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To whom it may concern

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Review of the Slow Positron Facility (SPF) and the Surface Science Section (SSS) of the Photon Factory (PF) at KEK by the Scientific Advisory Committee of the Institute of Materials Structure Science (IMSS-SAC)

The Review is organized by referring to both SPF and SSS according to six questions provided to the IMSS-SAC.

1. How does the SAC evaluate the scientific activities and research outputs of the SPF and SSS?

The scientific experiments performed at the SPF and within the SSS at IMSS cover a very broad variety of research projects ranging from fundamental physics over surface and solid state physics to applied physics and materials science. The forefront research of the researchers working at these facilities is presented in numerous scientific publications in high-ranked journals as well as at international conferences and workshops.

As one of the world leading positron research centers SPF at IMSS is well recognized and has an excellent scientific reputation. The team at SPF with collaborators pioneered various powerful techniques in applied physics and in fundamental research. Just to name two: they developed total-reflection high-energy positron diffraction (TRHEPD) for surface structure analysis with outstanding surface sensitivity, and they efficiently produce the Positronium negative ion – a bound leptonic three-particle system – as prerequisite for the generation of an energy variable low-energy Positronium beam in ultra-high vacuum. Recent activities and scientific achievements, which lead to 12 publications between 2018 and 2020, cover surface structure determination, developments of new experimental techniques as well as Positronium physics.

The SSS operates various state-of-the-art x-ray instruments at different beamlines (BLs) of the photon factory (PF). It has to be emphasized that the SSS has been developed novel powerful techniques based on x-ray absorption spectroscopy (XAS). These are depth-resolved XAS allowing the observation of, e.g., oxidation as function of depth and interface related phenomena as well as wavelength-dispersive soft XAS to study electrochemical reactions in operando. The high-quality scientific outcome is published in an impressively large number of publications. The scientific findings were obtained with analysis of surfaces and interfaces as well as photo-electron spectroscopy (BL-2A/B: 57 papers in the years 2018-2020), soft x-ray spectroscopy (BL-7A: 35 papers), variable polarization soft x-ray spectroscopy (BL-16A: 63 papers), and ultraviolet angle- resolved photo-emission spectroscopy (BL-28A/B: 23 papers).

In total, the achievements made and partially published in top-ranked journals demonstrate unquestionable the great scientific status of the SPF and the SSS.

2. How does the SAC evaluate the development of facilities and experimental techniques?

The research groups at SPF and the SSS have a longstanding expertise in the development of pioneering advanced experimental techniques. Both the development of the beam facilities and the experimental techniques, which cover a wide range of fields, are evaluated exceptional high since they lead to a broad scientific impact.

At SPF various techniques are available for fundamental research (laser cooling and time-of-flight experiments with Positronium) as well as for surface structure analysis with total-reflection high-energy positron diffraction (TRHEPD) and low-energy positron diffraction (LEPD). The team at SPF succeeded in setting up a new LEPD apparatus and demonstrating its power by recording first diffraction patterns. By enabling both complementary positron diffraction techniques TRHEPD and LEPD, SPF provides the world's forefront positron research for surface structure analysis with topmost layer sensitivity. Besides the intensity increase (see Section 5) a pulse stretcher with a Penning–Malmberg trap was implemented in order to extend the pulse width from 1.2 µs to ~20 ms. This great increase by more than four orders of magnitude (!) was demonstrated to be essential to avoid pile-up events and saturation effects in the detection systems for positron diffraction experiments.

For surface science, a broad variety of experimental methods is available in the SSS comprising photoemission spectroscopy (PES), soft XAS, soft x-ray magnetic circular dichroism (XMCD) as well as polarized neutron reflectivity (PNR). The x-ray techniques are well embedded in the instrument suite available at the PF at IMSS. Within the SSS a major step forward has been a recently developed device which allows the sample transfer without exposing them to air. Such a system is of highest importance since it allows the application of complementary surface analysis techniques at the same prepared samples under extreme vacuum conditions.

