SSRS-4

(Draft, BINP-NRC KI)

V. Korchuganov, NRC KI

Contents:

Development of the SR sources

- **First generation.**
- **SR sources, based on Synchrotrons and Colliders, working in parasitic mode with SR from BMs**

- **2nd generation.**
- **Specialized SR sources working with SR from bending magnets (10-100 nm-rad). DBA structures and its modifications**

- **3rd generation.**
- **SR sources working on the radiation from the insertion devices mostly (10-1 nm-rad.; 5-6 m long SSs, wigglers, undulators). DBA and TBA structures.**

- **4th generation.**
- **SR sources using: ERL and XFEL, SSRS-4 - based on linear accelerators; USR – circular machine with MBA-structure**

(critical parameter is emittance - 0.1- 0.01 nm-rad)

General Requirements for 4-th generation of X-ray sources:

- full spatial coherence;

- the highest temporal coherence ($\Delta\lambda/\lambda<10^{-4}$) without additional monochromatization;

- the averaged brightness of the sources is to exceed
  10^{23}-10^{24} photons/s/ mm^2 / mrad^2/(0.1% bandwidth);

- the full photon flux for the 4th generation sources must be at the level of the 3rd generation SR sources;

- high peak brightness of the order of 10^{33} photons/s/ mm^2 / mrad^2/(0.1% bandwidth) which is important for some experiments;

- electron bunch length up to 1 ps; and if a specialized technique is used, the X-ray pulses become smaller than 100 fs;

- high long-term stability;

- generation of linear, left-right circular polarized radiation with fast switching of the polarization type and sign;

- constant heat load on chambers and optics, etc.

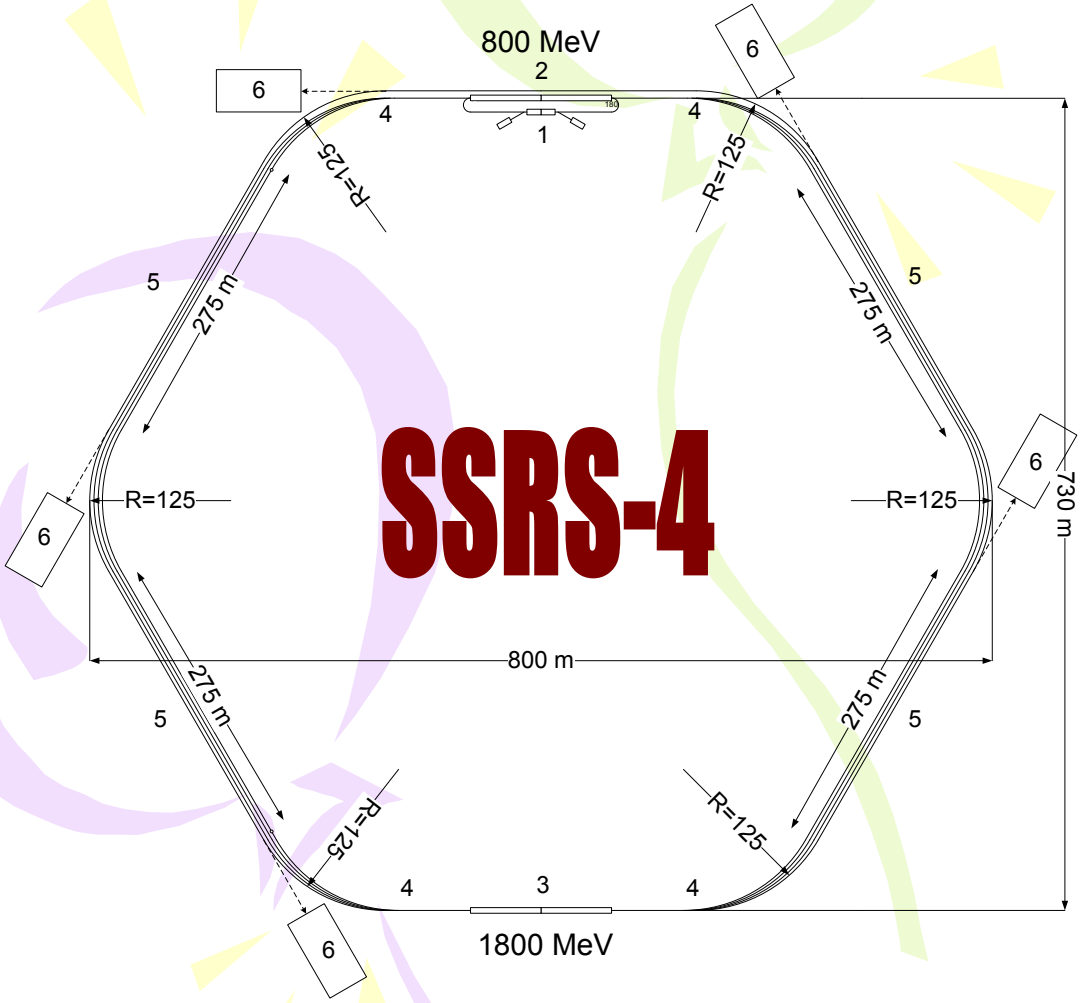
- servicing the multi-user community: **Users' demands: both cutting edge and workhorse.**

