3. Upgrading of BESSY I

3.1 Introduction

BESSY I is disassembled, very well packed, shipped from Berlin and has already been arrived in Jordan. The design of the building is very well advanced and the documents of the building for a call for tender process should be finished by the end of June. With the space in the experimental hall and the requirement of the users to have a length of the beam lines up to at least 30 m, the circumference of the storage ring should be smaller than 125m. The upgrading of BESSY I for SESAME is documented in the so-called “Green Book“, issued October 1999. From 1999 until now a lot of workshops concerning the scientific case at SESAME have been held and there exists a better understanding of what is needed in the “Middle East Region”. According to the report of H. Winick, the number of x-ray beamlines should be increased and also one should try to increase the performance of the machine. This has to be done within the existing budget boundaries. In the following report different versions for upgrading BESSY I are investigated and a new upgrading version is proposed.

3.2 Performance of a Synchrotron Light source

The performance of a synchrotron light source is given by three factors: 1) The spectral range covered by the synchrotron radiation. 2) The brilliance of the emitted light and 3) The number of experimental stations.

3.2.1 Spectral Range of the Synchrotron Radiation

The spectral range of the synchrotron radiation is given by the critical photon energy (ε_{critic}), which is proportional to the square of the electron beam energy and proportional to the magnetic flux of the magnet. In order to reach the 20 keV range, it is foreseen in the “Green Book” to run the machine at 1 GeV and make the installation of up to three super conducting wigglers (7.5 Tesla). This leads to critical photon energy of 5 keV. The useable spectrum is extending to roughly four times the critical photon energy. The 20 keV range can also be covered with a 2 GeV beam and a magnetic flux density of 1.88 Tesla. The present technology allows construction of permanent magnet wigglers with flux density of 2.25 Tesla. A 2 GeV beam deflected in such a wiggler would cover a spectral range of up to 24 keV. The radiation from the bending magnet (“Green Book” Design, 1 GeV and 1.87 Tesla) covers a range up to 5 keV. That one of a 2 GeV beam deflected in a bending with 1.5 Tesla covers a range up to 16 keV. Because the spectrum range goes with the square of the energy it would be very worthwhile increasing it. But this process is limited, because the emittance (see next paragraph) is proportional to the square of the energy.

3.2.2 Brilliance of the Radiation

The brilliance is the figure of merit for the classification of the synchrotron radiation. At a synchrotron light source, the radiation with the highest brilliance comes from the undulators or wigglers. At a 2 GeV machine the required 20 keV photons can only be delivered from wigglers (see chapter 2), hence SESAME will be a wiggler-dominated machine. The brilliance of a wiggler is given by Bessel functions, the energy of the beam, number of wiggler periods, current and the inverse of the cross section of the beam. The cross section of the beam is proportional to the emittance of the machine and the betatron functions. In general the emittance goes with the third power of the bending magnet deflection angle and with the square of the energy. In order to get a high brilliance of the wiggler radiation, the emittance of the machine and the betatron functions at the location of the wigglers should be small. Synchrotron light sources dominated by undulators or wigglers and with a small emittance (smaller than 15 to 20 nmrad) are called 3rd generation light sources. In order to increase the brilliance of the radiation in an upgrading process of BESSY I one should try to decrease the emittance of the machine.

3.2.3 Number of Experimental Stations

In general the number of experimental stations are given by the space in the experimental hall. In a 3rd generation light source the number of experimental stations is proportional to the number of available straight section for the installation of insertion devices (undulator and wigglers) and with a lower priority the number of bending magnets. In order to qualify this point one uses the percentage of the circumference that can be used for the installation of insertion devices. Furthermore as indicated in section 2.2 the length of insertion device sections should be long for increasing the brilliance. In an upgrading process of BESSY I one should try to increase the number and length of the straight sections.

3.3 Upgrading Versions of BESSY I

3.3.1 Green Book Proposal

With the "Green Book" proposal, the energy of the BESSY I will be increased from 0.8 to 1 GeV by changing the magnetic flux in the bending magnets from 1.5 to 1.87 Tesla. Decreasing the gap and modifying the pole profile of the bending magnet can do this. To reach the required photon spectrum, up to three 7.5 Tesla super conducting wigglers can be installed. To increase the number of straight sections the lattice is changed from the TBA- to a DBA- optic, which results in a 6-fold symmetry (increasing the useable straights by a factor 2). To avoid the influence of the high field wiggler to the beam and to increase the brilliance of the radiation a so-called "mini beta section" has to be introduced at the position of the wigglers. The circumference of the machine will increase from 64 to roughly 100 m. The parameters of BESSY I, the upgraded version without (SES_1_1) and with a mini beta section (SES_1_2) are given in Table (3.1). The number of the existing magnets and the power supplies of BESSY I are compiled in Table (3.2).

Table 3.1: Main parameters of BESSY I, the "Green Book Proposal" without (SES_1_1) and with a mini beta section (SES_1_2)

Parameter		BESSY I	SES_1_1	SES_1_2
Energy	(GeV)	0.8	0.8	1.0
Emittance	(nmrad)	56.8	7.85	50 – 107
Number of straights		4	6	6
Useable wiggler straights and length	(m)	2 / 2.60	4 / 4.80	3 / 2.00
Useable undulator straights and length	(m)			1 / 4.80
Circumference	(m)	64.0	100.8	100.8
Σ Length of straights/circumference	(%)	8.1	22.9	10.7
Beam size (σ_x, bending / wiggler)	(mm)	0.138/0.341	0.063/0.607	0.375/0.644
Beam size (σ_y, bending / wiggler)	(mm)	0.050/0.023	0.057/0.029	0.209/0.030
Beam size area ($2*\pi*\sigma_x*\sigma_y$)				
Bending magnet	(mm^2)	0.044	0.023	0.493
Wiggler / Undulator	(mm^2)	0.049	0.111	0.121/0.619
Critical photon energy				
Bending magnet	(keV)	0.64	0.64	1.24
Wiggler(2.25Tesla)	(keV)	0.96	0.96	1.50
Undulator	(keV)			
Wavelength shifter (7.5Tesla)	(keV)	3.0	3.0	5.0

Noticeable are the increase of the emittance and the reduction of the length of the straights by the introducing of the mini beta section. Also from the cross section of the beam (area of the spot size) SES_1_2 can't compete with BESSY I. The emittance depends upon the number of wigglers, according to the additional damping.

For the version SES_1_1 all magnetic elements of BESSY I can be used and 8 additional sextupoles with a length of 0.15 m are required. For the version SES_1_2 the 12 bending magnets have to be modified, furthermore 8 additional quadrupoles and 8 sextupoles are needed.

Table 3.2: Characteristic data of the BESSY I magnets and power supplies. In the column "Number" the first figure gives the number of power supplies and the second the number of magnets.

Power Supply	Number	Data	Data(mm)	Voltage(V)	Current(A)	Power(kW)
Bending magnet	1 / 12	1,5 T	60 gap	305	900	275.0
Quadrupole Q0	4 / 28	11.5 T/m	100 bore	52	1025	213.0
Quadrupole Q1	1 / 4	11.5 T/m	100 bore	30	1100	33
Quadrupole Q2	1 / 4	14,5 T/m	100 bore	38	1400	53.2
Sextupole Sh	1 / 8	557 T/m^2	120 bore	83	400	33.2
Sextupole Sv	1 / 4	418 T/m^2	120 bore	63	300	18.9
Corrector magnets	20			20	10	4.0

3.3.2 Upgrading of BESSY I to 2 GeV

3.3.2.1 Upgrading to a 6 fold Symmetry and DBA-Lattice

The energy of an accelerator is given by the integral of the magnetic flux around the ring. For the increase of the energy from 1 GeV to 2 GeV longer magnets must be installed. The easiest way is to keep the foreseen DBA-lattice in the Green-book-report and change the 12 bending magnets of BESSY I with a deflection radius of 1.779 m by new ones with a radius of 4.4474 m (the corresponding magnetic flux is 1.5 Tesla). In this case one needs 12 new bending magnets and 8 new sextupoles. This version is called SES_2_1; the parameters of this version are summarized in Table (3.3)

As in paragraph 2 stressed, for a high brilliance one needs a small cross section of the beam. This can be done locally in a storage ring by introducing a so-called "mini beta section". For doing this one has to introduce on each side of the straight section a quadrupole triplet instead of a doublet. This version is named SES_2_2; the parameters are summarized in Table (3.4).

