications necessary to fit the interface requirements for operation at TPS.

14.3 The mechanical support for the *500-MHz SRF Module for TPS* shall allow the beam axis of the *500-MHz SRF Module for TPS* to be manually adjustable (fine adjustment) at a beam height 1350 ±10 mm in the vertical (gravitational) direction, ±5 mm in the horizontal direction, and ±5 mm in the longitudinal (beam) direction with a resolution better than 0.1 mm (±0.05 mm). A gross adjustment shall be available in a separate manner.

14.4 The mechanical support for the *500-MHz SRF Module for TPS* shall include, or be able to be added, 360^{o} rotatable wheels for movement.

14.5 The mechanical support for the *500-MHz SRF Module for TPS* shall be able to be mounted rigidly on the ground in its test or operational area.

14.6 The *500-MHz SRF Module for TPS* shall include the supporting rings for the use of a crane or crane attachments for lifting. The design of the supporting rings or crane attachments shall take into consideration the force balance. The longitudinal center of gravity of the whole *500-MHz SRF Module for TPS* shall be marked.

15. Cryogenic Safety-relief Valves

15.1 The *Supplier* shall provide NSRRC with the report of the design calculations of the liquid-helium cryostat for the purpose of cryogenic safety.

15.2 The design of safety-relief valves for the *500-MHz SRF Module for TPS* shall be based on the design for the *508-MHz SRF Module for KEKB*.

15.3 The *Supplier* shall supply the safety-relief valve (0.03 MPa working pressure) for the helium vessel, rupture disk (0.098 MPa working pressure) for the helium vessel, and pop-off-type relief valve for the vacuum vessel of the liquid-helium cryostat for the *500-MHz SRF Module for TPS*. Note that 0.03 MPa = 0.3 bar = 4.351 psi and 0.098 MPa = 0.98 bar = 14.214 psi. The maximum allowed operational pressure of the *500-MHz SRF Module for TPS* is 19.05 psia.

15.4 The *Supplier* shall perform functional tests of the cryogenic safety-relief valves and report the results with photographs to NSRRC. The test procedure shall be described in details.

16. Transport and Shipping to KEK

16.1 The *Supplier* shall take full responsibility for the transport, delivery and insurance of the products for the *500-MHz SRF Module* from the *Supplie*r’s factory to the KEK Job Site for surface treatment, various tests and system integration and testing. The *Supplier* shall guarantee any product of the *500-MHz SRF Module for TPS* to be free of damage during the transport.

17. Re-assembly of the Liquid-helium Cryostat at KEKB

17.1 The assembly of the liquid-helium cryostat with the surface-treated niobium cavity will be undertaken at KEK under the supervision of KEK experts.

17.2 The *Supplier* shall guarantee the transport of the liquid-helium cryostat and the niobium cavity at KEK.

17.3 The *Supplier* shall assemble the liquid-helium cryostat including assembled parts of the cavity and thermal-transition pipes, liquid-helium vessel, super-insulation, thermal shield with liquid nitrogen, magnetic shield, helium supply and return tubes, and vacuum vessel. The *Supplier* shall undertake the fine adjustment at KEK.

17.4 Deleted.

17.5 The *Supplier* shall be able to use the assembly area at KEK gratis according to the Agreement on *Technology Transfer from KEK to NSRRC*.

17.6 Moved to Item 17.9.

17.7 Deleted.

17.8 The second *High-pressure Test* shall be applied after inserting the clean niobium cavity into the liquid-helium cryostat of the *500-MHz SRF Module for TPS*. The cavity will be at warm during the second *High-pressure Test.* The maximum testing pressure during the second *High-pressure Test* is 100 % of the maximum allowed operational pressure, 1.313 bara.

17.8.1 Neither buckling nor observable creep nor inelastic deformation shall be allowed during the second *High-pressure Test*.

17.8.2 The rate of vacuum leakage shall be measured before and after the second *High-pressure Test*. The vacuum leakage shall NOT be observed.

17.8.3 The cavity resonance frequency shall be measured before and after the second *High-pressure Test*. No drift of the cavity resonance frequency more than 10 kHz shall be observed.

17.9 The *Supplier* shall dismantle the inner conductor of the high-power input coupler and doorknob after the cryogenic liquid-helium test at KEK. The *Supplier* shall pack these items separately. NSRRC shall re-assemble the inner conductor and doorknob at NSRRC.