3

New Generation Facility in NRC KI

- NRC KI has an intention to build a high brightness fourth-generation "Specialized Synchrotron Radiation Source - SSRS-4"
- The aim is the creation of a unique national research - technological center on the basis of SSRS-4.
- Now SSRS-4 is considered as a facility with an optical structure based on multi-turn accelerator – recuperator (very preliminary project of BINP and NRC KI).
- But using the Ultimate Storage Ring structure is not excluded.
- One of the main goal is to reach the coherent radiation at wavelength of 1 Angstrem.

SSRS-4 - Multi-turn accelerator- recuperator with two linacs (BINP / NRC KI)



Scheme of SSRS-4 in horizontal plane

1. injector; 2.1-st linac; 3. 2-d linac; 4. spreders & recombiners; 5. undulators; 6. user stations.

Supposed parameters:

Energy range *5.6, 3.8, 3, 1.2 GeV*

To generate full spatially coherent undulator radiation with wavelength $\lambda = 0.1$nm it is necessary :

1. to decrease emittance of electron beam to diffraction limit $\varepsilon_{x,z} < \lambda/4\pi \approx 8$pm-rad ;

2. and to have normalized emittance of srf photogun

$$\xi_n < 10^{-7}\, m \cdot rad$$

3. to prevent IBS the charge in one bunch should be no more than

$$Q \le 10^{-11} C$$

SSRS-4 – the general accepted solutions - 1

- 1) **Emittance** of the electron bunch with energy E = 5-6 GeV is less, than **10^{-11}m-rad** , which corresponding to the normalized emittance **$e_n<10^{-7}$ m-rad**.

- 2) Bunch charge should not exceed **$Q=7.7*10^{-12}C$** . That corresponds to a current value of **10 mA**.

- 3) To compensate the current decreasing in ***10-50 times***, it is necessary to use the radiation from undulators and wigglers with number of periods ***Nu>100***.

- 4) To provide a low level of radiation hazard and eliminate induced radioactivity, the bunch energy should not exceed 5-8 MeV in the beam dump.

SSRS-4 – the general accepted solutions - 2

- 5) To provide easily achievable conditions for simultaneous movement of the electron bunches with different energies in accelerating (decelerating) RF structures, it is necessary to use cascade scheme of injection.

- 6) Two separated accelerating structures eliminate the main disadvantage of the scheme with single linac, where accelerating and decelerating bunches create two radiation sources in each undulator, and then simplifies the control of the beam.

- 7) Magnetic structure should contain long interspaces (L~200 m) for mounting a large number of the undulators with number of periods $Nu=10^2-10^4$.

- 8) Energy spread of electron bunch at low energy should not exceed $DE/E=10^{-4}$.

SSRS-4

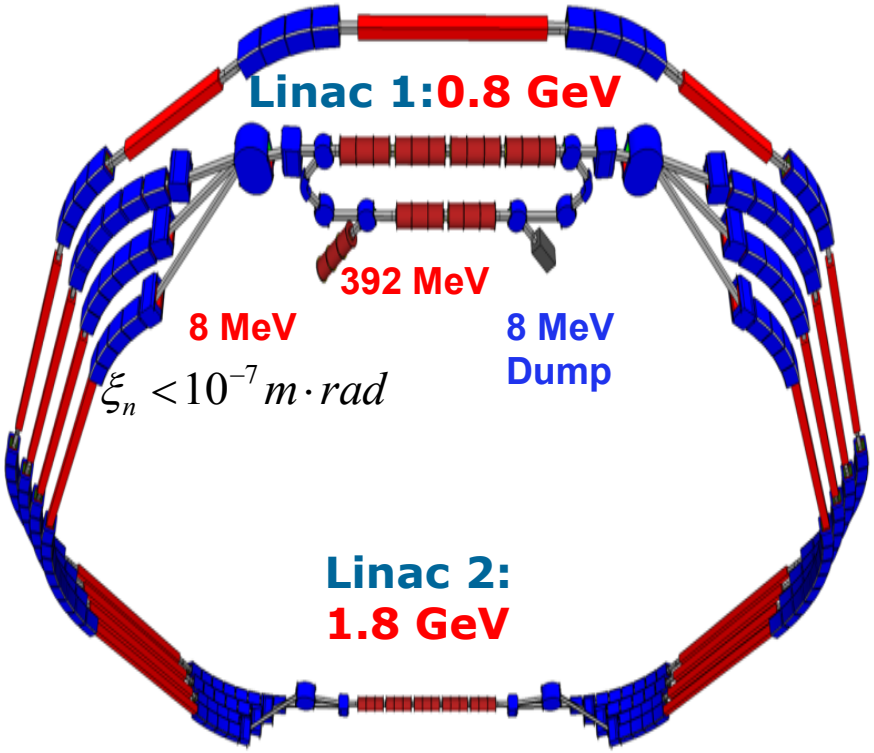
SSRS-4 space scheme with main features:

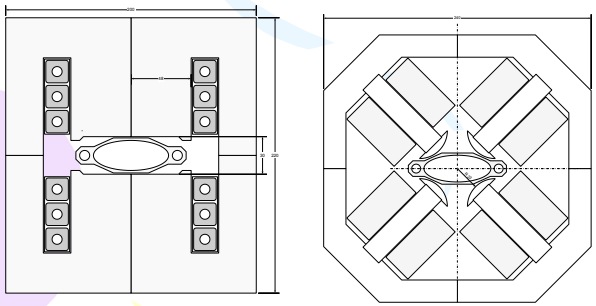
1. cascade injection;

2. two accelerating structures;

3. separated bending arcs ;

4. vertical separation of photon beamlines.





Users stations:

- 4 undulators for 1.2 GeV
- 4 undulators for 3 GeV
- 4 undulators for 3.8 GeV
- 7 undulators for 5.6 GeV

The main accelerator parameters of «SSRS-4»

- Electron Energy 5.6 GeV
- Average current 10 mA
- Peak current 10 A
- Normalized emittance 0.1 mkm
- Relative energy spread 2.2·10-5
- SR sources: 19 Undulators
  (Nu~10^2, Nu~10^3, Nu~10^4)
- Geometrical sizes 1x1 km

The parameters of «SSRS-4» radiation from the undulators

Photon energy, keV	1-30
Space coherence	total
Average brightness, ph/s/mm^2/mrad^2/0.1%BW	10^{24}
Pick brightness, ph/s/mm^2/mrad^2/0.1%BW	10^{27}
Polarization (linear or circular)	total
Electron bunch duration, ps	0.1

Comparison of SR sources SSRS-4 (10 mA) and Spring-8 (100 mA)

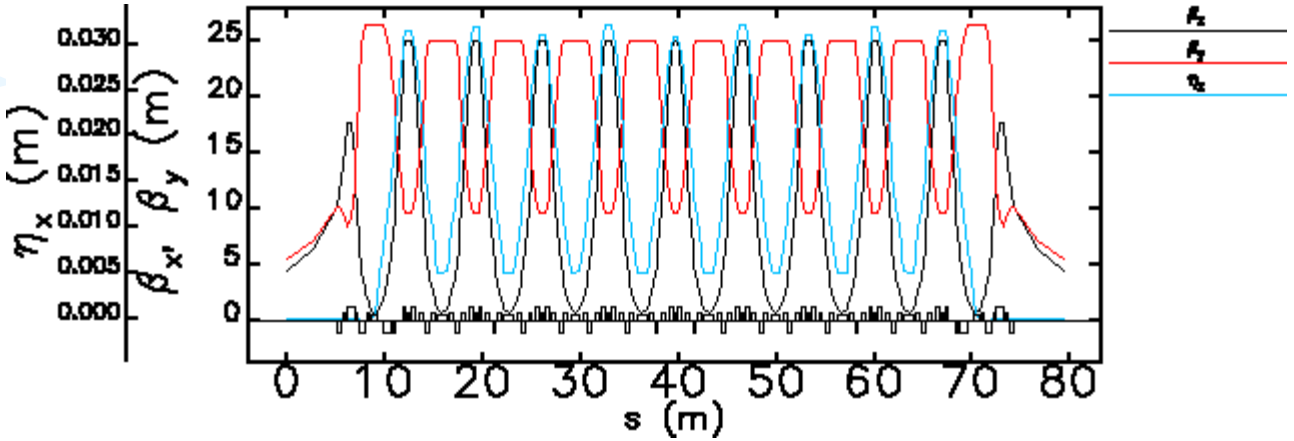
Facility	Nu. of undul. periods	Brightness, ph/s/mm^2/mrad^2/0.1%BW	Flux, ph/s/0.1%BW
SSRS-4	10^2	10^{22}	$7.7 \cdot 10^{13}$
	10^3	10^{23}	$7.7 \cdot 10^{14}$
	10^4	10^{24}	$7.7 \cdot 10^{15}$
SP-8	BMs	10^{16}	10^{13}
	130	$3 \cdot 10^{20}$	$2 \cdot 10^{15}$
	780	10^{21}	$1.2 \cdot 10^{16}$

“Ultimate Storage Ring”

An alternative could be the construction of SSRS-4 on the basis of a new generation synchrotron, the so-called Ultimate Storage Ring.