3.3.2.2 Upgrading to an 8-fold Symmetry and DBA-Lattice

The emittance of the electron beam is proportional to the third power of the deflection angle of the bending magnets. Going from the 6-fold symmetry to 8 fold would decrease the emittance by a factor 2.4 and would increase the number of useable straight sections from 4 to 6. This version is called SES_3_1. Per cell there is the same arrangements of magnets (DBA-lattice) as for the version SES_2_1. The corresponding version with a mini beta section is named SES_3_2. The parameters of both versions are summarized in Table (3.3) and (3.4).

3.3.2.3 Upgrading to an 8-fold Symmetry and a TME-lattice.

Introducing combined magnets, for example gradient bending magnets, can reduce the number of magnets in an accelerator. In the past a lot of synchrotron light sources have been designed with gradient bending magnets (ALS, ELETTRA, CLS, SPEAR3 etc.). This design has further the advantage that the emittance will be reduced. Sometimes this lattice is called the "Theoretical Minimum Emittance"-lattice (TME-lattice). This version is called SES_4_1 and the parameters of this version are given in Table (3.3). For the version SES_4_1 all quadrupoles and sextupoles from BESSY I can be used. By the given maximum circumference of 125 m this limits the length of the straight sections.

In an upgrading process the length of the quadrupoles and sextupoles can be changed in order to get longer straight sections. Furthermore a mini beta section can be introduced (version SES_4_2). The parameters of these versions are summarized in Table (3.3) and (3.4).

Table 3.3: Main parameters of the versions upgraded to 2 GeV. SES_2_1 has 6 fold, SES_3_1 and SES_4_1 have 8-fold symmetry. SES_4_1 uses gradient bending magnets and BESSY I quads and sextupoles.

Parameter		SES_2_1	SES_3_1	SES_4_1
Energy	(GeV)	2.0	2.0	2.0
Emittance	(nmrad)	62.2	23.7	18.7
Number of straights		6	8	16
Useable wiggler straights and length	(m)	4 / 4.64	6 / 3.20	8 / 2.43
Useable undulator straights and length	(m)			6 / 1.80
Circumference	(m)	112.0	116.0	120.0
ΣLength of straights / circumference	(%)	16.5	20.6	35.7
Beam size (σ_x, bending / wiggler)	(mm)	0.283/1.484	0.136/0.847	0.167/0.613
Beam size (σ_y, bending / wiggler)	(mm)	0.120/0.108	0.074/0.025	0.078/0.032
Beam size area ($2*\pi*\sigma_x*\sigma_y$)				
Bending magnet	(mm^2)	0.214	0.063	0.082
Wiggler/ Undulator	(mm^2)	1.007	0.133	0.123/0.092
Critical photon energy				
Bending magnet	(keV)	4.00	4.00	3.60
Wiggler (2.25Tesla)	(keV)	6.00	6.00	6.00
Undulator	(keV)			
Wavelength shifter (7.5Tesla)	(keV)	20.0	20.0	20.0

Table 3.4: Main parameters of the versions upgraded to 2 GeV with a mini beta section. SES_2_2 has 6 fold, SES_3_2 and SES_4_2 have 8-fold symmetry. SES_4_2 uses gradient bending magnets.

Parameter		SES_2_2	SES_3_2	SES_4_2
Energy	(GeV)	2.0	2.0	2.0
Emittance	(nmrad)	76.0	25.6	12.9
Number of straights		6	8	16
Useable wiggler straights and length	(m)	3 / 3.84	4 / 3.20	8 / 2.60
Useable undulator straights and length	(m)	1 / 4.64	2 / 3.20	6 / 1.70
Circumference	(m)	116	122.0	124.0
ΣLength of straights / circumference	(%)	13.9	19.6	34.6
Beam size (σ_x, bending / wiggler)	(mm)	0.336/0.322	0.149/0.145	0.097/0.254
Beam size (σ_y, bending / wiggler)	(mm)	0.139/0.033	0.083/0.029	0.062/0.0073
Beam size area ($2*\pi*\sigma_x*\sigma_y$)				
Bending magnet	(mm^2)	0.241	0.077	0.038
Wiggler/Undulator	(mm^2)	0.067/1.24	0.026/0.295	0.012/0.081
Critical photon energy				
Bending magnet	(keV)	4.0	4.0	3.6
Wiggler (2.25Tesla)	(keV)	6.0	6.0	6.0
Undulator	(keV)			
Wavelength shifter (7.5Tesla)	(keV)	20	20	20

3.4 Comparison of the Different Versions

3.4.1 Magnets

For the different upgrading versions the needed magnets are summarized in Table (3.5). To upgrade the storage ring to 1 GeV (version: SES_1_2) the bending magnets have to be modified in order to reach a field of 1.87 Tesla. Furthermore 8 quadrupoles and 8 sextupoles are needed. For this version a DBA lattice is foreseen and the symmetry of the machine is 6 fold.

For a 2 GeV storage ring (version SES_2_1) 12 new bending magnets and 8 new sextupoles are needed. In order to increase the brilliance of the radiation from the wiggler a “mini beta section” should be introduced. This is possible with the version SES_2_2 for which 6 additional quadrupoles with a length of 0.7 m are requested.

Table 3.5: Number of magnet elements needed for the different upgrading versions for SESAME. The lengths of the elements are given in brackets.
***) This is a combined quadrupole / sextupole magnet**

Version	Bendings	Quadrupoles	Sextupoles	New bends	New quads	New sextup.
BESSY I	12	32 (0.44) 4 (0.25)	16 (0.25)			
SES_1_1	12	30 (0.44)	16 (0.25) 8 (0.15)			8 (0.15)
SES_1_2 (Green book)	12	30 (0.44) 12 (0.25)	16 (0.25) 8 (0.15)	12 modified	8 (0.25)	8 (0.15)
SES_2_1	12	30 (0.44)	16 (0.25) 8 (0.15)	12		8 (0.15)
SES_2_2	12	30 (0.44) 6 (0.70)	16 (0.25) 8 (0.15)	12	6 (0.70)	8 (0.15)
SES_3_1	16	32 (0.44) 8 (0.25)	16 (0.25) 16 (0.15)	16	8 (0.25)	16 (0.15)
SES_3_2	16	32 (0.44) 8 (0.22) 8 (0.60)	16 (0.25) 16 (0.15)	16	8 (0.22) 8 (0.60)	16 (0.15)
SES_4_1	16	32 (0.44)	16 (0.25) 16 (0.15) 32 (0.20)*)	16		16 (0.15) 16-32 (0.20)*)
SES_4_2	16	16 (0.23) 16 (0.45) 16 (0.35)	32 (0.15) 32 (0.20)*)	16	16 (0.23) 16 (0.45) 16 (0.35)	32 (0.15) 32 (0.20)*)

For an eight fold symmetry (SE_3_1) 16 new bending magnets, 8 quadrupoles and 16 sextupoles are needed. In order to get 4 mini beta sections in the storage ring (SES_3_2) 8 more quadrupoles with a length of 0.6 m are needed.

The version SES_4_1 needs 16 new bending magnets, 16 sextupoles with a length of 0.15 (m) and 16 to 32 combined sextupole / quadrupole magnets. In order to increase the length of the straight sections it is possible to change on a later stage the BESSY quadrupoles and sextupoles by more compact magnets. Furthermore by introducing 16 new quadrupoles it is possible to make in each cell a mini-beta-section (version SES_4_2).

3.4.2 Performance of the Different Upgrading Versions

Performance of the radiation of a synchrotron light source is given by the brilliance of the beam, the spectral range of the radiation and the overall length (or the number) of insertion devices that can be installed. The spectral range is given by the so-called critical photon energy, which is proportional to the magnetic field and proportional to the square of the beam energy. Hence by changing the energy from 1 GeV to 2 GeV, the useable spectrum is a factor of 4 broader. As already discussed in chapter 2 the spectrum is broader by a factor of 10.

