Where is the CLS Located?
Saskatoon, Saskatchewan, CANADA

M. Benmerrouche, HSE Manager

http://www.lightsource.ca
University of Saskatchewan campus
CLS Facility

- Located on the University of Saskatchewan campus
- CLSI has the responsibility for operating the synchrotron facility in Canada and providing infrastructure support for the Canadian synchrotron research community as well as contributions to international synchrotron projects.
- It includes:
  - Linac - a 250 MeV electron accelerator, which was part of the former SAL,
  - Booster Ring - a 250 MeV to 2.9 GeV electron accelerator,
  - Storage Ring - a 2.9 GeV storage ring and the source of the SR,
  - Beamlines - for transport of SR to experimental target stations, where scientific experiments or processes requiring SR are carried out (infrared to hard X-rays, 0.01 eV – 100 keV)
- Facility Conventional Construction
  - began ~ June 1999 and completed ~ January 2001
  - Bulk shielding completed April 2001
  - Building expansion on the north-east to accommodate BMIT beamlines completed in December 2007
- Accelerator commissioning
  - began ~ June 2001 and completed ~ May 2004
- Routine Operation
  - began in August 2004 and includes 7 research beamlines and 2 diagnostic beamlines (Phase I)
  - Users other than CLSI staff were allowed to access synchrotron beamlines for research
- Top-up mode
  - Preliminary radiological studies completed in December 2005
- Phase I beamlines
  - The CLS Phase I project was finished in 2005 and included first set of 7 beamlines.
- Phase II Beamlines Projects
  - 7 additional Phase II beamlines are in the final stages of commissioning.
  - Expected to be available for general users by the end of 2009.
- Phase III Beamlines Projects
  - Three projects together comprise five new beamlines and are in planning/design/Early construction phase
  - Commissioning phase to start by 2012.
  - Building expansion required to house some of the Phase III beamlines
CLS Facility Main Components
Accelerators & beamlines

- **E-gun & Linear Accelerator 300 MeV**
  - Commissioned 2002

- **Booster Ring & Transfer Line**
  - Commissioned 2002

- **Storage Ring (2.9 GeV, 200 mA)**
  - Commissioned 2003

- **Beamline & End Stations**
  - 1st beamline
  - Commissioned 2004

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CLS Beamlines
Existing, Planned, and Future

Building
Linac - LTB1
BR1 - BTS1
SR1

Shielding

Phase I
Phase II  Phase III
Beamlines - Future
Some Components of Front-End and Beamines

- Shield Wall
- Aperture
- Slits
- Filters
- Scanner
- DC Monochromator
- Shutters
- Slits
- Screen
- Windows
- Shutters
- Windows
Sources of Radiation For Beamlines
Enclosure Shielding

- **Gas Bremsstrahlung:**
  - Production rate well described by Koch/Motz formula [Rev. Mod Phys 31, 1959]
  - Depends on
    - energy of circulating electrons and stored current
    - residual gas composition and pressure
    - length of straight section

- **Synchrotron Radiation:**
  - Bending magnet or Insertion Device (Wiggler or undulator)
  - Depends on
    - electron energy and stored current
    - SR source parameters such as magnetic field strength, critical energy, no of poles
  - Fluka simulations performed for the bending magnet beamline
<table>
<thead>
<tr>
<th>MB_LSOPT</th>
<th>Type: ▼</th>
<th>Optimize: off ▼</th>
</tr>
</thead>
<tbody>
<tr>
<td>h/µ steps: 0</td>
<td>h/µ Corr: No corrections ▼</td>
<td>e-e+ Corr: no MCS ▼</td>
</tr>
<tr>
<td>e-e+ steps: 0</td>
<td>to Mat: ▼</td>
<td>Step:</td>
</tr>
<tr>
<td>Mat: AIRPLOW ▼</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Physics**