Example.
USR7: A 7 GeV, 40 Sector Ultimate Ring

Quantity	Value Unit
Circumference	3.16 km
Natural emittance	0.028 nm
Energy spread	0.079 %
Maximum ID length	8 m
Number of dipoles	10 per sector
Horizontal/vertical tune	183.18/36.18
Natural chromaticities	-535/-175
Energy loss	3.7 MeV/turn
Beta functions (x/y) at ID	4.4/5.5 m



1M. Borland, LSU Grand Challenge Workshop, 2008.

Examples of USR structure calculations.

Closeout of Lattice Design Session in Workshop on Accelerator R&D for Ultimate Storage Ring
Huairou, Beijing, Nov. 1, 2012

"Upgrade of the ESRF Light Source : Achievements and Perspectives" by P. Raimondi (ESRF)
Accelerator Upgrade Phase I (6m, 7m straight sections), Top-up project
E=6GeV, C=844, 7BA, ε = 130 pm.rad, SS 32x5m

"Lattice Design for SPring-8 II" by Y. Shimosaki (SPring-8)
E=6GeV, C=1436m, 6BA, ε = 67.5 pm.rad, SS: 44×4.5m, 4×27m with FODO

"Future Synchrotron Light Sources Based on Ultimate Storage Rings" by (Y. Cai) M. Borland (ANL)
PEP-X : E=4.5GeV, 7BA, C=2199.32m, εx = εy = 12 pm.rad, SS: 5m
DA = +-10mm with error of 20 μm

"Exploration of a Tevatron-Sized Ultimate Light Source" by M. Borland (ANL)
E=9GeV, C=6210m, 180 IDs, ε = 2.98pmrad, Coupling factor ~ 100%
|DA|=+-0.8mm (that may improve with more running time of MOGA).

Location of the SSRS-4 Project

- A possible location for the SSRS-4 must meet the following requirements:
- - availability of energy and network infrastructure;
- - convenient facility location relative to the main participants in the project;
- - transport accessibility;
- - relative proximity to major scientific, educational and industrial center of Russia;
- - favorable geological structure of the soil at SSRS-4 territory.
- Gatchina (Leningrad region), Troitsk (Moscow) and Protvino (Moscow region) might be considered as possible candidates for accepting this project.

The Project Time Schedule Estimate:

There is every reason to create national SR source of 4th generation in Russia, with a broad international cooperation in the framework of the following basic steps.

1. **2016 - 2018. - Creation, on the basis of the necessary R&D, of prototyping separate systems of SSRS-4 - specifically prototype of injector accelerating module with the RF generator and the undulator, their respective benches for assembly and testing.**

2. **2019 - 2020. – By using the prototypes a carrying out studies the devices characterization and nodes and achievable technical and operational parameters of the full 4th generation SR source in X-ray range.**

3. **2021-2027 . - The construction of full-scale of 4th generation X-ray range SR source, with the necessary built-in equipment for generating radiation, the photon beam lines and experimental research stations.**

4. **The cost of building of the complex SSRS-4, and the mega-project as a whole was preliminary estimated within 50 billion. Rub. The timing of implementation: 2016-2027 Years.**

Conclusion 1

- The most important technical result of the project will be obtaining the fully spatially coherent flux of X-rays, which will exceed the currently existing world-class research in this field.

- The structure of the source of SSRS-4 will create on its basis a set of unique research stations. Taking into account the possibility of separating the beams from the undulators total number of experimental stations can be up to 40.

- Implementation of the SSRS-4 project will provide adequate toolkit to future phase of engineering and technology, which consists of qualitative transfer:
  - from crystal to unstructured environments and living systems;
  - from the macroscopic to the micro - and nano - objects;
  - from the three-dimensional - to two-dimensional and one-dimensional structures;
  - from diffraction – to not diffractional methods, such as small-angle scattering, total external reflection, holography and others.

Conclusion-2

1. The accelerating schemes and most of the systems , which make the basis of the projects, have already been tested in many laboratories (Jefferson Laboratory, DESY, LEP, Budker INP, KEK, MAX).

1. **Main task is the organization of the partner relationship of accelerator`s, user`s and industry`s communities both in Russia and abroad as the active force for the newest modern SR source creation. Both closer contacts between our institutions and the scientific and technological experience exchanges will shorten the time period before the commissioning and will automatically help to make the Project cheaper.**

17

Thank you very much for your attention!