To avoid a super-conducting wiggler has two more advantages: 1) The high field of the wiggler has a strong influence of the behavior of the beam. 2) The operation of a super-conducting wiggler needs a special knowledge, which at present is not available at SESAME. 3) The super-conducting wiggler is much more expensive.

According to these arguments it would be worthwhile changing the energy of SESAME from 1 GeV to 2 GeV.

For a comparison of the different versions the main parameters are summarized in Table (3.6) and (3.7). In Table (3.6) without and in Table (3.7) with a mini beta section.

Table 3.6: Main parameters of the different upgrading versions of SESAME in comparison to BESSY I and the "Green book Proposal" (SES_1_2). These are the basic versions without any mini beta section. The column "Factor" gives the overall length of the straight section (foreseen for the installation of all wigglers and undulators) divided by the cross section of the beam and the period length (8-cm) of the insertion device.

Version	Energy (GeV)	Emittance (nmrad)	Circumf. (m)	%	Area Wiggler (mm^2)	Area Undulat. (mm^2)	Area Bend. (mm^2)	Factor
BESSY I	0.8	55.2	64.0	8.1	0.049		0.044	758
SES_1_1	0.8	7.8	100.8	22.9	0.111		0.023	2162
SES_1_2	1.0	50 –100	100.8	10.7	0.121	0.638	0.493	450
SES_2_1	2.0	62.2	112.0	16.6	1.01		0.214	230
SES_3_1	2.0	24.0	116.0	20.5	0.095		0.044	2526
SES_4_1	2.0	18.7	120.0	33.0	0.123	0.092	0.082	3442

3.4.2.1 Without a "Mini-Beta-Section"

The version SES_4_1 has an emittance in the range of 13 to 19 nm rad, which is a factor 2 to 3 smaller than version SES_1_2. This yields to an increase in the brilliance by a factor 4 to 8. The emittance scales with the energy squared. Hence the emittance of version 4 would drop down to around 5-nm rad, running with an energy of 1 GeV (as in version 1). The dependency of the emittance on the deflection angle of the bending magnets is given by the comparison of version 2 and 3; see Table (3.6). Going from a 6-fold to an 8-fold symmetry the emittance decreases by a factor of 2.8

The column "%" gives the percentage of the circumference, which is available for the installation of insertion devices (wigglers or undulators). At BESSY I and SES_1_2 (the "Green Book" proposal) roughly 10 percent of the circumference can be used for wigglers. For the version SES_2_1 roughly 16 %, for the versions SE_3_1 around 20 % and for the version SE_4_ over 30 %. Hence moving over from version SES_1_2 to SES_4_1 a length of roughly 30 m is further available for the insertion devices. These are more arguments in favor of higher energies or another layout of the machine.

Important for the brilliance is the cross section of the beam. In Table (3.6) these values are given for the position of the wigglers, the undulators and the bending magnets. For the versions SES_2_1, SES_3_1 and SES_4_1 the cross section of the beam within the bending magnets is smaller than that of version SES_1_2. For the wigglers and undulators, versions SES_3_1 and SES_4_1 have roughly the same cross section but for the version SES_2_1 it is at this position up to a factor 8 to 9 higher.

In order to make a comparison of the different version a new column "Factor" is introduced in Table (3.6), which gives the overall length of the insertion devices divided by the period length and the cross section of the beam. The brilliance of the radiation is proportional to this factor. The version SES_1_2 (Green-Book-Proposal) has a factor of 450. This factor decreases by a factor 2 for the version SES_2_1 because of the large emittance. The version SES_3_1 with a factor of 2526 has a performance, which is about 5 times higher than the version SES_1_2. The performance increases further more (factor 1.3) by moving over to version SES_4_1. The factor 1.3 is given by the ratio of the straight sections (8/6=1.33).

3.4.2.1 With a "Mini-Beta-Section"

As mentioned before, the brilliance of the radiation from a wiggler and a bending magnet is inversely proportional to the cross section of the beam within these devices. The cross section within the wigglers can be changed and minimized with the introduction of a "mini-beta-section". The installation of this "mini-beta-section" can be made in a later stage as an upgrading process. The main parameters of the different upgrading versions with a mini-beta-section are summarized in Table (3.7). By moving over from version SES_1_2 to SES_3_1 and SES_4_1 the performance would be increased by a factor 5.6 to 7.6. Not included in this number is the broader spectrum (up to a factor 10).

Table 3.7: Main parameters of the different upgrading version of SESAME with a "mini-beta-Section" in comparison to BESSY I and the "Green-Book-Proposal" (SES_1_2). The column "Factor" gives the length of the straight section (foreseen for the wigglers and undulators) divided by the cross section of the beam and the length of the insertion device.

Version	Energy (GeV)	Emittance (nm*rad)	Circumf. (m)	%	Area Wiggler (mm^2)	Area Undulat. (mm^2)	Area Bend. (mm^2)	Factor
BESSY I	0.8	55.2	64.0	8.1	0.049		0.044	758
SES_1_2	1.0	50 –100	100.8	10.7	0.121	0.638	0.493	450
SES_2_2	2.0	76.0	116.0	13.9	0.053	1.071	0.214	2757
SES_3_2	2.0	26.0	122.0	19.6	0.026	0.295	0.077	6425
SES_4_2	2.0	13.0	124.0	34.6	0.012	0.081	0.038	23240

With the installation of the mini-beta-section, the performance will be increased very much: for the version SES_2_2 to 6, for the version SES_3_2 to 14 and for the version SES_4_2 to a factor 52.

The versions SES_4_1 and SES_4_2 have the best performances. The version SES_4_2 is an upgrading of version SES_4_1, which can be performed in a later stage. But one has to start with the version SES_4_1 to make this opportunity possible.

3.5 Main Parameters of the Versions SES_4_1 and SES_4_2

The lattice of these two versions are given in the Figures (3.1) and (3.2). The main parameters of the versions SES_4_1 and SES_4_2 are given in Table (3.8). Version SES_4_1 is the proposed starting version and SES_4_2 is an upgrading version, which can be erected in a later stage.

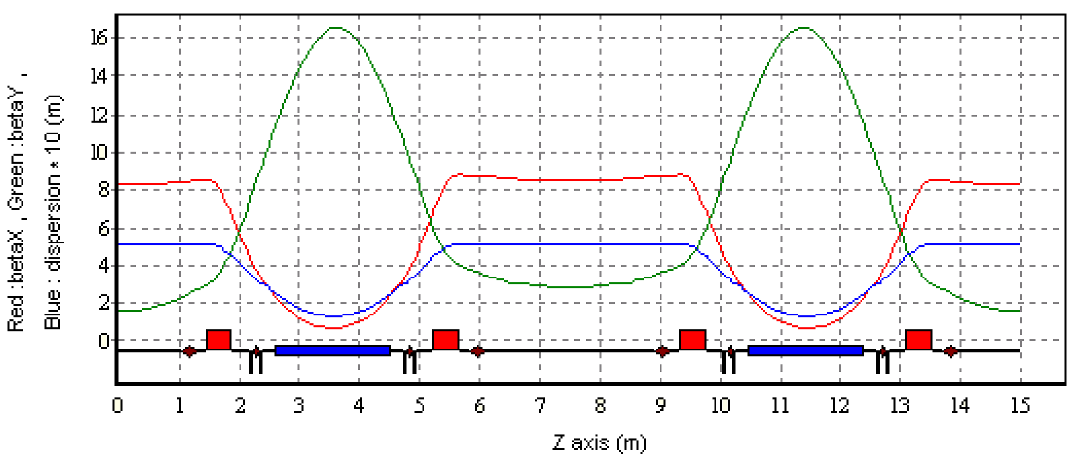

Figure 3.1: Lattice and machine functions of the version SES_4_1. This is the proposed upgraded version of BESSY I for SESAME