18. Cryogenic Liquid-Helium Test at KEK

18.1 The *Supplier* shall provide sufficient (referring to Item 1.2 of this *Technical Specification*) manpower to support the following operation at KEK:

18.1.1 Tests of vacuum leakage after re-assembly of the liquid-helium cryostat at KEK

18.1.1.1 The rate of leakage shall be smaller than $5 \cdot 10^{-9}$ mbar-L/s at room temperature.

18.1.2 Liquid nitrogen and helium cooling with continuous testing of vacuum leakage.

18.1.3 Cryogenic liquid-helium test (low-power RF measurement for cavity resonance frequency and external coupling coefficient (Q_{ext}), functionality test of the frequency tuner, measurements of cryostat heat loss, tests of vacuum leakage, functional testing of instrumentation);

18.1.4 Warming of the liquid-helium cryostat to room temperature with testing of vacuum leakage.

18.2 The functionality of instrumentation shall be verified before the cooling (at room temperature), after cooling (at liquid-helium temperature), and after warming (at room temperature).

18.2.1 The functionality of the liquid-helium level, heater for the liquid-helium vessel, heater for the high-power input coupler, pin photo diodes, and the cryogenic temperature sensors shall be verified.

18.2.2 The functionality of the spare liquid-helium level, spare heater for the liquid-helium vessel, the spare heater for high-power input coupler and the spare cryogenic-temperature sensors shall be verified.

18.3 The *Supplier* shall NOT guarantee the connection of the *500-MHz SRF Module for TPS* and cryogenic transfer-lines.

18.4 The cryogenic static loss of the *500-MHz SRF Module for TPS* will be measured with the rate of helium consumption and shall be less than 35 W at 4.2 K or 4.5 K.

18.5 The external quality factor (Q_{ext}) of the *500-MHz SRF Module for TPS* shall be measured with the niobium cavity at 4.2 K or 4.5 K and shall be within the target value required by NSRRC with an acceptable tolerance ±10%.

18.6 The external quality factor (Q_{tran}) of the D15 RF pickup monitor antenna (pick-up) for the niobium cavity of the *500-MHz SRF Module for TPS* shall be measured and shall be in the range between $5\text{x}10^{10}$ and $2\text{x}10^{11}$ such that the detected RF power is the range 10^2 mW at 1.6 MV.

18.7 The *Supplier* shall provide sufficient (referring to Item 1.2 of this *Technical Specification*) manpower to support the cryogenic helium-test at KEK.

19. Governing Standard and Laws

19.1 All components shall be governed by the Japanese Industrial Standard (JIS).

20. Supplies from NSRRC

20.1 If the installation and wiring of the instrumentation sensors and devices will be done by the *Supplier*, the *Supplier* shall confirm the connection of the items provided by NSRRC by visual inspection and continuity test before and after their installation. Refer to Item 13.13 of this *Technical Specification*.

20.2 The *Supplier* shall properly install the items provided by NSRRC into the liquid-helium cryostat for the *500-MHz SRF Module for TPS*. Refer to Item 13.13 of this *Technical Specification*.

20.3 Fully functional spare units in situ of cryostat heaters, monitoring transducers for cryogenic temperatures, monitoring transducers for the liquid-helium level will be provided by NSRRC, and the *Supplier* is responsible for their installation into the *500-MHz SRF Module for TPS*. Refer to Item 13.13 of this *Technical Specification*.

20.4 NSRRC shall prepare and set up the following items at NSRRC:

20.4.1 RF plant, low-level RF system, in-air RF feed-line (waveguide) at NSRRC;

20.4.2 cryogenic plant, SRF valve box, cryogenic transfer-lines between the SRF valve box and the *500-MHz SRF Module for TPS*;

20.4.3 electronics for window arc detection;

20.4.4 quench detector;

20.4.5 cryogenic load leveler;

20.4.6 monitoring transducers for rates of water flow and water temperature;

20.4.7 monitoring transducers for surface temperatures of associated vacuum beam-line components;

20.4.8 tuner signal converter and tuner circuit board, instrumentation required for the frequency-tuning system (load cells transducers, LVDT, potentiometers);

20.4.9 ion pumps for vacuum beam-line components;

20.4.10 vacuum interlock module, and

20.4.11 ball valve, flow meter, temperature sensor, ultra-low-pressure check valve for helium cooling gas for the high-power input coupler.

