Chapter 1

Executive Summary

We propose upgrading the SPring-8 light source in the year 2019 in order to advance promising science and to support industrial innovations that will improve our life and contribute to a more sustainable society. The upgrade is expected to bring fundamental changes to photon science by providing (1) the highest ever brilliance and user capacity via unprecedented throughput, and (2) a unique combination with the X-ray Free Electron Laser (XFEL), SACLA. Further, the outstanding capabilities of the X-ray light source will be delivered within a highly energy-efficient facility. New scientific research enabled by the upgrade will be indispensable for developing sciences and technologies as well as creating new industrial fields that will solve diverse problems affecting human health, energy consumption, and other critical issues.

Photon science has contributed to a wide spectrum of fields in science, technology, culture and other areas. Taking advantage of its high brilliance and the short wavelength X-rays from a storage ring, scientists have been able to determine microscopic structures of functional materials and bio-molecules, which are indispensable for today's society. Because current observations are limited to certain layers of hierarchy in the key materials, our current knowledge is insufficient to create elaborate designs for advanced functional materials and for the development of versatile drugs. Demands for such functional materials have been increasing and will grow even faster due to the strong desire for a more "green" society. One sought-after key technology is self-organizing material fabrication with a low energy cost and high efficiency. Development of this technique is urgent but relies upon quick screening and precise determination of the structure and the dynamics of the synthesized materials. Current drug design, on the other hand, is facing difficulties because only the "static" structures of target proteins have been available. More efficient drug design requires a deeper understanding of the "dynamic" interactions among multiple proteins and on their temporal fluctuations. Further, a new scientific approach is needed that reveals valuable information from inhomogeneous systems since the methodologies currently used at synchrotron radiation facilities rely too much on the purity of materials under investigation. To accomplish these breakthroughs, it is extremely important to illuminate high brilliant coherent X-ray beams on such systems so that the hierarchy and dynamics of these systems can be determined. This is why we strongly urge the upgrade of the SPring-8 light source.

SPring-8, the third generation light source, has served as one of the most powerful and reliable X-ray light sources in the world. Since operations started in 1997, a great number of achievements have been accomplished in both scientific and technological fields at the site. Moreover, SPring-8 has been one of the major pioneers in industrial uses for the light source, with beamlines dedicated to industrial applications. The performance of the light source has been continuously updated, achieving electron emittance of 3.4 nm.rad and brilliance in the order of 10^{20} [photons/sec/mm^2/mrad^2/0.1% B.W.] in the hard X-ray region. While users take full advantage of the performance from the third generation light source, they increasingly demand even higher performance in order to remain competitive with their research and innovation. Such demands are obviously common worldwide and several other new light sources have been constructed, some of which already exceed or plan to exceed the current emittance capabilities of SPring-8.

Our main goal is to provide world-leading brilliance by bringing the SPring-8 storage ring into a new *"ultimate"* configuration in order to best meet future scientific requirements. The ultimate storage ring, i.e., one in which the electron beam emittance reaches the diffraction limits of X-rays, would produce orders of magnitude higher brilliance and a higher degree of coherence than any existing storage ring. Such a high quality beam would certainly lead to significant scientific and social impacts as discussed in Chapters 2 to 4. Yet, it is worth noting that the energy consumption of the new facility would be less than that of the current SPring-8 facility, and existing resources, such as buildings, facilities, and equipment, would effectively be reused. In summary, the SPring-8 upgrade plan aims to achieve *an ultimate-performance energy-effective facility*. From the perspective of user experiments, major characteristics of the ultimate storage ring are: 1) The new ring would produce 1,000 times higher brilliance than the current SPring-8, and would significantly reduce the time and cost for experiments. 2) The increase in the degree of coherence would expand applications based on the coherent nature of light. The coherent X-ray imaging would allow observations of interacting systems in various length scales with a resolution, in principle, of an X-ray wavelength. 3) A short X-ray pulse option of around one pico-second would allow us to explore time domain studies with a wide range of time scales. SPring-8 after the upgrade would definitely open frontiers of new methodologies required for the future. Consider two orientations of scientific research as examples. First, the upgraded SPring-8 would have no equal for the comprehensive understanding of the hierarchy of interacting and inhomogeneous systems in science using coherent X-ray imaging and time-domain studies. Second, in a similar manner, there would be no other facility other than the upgraded SPring-8 better suited for statistical analysis using X-rays for understanding the fundamental individual differences in the diversity of nature.

In 2011 the Japanese XFEL (SACLA) achieved successful lasing, and in 2012 user operations will commence. The roles for SACLA and the upgraded SPring-8 are clear since these two ultimate light sources are dedicated to completely different applications. The synergetic use of the two world-leading light sources will lead us to fruitful scientific frontiers by allowing an accumulation of complementary knowledge of scientific objects. First, SACLA enables ultra-fast measurements and atomic-resolution snapshots of local structures due to its high peak brilliance and femto-second pulse widths. While measurements using SACLA may severely damage samples, the peak brilliance of the upgraded SPring-8 would be orders of magnitude less, below the destruction threshold, but with an average brilliance still sufficiently high. Such performance of the upgraded SPring-8 would enable non-destructive or repeated data-accumulation on individual samples with an extremely short exposure time, complementarily to the measurements using SACLA. Second, SACLA offers an opportunity to investigate highly excited states in relatively simple matter samples, while the upgraded SPring-8 would be well-suited for the study of complex systems in the ground or at lower excited states. In addition to the separate use of the two facilities, X-ray (SACLA) pump-X-ray (SPring-8) probe experiments are planned to explore fundamental physics in the X-ray-excited states and their relaxation processes in matters. Thus, not only would the two world-leading light sources produce important results independently, the combination of the two would provide brand-new opportunities for future research in photon science.

The cost range of the upgrade is expected to be approximately 40 billion Japanese yen. This includes the upgrade of the storage ring, insertion devices, and beamlines. The existing buildings, including the accelerator tunnel and beamline hutches, would be reused in order to contain the total budget. The upgrade is planned to be executed in 2019, with an expected shutdown time of one year for minimizing the influence on users. The upgrade design discussed in this report takes all these conditions into consideration.