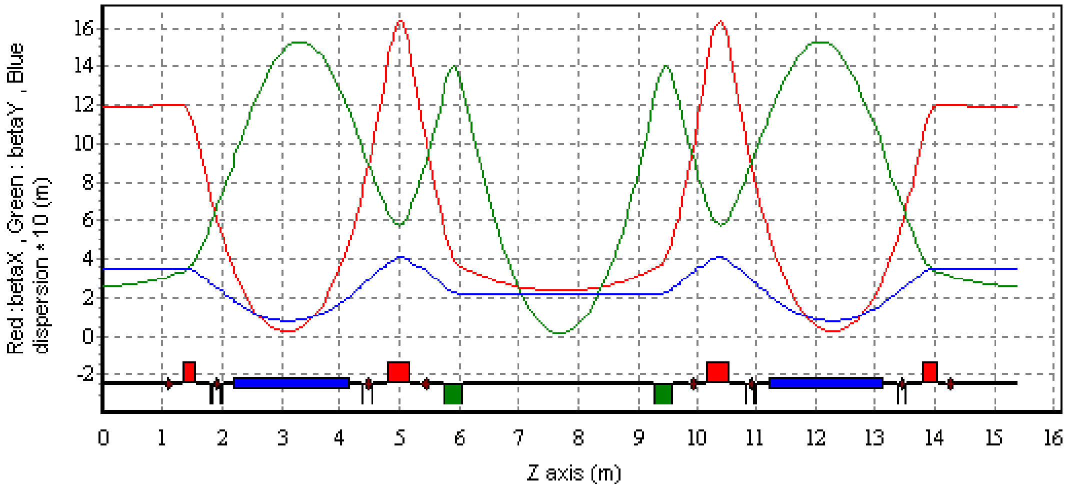

Figure 3.2: Lattice and machine functions of the version SES_4_2. This version is an upgraded version of SES_4_1. The upgrading can be performed in a later stage.

Table 3.8: Main Parameters of the proposed upgraded version SES_4_1 and the final one SES_4_2

Parameter		SES_4_1	SES_4_2
General Parameters			
Energy	(GeV)	2.0	2.0
Beam current	(mA)	400	400
Circumference	(m)	124.8	124.8
Natural emittance	(nmrad)	18.7	12.9
Coupling	(%)	2.0	2.0
Horizontal emittance	(nmrad)	18.4	12.65
Vertical emittance	(nmrad)	0.37	0.253
Horizontal working point		6.79	9.20
Vertical working point		4.72	6.28
Momentum compaction factor		0.0090	0.0061
Relative energy spread	(%)	0.091	0.088
Chromaticity (horizontal)		-9.6	-26.6
Chromaticity (vertical)		-12.1	-21.7
Machine functions			
Horizontal beta functions			
Wiggler / bending / undulator	(m/rad)	8.42/0.70/8.24	2.30/0.32/11.9
Vertical beta functions			
Wiggler / bending / undulator	(m/rad)	2.78/16.5/1.55	0.21/15.1/2.57
Dispersion function			
Wiggler / bending / undulator	(m)	0.51/0.13/0.51	0.21/0.08/0.35
Beam sizes and cross sections			
Horizontal beam size			
Wiggler / bending / undulator	(µm)	613/167/610	254/97/495
Vertical beam size			
Wiggler / bending / undulator	(µm)	32 / 78 / 24	7.3 / 25 / 62
Cross section			
Wiggler / bending / undulator	(mm^2)	0.123/0.082/0.092	0.012/0.038/0.081
R.F-System			
Energy loss per turn (bending)	(keV)	286.4	286.4
Energy loss per turn (wiggler)	(keV)	2*25.7= 51.4	8* 25.7= 205.6
R.F.-frequency	(MHz)	499.654	499.654
Harmonic number		208	208
R.F.-power	(kW)	250	500
Number of cavities		2	4
Shunt impedance per cavity	(MΩ)	3.6	3.6
R.F.-cavity voltage	(kV)	576	681
Overvoltage factor		3.4	5.5
Energy acceptance	(%)	1.13	1.8
Bunch length	(mm)	12.1	7.0

3.6 Characteristics of the Radiation from the Different Versions

The real advantage or disadvantage of the different versions is given by a comparison of the performances of the synchrotron radiation emitted from the bendings and wigglers. This will be performed in the next subsections.

3.6.1 Characteristics of the Radiation from the Bending Magnets

The flux, flux density and brilliance of the emitted radiation from the bendings of the discussed versions are presented in the Figures (3.3) to (3.8). Figure (3.4) gives the vertical opening angle of the radiation from a 1 GeV and 2 GeV beam.

The fluxes emitted from a stored beam in a 1 GeV/1.87Tesla and 2 GeV/1.35Tesla storage ring are presented in Figure (3.3). According to the higher energy, the flux emitted from a 2 GeV machine is a factor of 2 higher. The critical photon energies of the machines are ε_c= 1.24 for the (1GeV/1.87T) version and 3.59 KeV for the (2GeV/1.35T) version. The spectrum for the 2 GeV storage ring is at least a factor 5 broader, although the critical photon energy of the machines differ only by a factor 3.

Most of the users are more interested in the flux density, which gives the number of photons per second and sample area. The flux densities are presented in the Figures (3.5) and (3.6). The spectrum is the same as for the flux. According to the different emittances the flux density increases with the number of cells in the machine. There isn't any large difference between the versions SE_4_1 and SE_3_1. The flux density of these two versions is however two orders of magnitudes higher than that for the version SE_1_2. Furthermore the spectrum is one order of magnitude broader. Overall we have a gain by moving over from version SE_1_2 to SE_3_1 or SE_4_1 by three orders of magnitude. There isn't any big change by moving over to the mini beta versions (SE_3_2 or SE_4_2)

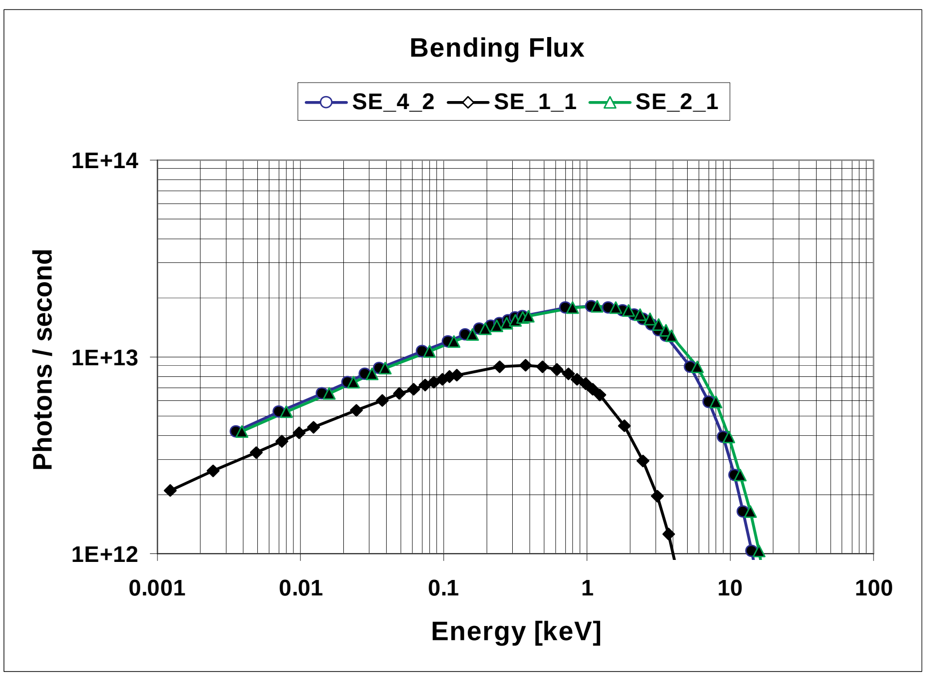

Figure 3.3: Flux of the synchrotron radiation from the bending magnets. Version SES_1_1: Green book, 1GeV, 1.87 Tesla, 400 mA; version SES_2_1: 2GeV, 1.5 Tesla, 400 mA; version SES_4_2: 2GeV, 1.35 Tesla, 400 mA