21. Transport and Shipping to NSRRC

21.1 The *Supplier* shall take full responsibility for the transport, delivery and insurance of all components of the *500-MHz SRF Module for TPS* to the NSRRC Job Site. The *Supplier* shall guarantee any product of the *500-MHz SRF Module for TPS* to be free of damage during transport.

21.1.1 The *Supplier* shall send the HOM dampers, vacuum beam-line tapers, vacuum beam-line bellows, and their mechanical supports for the

500-MHz SRF Module for TPS to NSRRC.

21.1.2 The *Supplier* shall send the dismantled inner conductor of the high-power input coupler and doorknob for the *500-MHz SRF Module for TPS* to NSRRC.

21.1.3 The *Supplier* shall send the assembled liquid-helium cryostat for the *500-MHz SRF Module for TPS* to NSRRC.

21.2 Deleted.

21.3 NSRRC shall take full responsibility for obtaining import licenses.

21.4 The *Supplier* shall guarantee the packing for export.

21.5 The *Supplier* shall prepare a shipping plan (as part of the *Monthly Progress Report*) with detailed shipping items and information about forwarders (selected by the *Supplier*) at least one (1) month before shipment of the *500-MHz SRF Modules for TPS* or their sub-components to NSRRC for obtaining the import licenses.

21.6 The *500-MHz SRF Modules for TPS* and their sub-components might be sensitive to shock and vibration.

21.6.1 Fragile items shall be specially protected from vibration and acceleration during shipment through the use of special shipping brackets. Special transport arrangements shall be made for the shock- or vibration-sensitive components. The equipment must be packed properly and protected with shock-absorbing material.

21.6.2 One continuously recording shock detector (for which the G-factor can be set manually) shall be mounted on the base, and two permanent tilt indicators shall be attached to the shipping crate by the *Supplier*.

21.6.3 The *Supplier* shall report to NSRRC the recording log within one (1) month after transport and delivery (as part of a *Monthly Progress Report*).

21.7 Overland transport shall be effected with an air-ride van (e.g. a furniture-moving van); rail transport is prohibited.

21.8 Oversea shipment in hermetically sealed plastic bags filled with dry gaseous nitrogen shall be used for internal package to prevent corrosion and to maintain cleanliness.

21.9 All items heavier than 30 kgw shall have lugs to permit lifting into place. All special lifting gear, such as lift rings, shall be furnished by the *Supplier*. Special lifting gear required for maintenance shall be made part of the equipment supply.

21.10 All shipping containers shall be marked or tagged with the following information:

21.10.1 NSRRC purchase order number,
21.10.2 Shipping address as specified within the *Contract*;
21.10.3 *Supplier*'s name;
21.10.4 Components contained within each package;
21.10.5 Weight and size of each package;
21.10.6 'Top-side up' if applicable, and 'Fragile' if applicable.

22. High-Power RF Test at NSRRC

22.1 NSRRC will perform the *High-Power RF Test* for the *500-MHz SRF Module for TPS* at cryogenic temperature at NSRRC. The target of the *High-Power RF Test* for the *500-MHz SRF Module for TPS* is as follows.

22.1.1 The RF loss is NOT larger than 30 W at V_c of 1.6 MV, CW, with $Q_0 \geqq 1.0\text{x}10^9$.

22.1.2 The RF loss is NOT larger than 135 W at V_c of 2.4 MV, CW, with $Q_0 \geqq 5\text{x}10^8$.

22.2 Preparation for *High-Power RF Test* of the *500-MHz SRF Module for TPS* will be done at NSRRC as follows.

22.2.1 NSRRC will assemble, bake (at NSRRC) and test the leakage of the associated vacuum beam-line components for the *500-MHz SRF Module for TPS* at NSRRC.

22.2.2 NSRRC will attach the associated vacuum beam-line components (the pre-assembled units) to the liquid-helium cryostat for the *500-MHz SRF Module for TPS* at NSRRC.

22.2.3 NSRRC will re-install the inner coaxial of the high-power input coupler into the liquid-helium cryostat for the *500-MHz SRF Module for TPS* at NSRRC.

22.2.4 NSRRC will measure the RF resonance frequency and coupling coefficient or external quality factor (Q_{ext}) of the *500-MHz SRF Module for TPS*. The measurement results shall be identical to those tested at KEK to demonstrate freedom from damage during transport.