3. Are the SPF and the SSS functioning as a hub through cooperation with users?

Both SPF and SSS accommodate various user experiments as well as in-house own scientific research. In total, about 3000 hours/year of beamtime is allocated to users. It is noteworthy that more than ~110 experimental proposals per year (2017-2019), and – despite the Covid19 pandemic – still 1100 proposals have been realized in the FYs 2020 and 2021.

Strong and very skilled in-house research groups with well-recognized scientific reputation (as it is given here; see Section 1) is of outmost importance to attract excellent external scientists.

Given this valuable basis for forefront collaborative research, a potential increase of positron beamtime at the SPF and for experiments in the SSS would further foster the interaction and cooperation with top-researches of the international scientific user community.

4. Are the SPF and SSS moving in the right direction? Are the future prospects adequate?

Both SPF and SSS have demonstrated their ability to pioneer new experimental techniques and to apply them in forefront research in surface science physics and fundamental physics. By this and with state-of-the-art methods top-users are attracted for forefront experiments that in turn lead to a great number of publications.

By pursuing the ambitious goal to upgrade the slow positron facility with a 100-fold increase in beam intensity the positron beam experiments at SPF are expecting an exciting future with novel applications in surface science and fundamental physics. Examples will be time-resolved observation of surface structure variations and the investigation of functional materials with positron microbeams. The cooperation of SPF and SSS at the PF is expected to be beneficial to IMSS and KEK as a whole. Due to their characteristic probing depth (from 0.1 to 100 nm from the surface) and interaction with matter the combination of complementary techniques using various quantum beams (synchrotron radiation, slow positrons, neutrons, and muons) provides a unique tool box to study novel functional materials and thin film devices. This "multi-probe approach" with advanced experimental techniques allows the investigation of various aspects such as atomic arrangement, chemical and electronic states, as well as magnetic phases. For this reason, the future prospects are estimated to be fully adequate.

5. In particular, how does the SAC evaluate the upgrade plan of SPF?

Although changing of targets at linacs is usually challenging – due to activation of components, limited access etc. – the team at SPF has already installed a newly designed converter and positron moderator in 2020. By implementing a sophisticated geometry, the new positron source at the 50 MeV-linac provides a stable positron beam with an energy of up to 35 keV energy and improved intensity of 10^8 low-energy positrons per second. This excellent upgrade on its own has been a great achievement.

For the near future, it is planned to increase the power of the Linac that in turn would enable an increase in positron beam intensity by two orders of magnitude. With state-of-the-art high-gradient accelerators and the high-intensity positron source developed at IMSS this project could be realized within a few years. Although this goal seems ambitious, this intensity upgrade would make SPF the world's most intense pulsed positron beam facility.

This upgrade plan is evaluated extremely high: it would not only lead to an exceptional increased signal-to-noise ratio and tremendously reduced measurement time in state-of-the-art experiments but also enable breakthroughs in research fields of surface science and fundamental physics by applying novel positron beam techniques. Numerous techniques – e.g., surface structure analysis by positron diffraction, time-resolved measurements, generation of a microbeam, and in-operando experiments – would considerably profit from the upgraded SPF. Consequently, the planned upgrade would open up new research fields in surface and interface physics by using low-energy positrons.

6. Any other comments for the SPF and SSS ?

All lab experiments using ^{22}Na as positron source rely on the availability of such beta sources provided by a single supplier worldwide. For this reason, the availability of positron beams, which do not dependent on ^{22}Na – e.g., positrons generated at linacs, is of utmost importance for the scientific community. In addition, after the upgrade SPF would provide a positron beam intensity several orders of magnitude higher compared to standard ^{22}Na based beam setups.

The continuous operation and planned developments at SPF and SSS are guaranteed by highly skilled scientific and technical staff. The number of group members, however, seems to be small. Therefore, it is recommended to support the present experienced team by additional scientific staff to further strengthen the SPF and the SSS at IMSS as centers of excellence in the future.