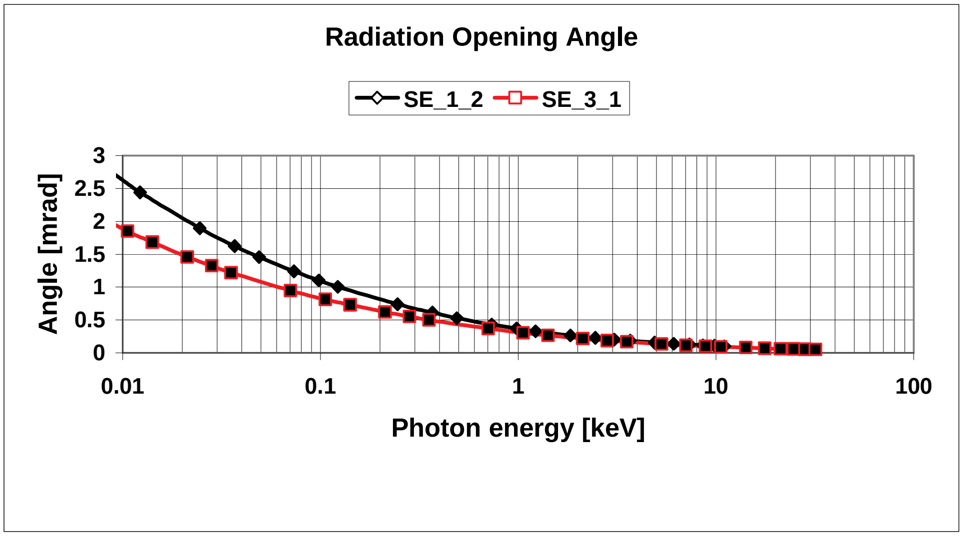

Figure 3.4: Opening angle of the synchrotron radiation from the bending magnets with an energy of 1GeV (SES_1_2) and 2GeV (SES_3_1)

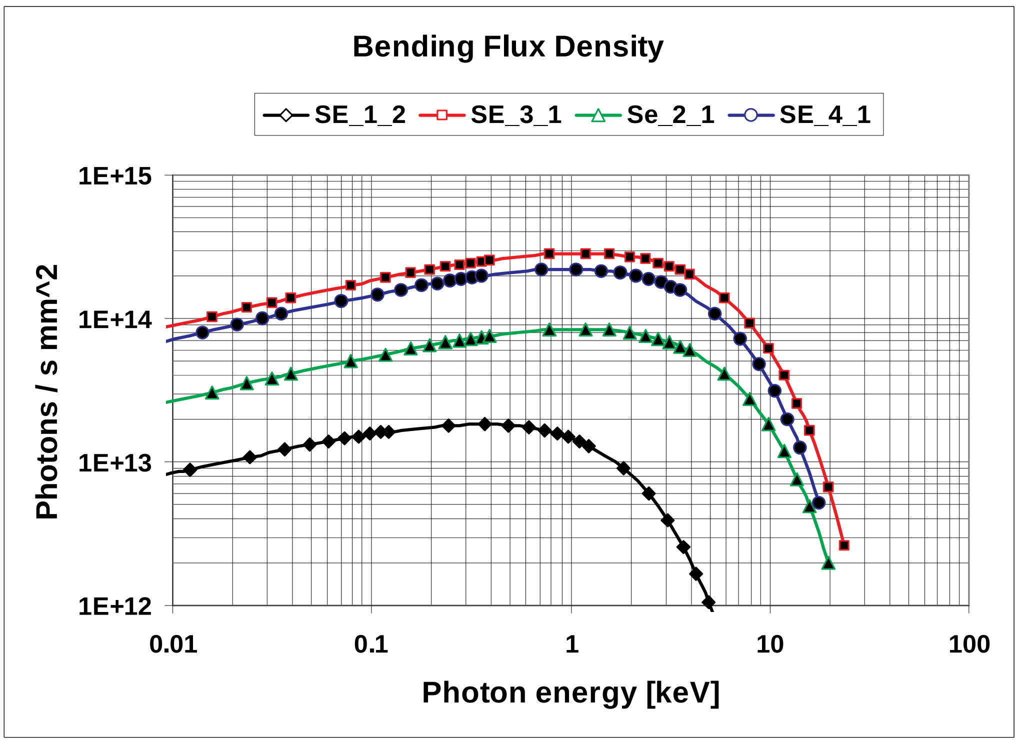

Figure 3.5: Flux density of the synchrotron radiation from the bending magnets for versions: SES_1_2 (1GeV, 6 fold), SES_2_1 (2GeV, 8 fold), SES_3_1 (2GeV, 8 fold) and SES_4_1 (2GeV, 8 fold)

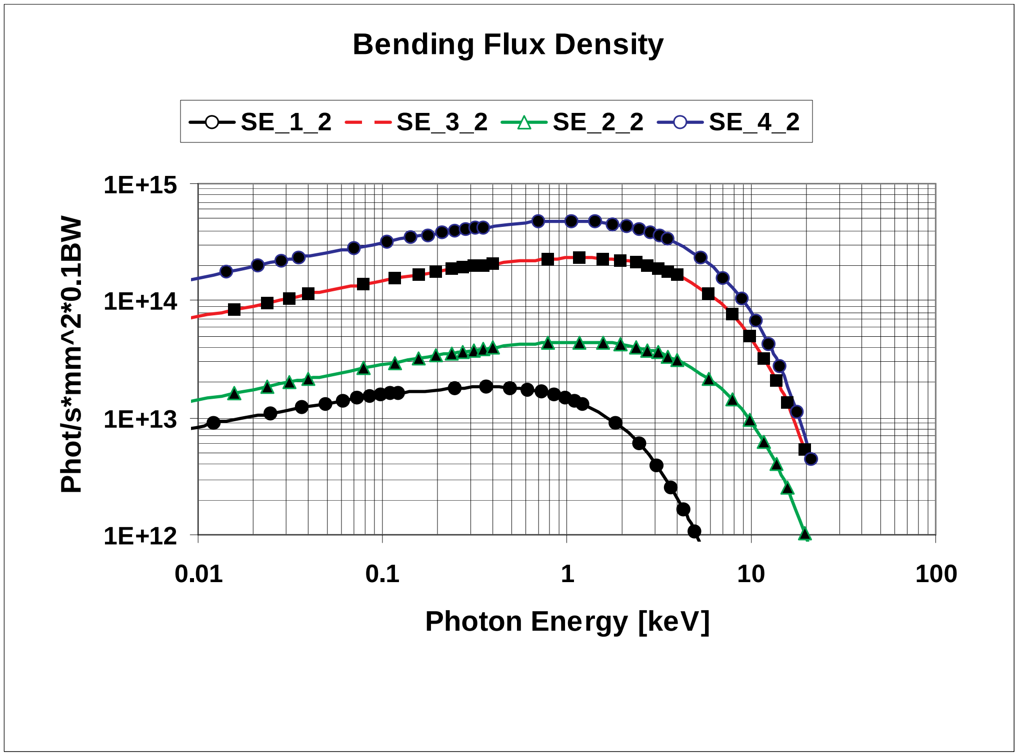

Figure 3.6: Flux density of the synchrotron radiation from the bending magnets for versions: SES_1_2 (1GeV, 6 fold), SES_2_2 (2GeV, 8 fold), SES_3_2 (2GeV, 8 fold) and SES_4_2 (2GeV, 8 fold)