22.2.5 NSRRC will pump the *500-MHz SRF Module for TPS* and perform comprehensive tests of leakage. The results of these leakage tests shall be identical to those tested at KEK to demonstrate freedom from damage during transport.

22.2.6 NSRRC will complete the cryogenic piping and cabling or wiring for cryogenic operation of the *500-MHz SRF Module for TPS* at NSRRC.

22.2.7 NSRRC will complete the waveguide piping and cabling or wiring for the high-power RF operation of the *500-MHz SRF Module for TPS* at NSRRC.

22.2.8 NSRRC will complete the installation of the water-cooling systems for HOM loads, the high-power input coupler, and the vacuum beam-line tapers to the *500-MHz SRF Module for TPS*.

22.2.9 NSRRC will perform the high-power RF processing for the high-power input couple of the *500-MHz SRF Module for TPS* at room temperature.

22.2.10 NSRRC will perform the cooling for the *500-MHz SRF Module for TPS* with various cryogenic liquid-helium tests at NSRRC.

22.2.11 NSRRC will perform the high-power RF processing for the high-power input couple and for the niobium cavity of the *500-MHz SRF Module for TPS* at cryogenic temperature.

22.2.12 The *Supplier* shall supervise the installation of the inner coaxial of the high-power input coupler, attachment of the associated vacuum beam-line components (the pre-assembled units) to the liquid-helium cryostat, and the high-power RF test of the *500-MHz SRF Module for TPS* at NSRRC.

22.3 Deleted.

22.4 The *Supplier* shall be fully responsible for the vacuum tightness of the liquid-helium cryostat (including its cryogenic piping and connection inside the liquid-helium cryostat) for the *500-MHz SRF Module for TPS* operating at cryogenic temperature or after thermal cycling whenever the vacuum sealing was done by the *Supplier* <u>(neither by KEK nor by NSRRC)</u>. The *Supplier* shall not take the responsibility for any damage or defect of the *500-MHz SRF Module for TPS* resulting from improper storage, handling or instillation by NSRRC after DDU delivery by the *Supplier*.

22.5 The *Supplier* shall be fully responsible for the cryogenic static loss of the *500-MHz SRF Module for TPS* to be measured with the rate of helium consumption. The cryogenic static loss should be less than 35 W at 4.5 K. The *Supplier*'s warranty shall exclude any defects in design provided either by KEK or NSRRC.

23. Spare Parts as Default

23.1 The *Supplier* shall supply spare parts as default within the *Contract*.

23.2 The spare parts as default for the *Contract* of three (3) sets of *500-MHz SRF Module for TPS* ordered by NSRRC include the following items:

23.2.1 one (1) set of RF-tested HOM dampers;

23.2.2 one (1) set of RF-conditioned inner coaxial for the high-power input coupler;

23.2.3 one (1) set of 15D RF monitor antenna (pick-up) for the niobium cavity;

23.2.4 six (6) sets of rupture disk (0.098 MPa working pressure) for the liquid-helium vessel;

23.2.5 three (3) sets of female and male bayonet joints for cryogenic connection between the *500-MHz SRF Module for TPS* and the SRF valve box;

23.2.6 nine (9) complete sets of spare nuts, bolt and stubs used for assembly of the liquid-helium cryostat for the *500-MHz SRF Module for TPS*, and

23.2.7 three (3) complete sets of vacuum seals used for vacuum sealing of the liquid-helium cryostat for the *500-MHz SRF Module for TPS* if the property of vacuum seals can be maintained more than one (1) year. The *Supplier* shall provide the detailed vendor information (including contact persons and e-mail addresses) of various vacuum seals (including U-type sealing) used for the *500-MHz SRF Module for TPS*.

24. Spare Parts as Options

24.1 The *Supplier* shall provide separate quotations for spare parts as options as follows:

24.2 one (1) set of spare niobium cavity (w/o thermal-transition beam tubes) ready for insertion into the liquid-helium cryostat for any *500-MHz SRF Module for TPS* for cryogenic testing. This spare niobium cavity shall be correctly tuned for the frequency, high-pressure-tested, surface-treated, vacuum-annealed, vacuum-baked, vertical-tested, and properly vacuum-sealed.