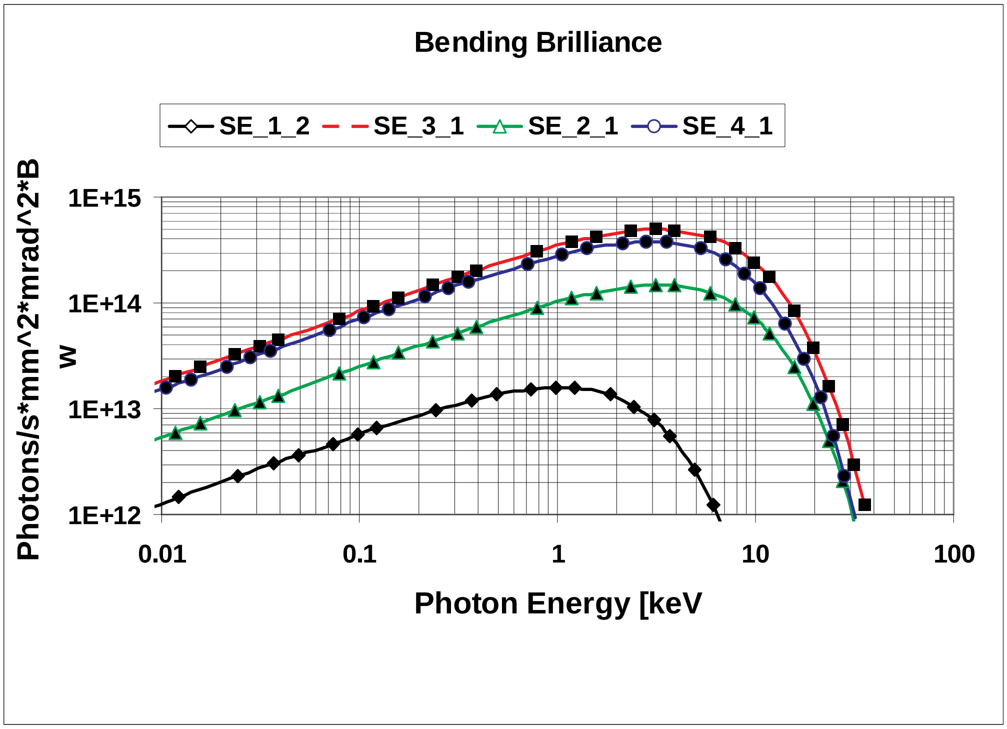

Figure 3.7: Brilliance of the synchrotron radiation from the bending magnets for the versions SES_1_2, SES_3_1, SES_2_1 and SES_4_1

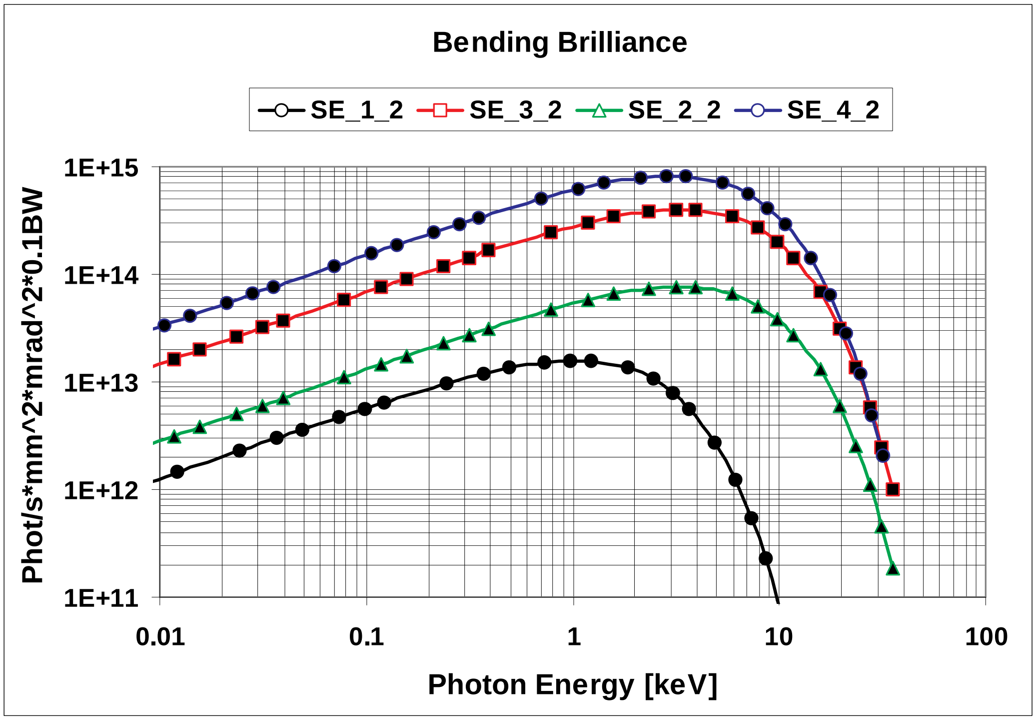

Figure 3.8: Brilliance of the synchrotron radiation from the bending magnets for the versions SES_1_2, SES_3_2, SES_2_2 and SES_4_2.

The brilliances of the 1 and 2 GeV beams (400 mA) are given in the Figures (3.7) and (3.8). The critical photon energies of the different versions are: SE_1_I = 1.24 keV, SE_2_I = 4.00 keV, SE_3_I = 4.00 keV and SE_4_I = 3.60 keV. From the figures it follows that the maximum brilliance is around the critical photon energy. Because of the higher energy the brilliance of the 2 GeV beam is one order of magnitude broader than for a 1 GeV beam. According to the smaller cross sections (emittances) the brilliances of the versions SE_3_I and SE_4_I are of a factor up to 50 higher than from the 1 GeV beam (version SE_1_I). Also for the brilliance we gain a factor up to 500 by moving over to the versions SE_3_1 or Se_4_1.

3.6.2 Characteristics of the Radiation from the Wigglers

The photon flux as well as the central intensity of the radiation emitted by the wiggler is the same as from the bending magnet but by a factor N_p more intensive, where N_p is the number of poles within the wiggler. The photon flux emitted from the wigglers beams for the "Green Book" and this "Proposal" are presented in the Figures (3.9) and (3.12). Both wigglers have roughly the same critical photon energy (ε_c(Green Book) = 5.0 keV, ε_c(Proposal) = 6.0 keV) and therefore the spectrum of the flux is roughly the same.

For the intensity of the photon flux the amplitudes X_0 of the beam oscillations within the wigglers have to be considered (see Table (2.1)). Because of the amplitude of 1.1mm in the "Green Book" design the spot sizes in the wigglers have a difference of 2.2 mm and it is not possible to collect both sources within one beam line. Therefore the useable flux from the wiggler for an experiment is only proportional to half of the number of the poles for the "Green Book" design. For the wiggler in this "Proposal" with an amplitude of 50 µm it is completely different; here all poles have to be considered. All these arguments are included in the Figure (3.9) and (3.12), with the result that the flux from the 2 GeV stored beam is of a factor 18 higher than that from the 1 GeV one.

The flux density of the wiggler radiation is given in the Figures (3.10) and (3.13) (with mini-beta-section). In these cases the spectrum is the same as for the flux, but with a different ratio of the intensities. Without a mini-beta-section the intensity of the flux density is a factor 18 higher and with a mini-beta-section it is a factor 200 higher. This already shows how important the introduction of a mini-beta-section is.

The brilliance of the radiation emitted from the wigglers within the “Green Book” and this “Proposal” are presented in the Figures (3.11) and (3.14). Figure (3.14) is that one with the “mini-beta-sections”. Again, because of the same critical photon energies the emitted spectrum covers the same range, because of the different cross sections of the beam the intensity is however different. For the versions SE_3_1 and SE_4_1 the intensity is roughly the same, but in comparison to version SE-1_2 they have a factor 35 higher intensity. The version SE_2_1 is of a factor 5 more intensive. The picture changes completely by introducing “mini-beta-sections”. The brilliance of the wiggler radiation for this version is presented in Figure (3.14), with the result that the brilliance of the version SE_4_2 is of a factor 350 higher than that of the version SE_1_2.

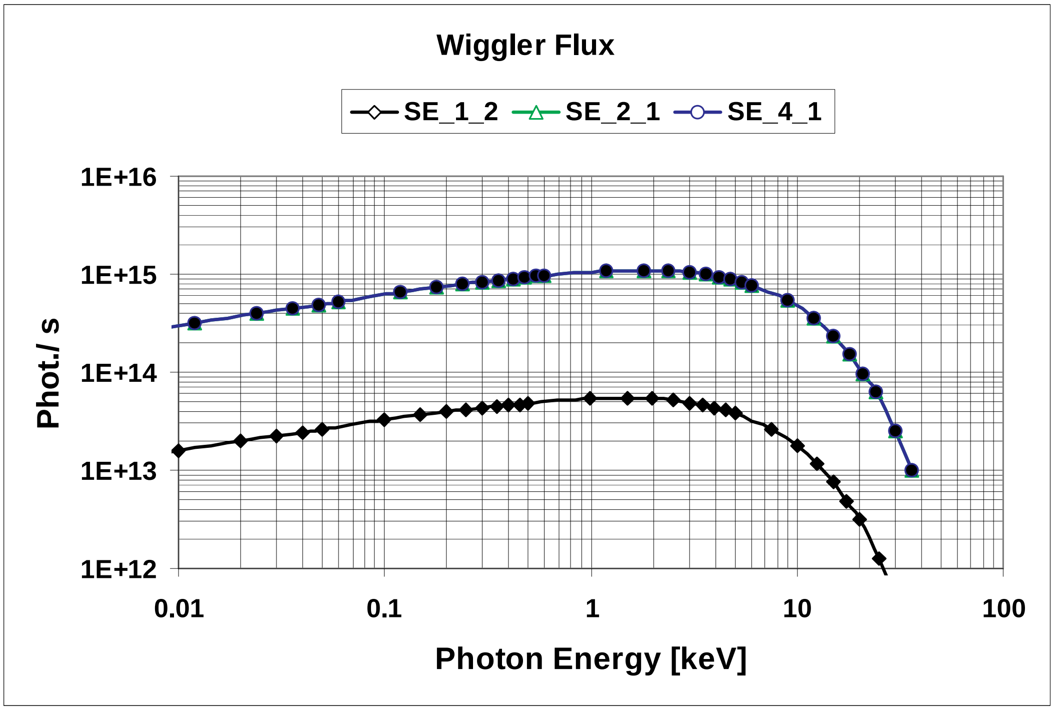

Figure 3.9: Flux of the synchrotron radiation from the wiggler for the versions: SES_1_2, SES_2_1 and SES_4_1. As shown, the flux of the versions SES_2_1 and SES_4_1 are the same because of the same specifications.

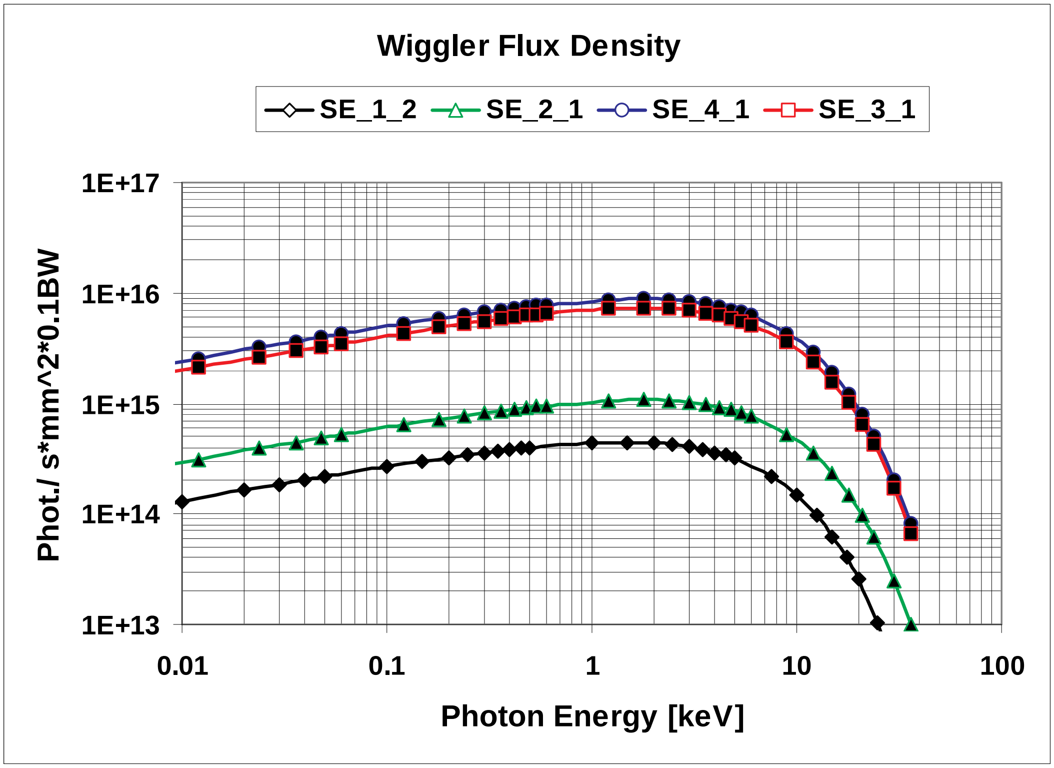

Figure 3.10: Flux density of synchrotron radiation from the wigglers of the versions SES_1_2, SES_2_1, SES_4_1 and SES_3_1

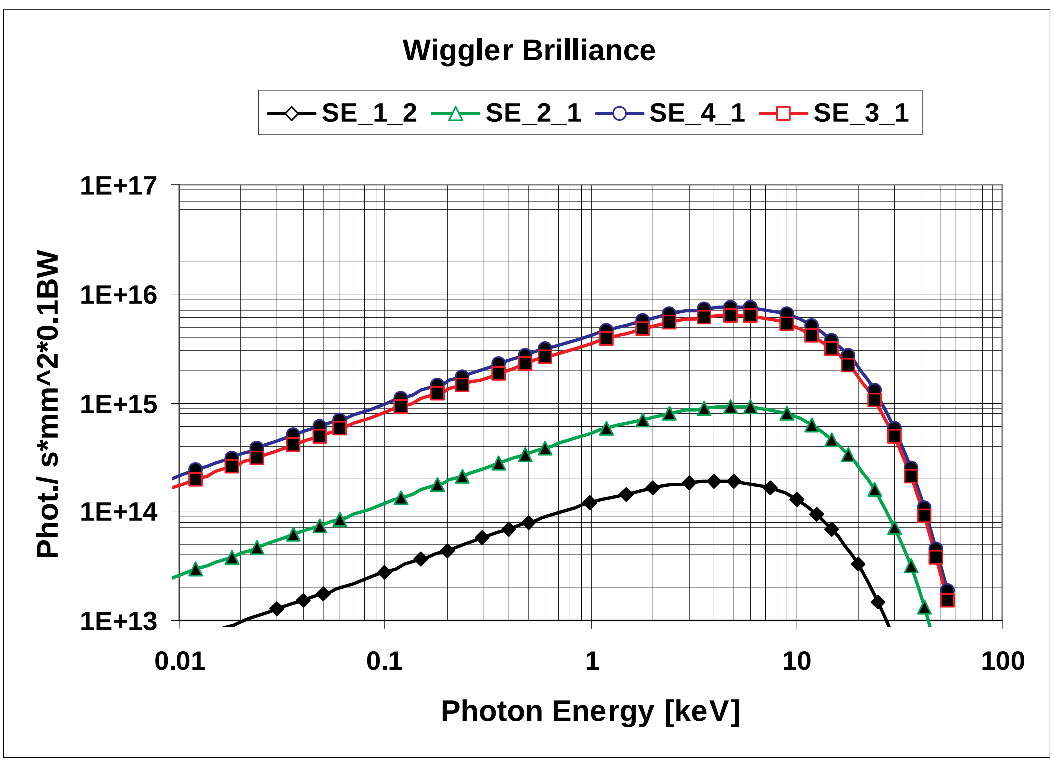

Figure 3.11: Brilliance of synchrotron radiation from the wigglers of the versions SES_1_2, SES_2_1, SES_4_1 and SES_3_1