24.3 one (1) set of test niobium cavity. This test niobium cavity will be used for an initial test run of the mechanical production of the niobium cavity before manufacture of niobium cavities for the *500-MHz SRF Modules for TPS*. The *Supplier* shall NOT guarantee the final performance of this testing niobium cavity. NSRRC is the owner of this test niobium cavity.

25. Quality Assurance, Quality Control, and Monthly Progress Report

25.1 Technical discussion among KEK experts, representatives of the *Supplier*, and representatives of NSRRC shall proceed on a regular basis mainly at KEK during execution of the *Contract*.

25.2 The *Supplier* is responsible to inform NSRRC immediately when a delay occurs of completion of any major action item or milestone by more than three (3) months.

25.3 After the award of the *Contract*, the *Supplier* shall submit regularly to NSRRC the *Monthly Progress Reports* via e-mail communication describing a summary of the progress made during the preceding month on or before the fifth business day of every calendar month until the end of the *Contract*. *Monthly Progress Reports* will include the following content:

25.7.3.1 most updated production schedule;

25.7.3.2 status of long-lead purchasing items;

25.7.3.3 minutes of meetings during the preceding month;

25.7.3.4 approval of application drawings during the preceding month;

25.7.3.5 results of various tests, inspections, dimension measurements, RF processing, and calculations of major components during the preceding month;

25.7.3.6 working plan including major action items and milestones for delivery of the *500-MHz SRF Module for TPS* to proceed in the coming month;

25.7.3.7 response to concerns and questions by NSRRC, and

25.7.3.8 other relevant issues regarding the manufacture of the *500-MHz SRF Module for TPS*.

25.4 Receiving and confirming the messages describing the *Monthly Progress Reports* shall not release the *Supplier* from its responsibility to correct errors, oversights and omissions to ensure conformity to this *Technical Specification*.

25.5 An electronic form in Adobe Acrobat format is selected for the *Monthly Progress Reports*.

26. Engineering Review Meeting

26.1 The *Supplier* shall be responsible to hold an *Engineering Review Meeting* at NSRRC. NSRRC will invite the KEK experts to participate in this meeting.

26.2 The *Supplier* shall deliver the Report of the Engineering Review (part of *Monthly Progress Reports*) to NSRRC at least two (2) weeks before the *Engineering Review Meeting* to be held at NSRRC.

26.3 The items that will be presented by the *Supplier* in the *Engineering Review Meeting* shall include, but be not limited to,

26.3.1. the conceptual design of the *500-MHz SRF Module for TPS* with block diagram and major components,

26.3.2. a mechanical layout diagram of all components including dimensions,

26.3.3. the performance specifications and procedure of test items, which shall be undertaken at the *Supplier*'s premises, at KEK, or at NSRRC,

26.3.4. the survey and alignment procedure for the niobium cavity and liquid-helium cryostat,

26.3.5. the timetable, manpower, and status of manufacturing,

26.3.6. the plan of the *Factory Acceptance Tests*,

26.3.7. the working plan of *Vertical Test* at KEK,

26.3.8. the working plan of HOM dampers at KEK,

26.3.9. the working plan of high-power input coupler at KEK,

26.3.10. the working plan of system integration at KEK,

26.3.11. the interfaces between NSRRC and *Supplier*,

26.3.12. a name list and pin-assignment of the analog monitoring signals,

26.3.13. the order of long-lead items,

26.3.14. the requirements of water quality, inlet water pressure, outlet water pressure and tube diameters of the inlet and outlet of the cooling-water manifold for operation of the *500-MHz SRF Module for TPS*, and

26.3.15. detailed plans of transport and installation.

26.4. The conclusions of the *Engineering Review Meeting* will be drafted by the *Supplier* and made under agreement by both parties and will become part of the *Monthly Progress Reports*.

27. Documents

27.1 The *Supplier* shall present the following documents in English language:

27.1.1 *Monthly Progress Reports;*

27.1.2 final report of the *Engineering Review Meeting* held at NSRRC;

27.1.3 mechanical final layouts and mechanical final drawings of major components (approved drawings in their latest version);

27.1.4 pin assignments and lists of analog signals;

27.1.5 inspection procedures and measurement results for main components;

27.1.6 installation instruction and procedure;.

27.1.7 alignment procedure, and

27.1.8 trouble-shooting lists and procedure for mechanical and vacuum trouble.