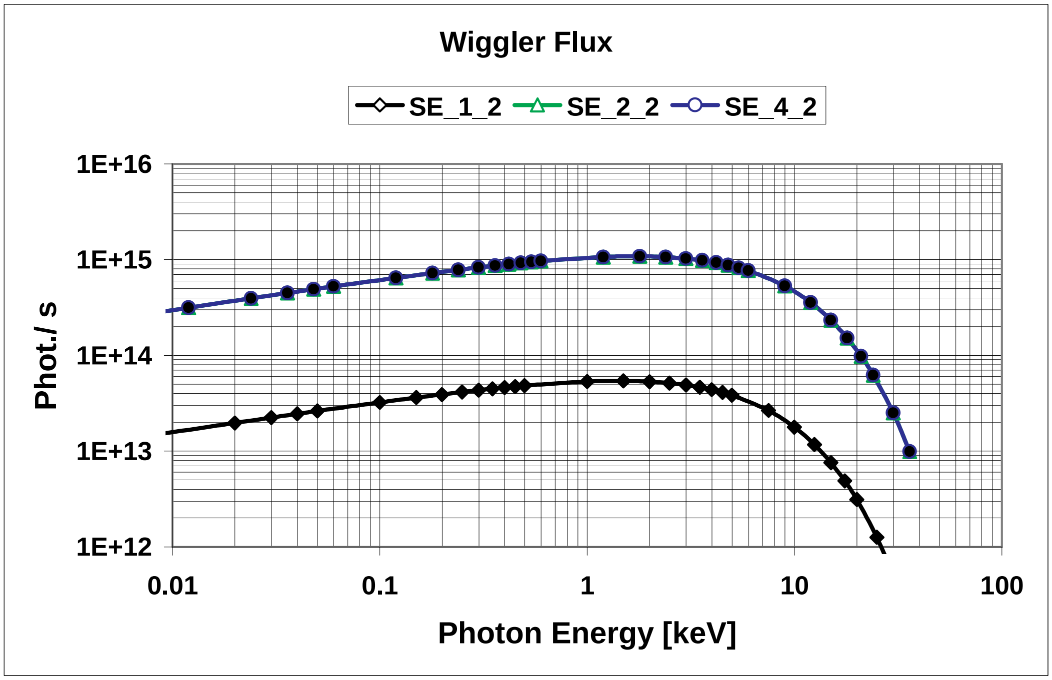

Figure 3.12: Flux of the synchrotron radiation from the wiggler for the versions: SES_1_2, SES_2_2 and SES_4_2. As shown the flux of versions SES_2_2 and SES_4_2 are the same because of the same specifications.

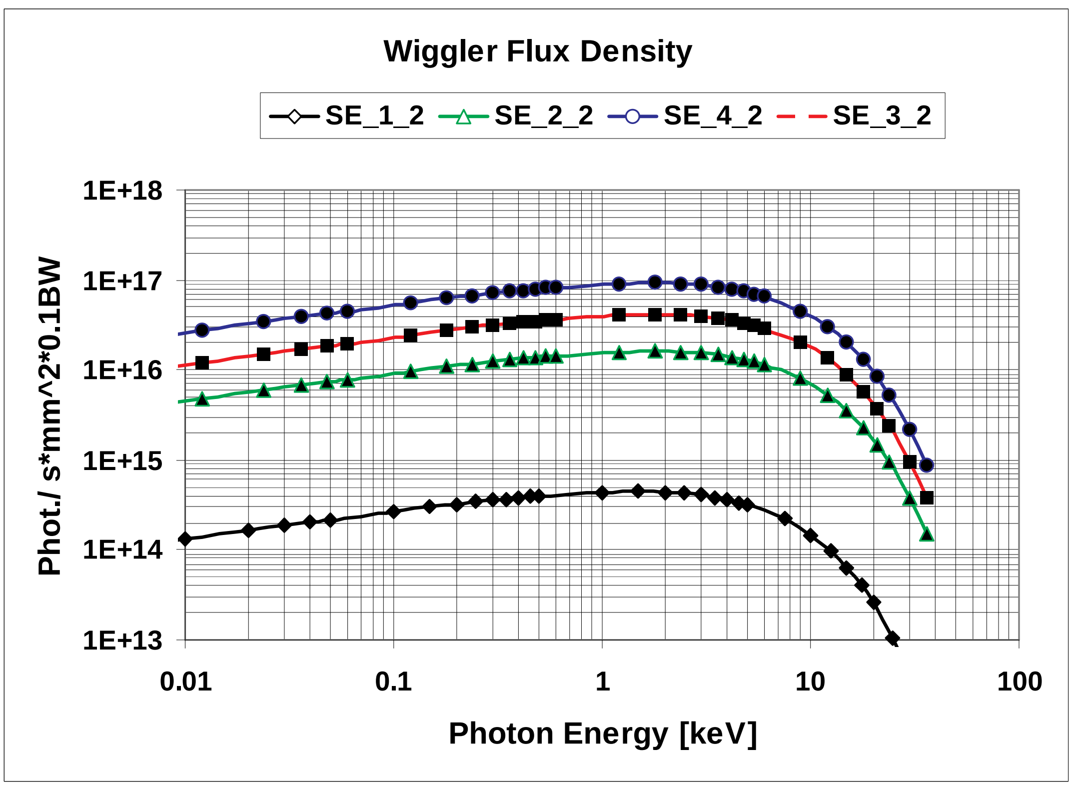

Figure 3.13: Flux density of synchrotron radiation from the wigglers of the versions SES_1_2, SES_2_2, SES_4_2 and SES_3_2

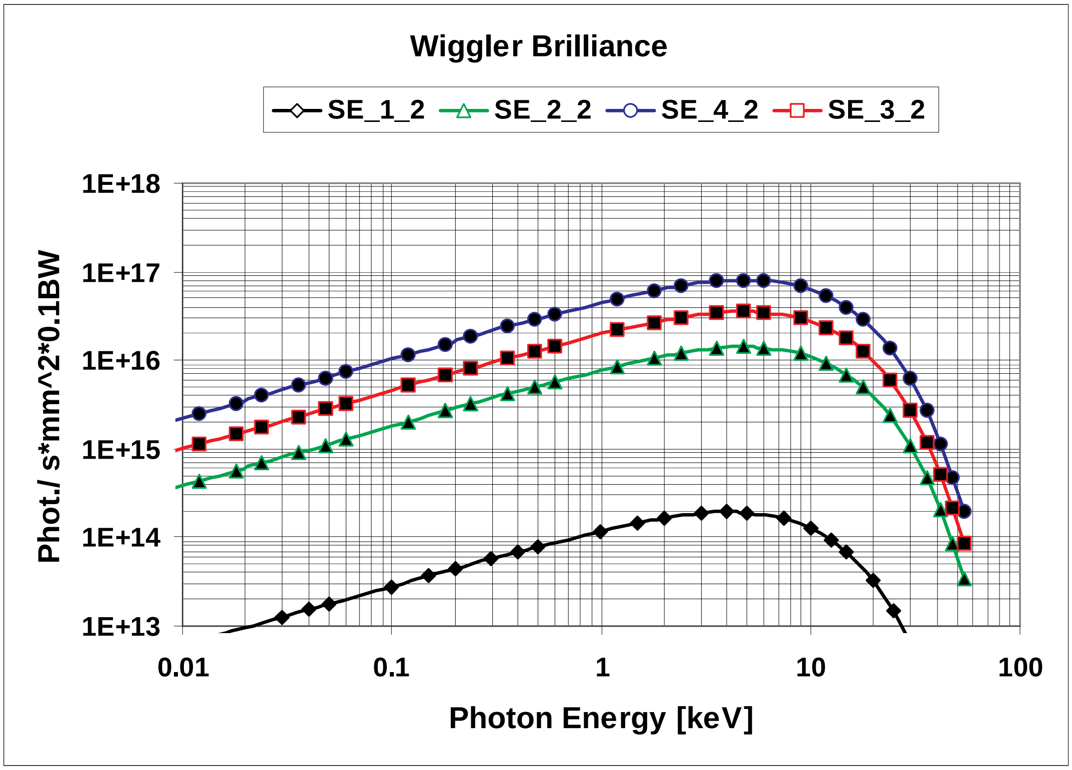

Figure 3.14: Brilliance of synchrotron radiation from the wigglers of the versions SES_1_2, SES_2_2, SES_4_2 and SES_3_2