<table>
<thead>
<tr>
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<th>e-e+ Brem: 0.0</th>
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<tr>
<td>Photonuc: 0.0</td>
<td>to Mat: ▼</td>
<td>y Bhabha/Moller: 4.0</td>
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<tr>
<td>Old brems.: off ▼</td>
<td>Step:</td>
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</tr>
<tr>
<td>Compton: off ▼</td>
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<table>
<thead>
<tr>
<th>EMFCUT</th>
<th>Type: ▼</th>
<th>e-e+: -4.0</th>
</tr>
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<tr>
<td>Bremsstrahlung: off ▼</td>
<td>Pair Prod.: off ▼</td>
<td>y: 0.0</td>
</tr>
<tr>
<td>Bhabha&amp;Moller: off ▼</td>
<td>Photo-electric: off ▼</td>
<td>e+ ann @rest: off ▼</td>
</tr>
<tr>
<td>Reg: EX6 ▼</td>
<td>to Reg: ▼</td>
<td>e+ ann @flight: off ▼</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>EMFCUT</th>
<th>Type: ▼</th>
<th>e-e+: -0.0005</th>
</tr>
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<tr>
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<td>Pair Prod.: off ▼</td>
<td>y: 0.00001</td>
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<tr>
<td>Bhabha&amp;Moller: off ▼</td>
<td>Photo-electric: off ▼</td>
<td>e+ ann @flight: off ▼</td>
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<tr>
<td>Reg: PSH ▼</td>
<td>to Reg: ▼</td>
<td>Step:</td>
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</table>

<table>
<thead>
<tr>
<th>PHOTONUC</th>
<th>Type: ▼</th>
<th>All E: off ▼</th>
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</thead>
<tbody>
<tr>
<td>E&gt;0.7GeV On ▼</td>
<td>Quasi D On ▼</td>
<td>Giant Dipole On ▼</td>
</tr>
<tr>
<td>Δ resonance On ▼</td>
<td>to Mat: ▼</td>
<td>Step:</td>
</tr>
<tr>
<td>Mat: LEAD ▼</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

reduce inelastic interaction length of photons by 0.02

<table>
<thead>
<tr>
<th>LAM-BIAS</th>
<th>Type: ▼</th>
<th>± mean life: 0.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mat: ▼</td>
<td>to Part: ▼</td>
<td>± λ inelastic: 0.02</td>
</tr>
<tr>
<td>Part: PHOTON ▼</td>
<td>Step:</td>
<td></td>
</tr>
</tbody>
</table>
Geometry Material View
IDEAS Bending Magnet Beamline

CLS B208 IDEAS POE for GB and SR Simulations

M. Benmerrouche, HSE Manager
http://www.lightsource.ca
## Materials

<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>Name: AIRPLOW</th>
<th>Z:</th>
<th>A:</th>
<th>#: 26.0</th>
<th>p: 0.0001205</th>
<th>dE/dx: ▼</th>
</tr>
</thead>
<tbody>
<tr>
<td>COMPOUND</td>
<td>Name: AIRPLOW ▼</td>
<td>M1: NITROGEN ▼</td>
<td>M2: OXYGEN ▼</td>
<td>f1: 0.78084</td>
<td>f2: 0.20946</td>
<td>Elements: 1,3 ▼</td>
</tr>
<tr>
<td>MAT-PROP</td>
<td>Type: ▼</td>
<td>Mix: Mass ▼</td>
<td>M3: ▼</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mat: AIRPLOW ▼</td>
<td>to Mat: ▼</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Set pressure in the air column to 0.1 atm.

### 276 Water liquid H2O

**Chemical Formula:** H -- O -- H

<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>Name: WATER</th>
<th>Z:</th>
<th>A:</th>
<th>#:</th>
<th>p: 1.0</th>
<th>dE/dx: ▼</th>
</tr>
</thead>
<tbody>
<tr>
<td>COMPOUND</td>
<td>Name: WATER ▼</td>
<td>M1: HYDROGEN ▼</td>
<td>M2: OXYGEN ▼</td>
<td>f1: 2.0</td>
<td>f2: 1.0</td>
<td>Elements: 1,3 ▼</td>
</tr>
<tr>
<td>MAT-PROP</td>
<td>Type: ▼</td>
<td>Mix: Atom ▼</td>
<td>M3: ▼</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ionization: 75.0</td>
<td>Gas pressure:</td>
<td>to Mat: ▼</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mat: WATER ▼</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### STERNHEI

- Cbar: 3.5017
- a: 0.9116

### 104 Air dry (near sea level)

<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>Name: AIR</th>
<th>Z:</th>
<th>A:</th>
<th>#:</th>
<th>p: 0.0012048</th>
<th>dE/dx: ▼</th>
</tr>
</thead>
<tbody>
<tr>
<td>COMPOUND</td>
<td>Name: AIR ▼</td>
<td>M1: CARBON ▼</td>
<td>M2: NITROGEN ▼</td>
<td>f1: 0.0001248</td>
<td>f2: 0.755267</td>
<td>Elements: 4,6 ▼</td>
</tr>
<tr>
<td>M3: OXYGEN ▼</td>
<td>f3: 0.231781</td>
<td>M4: ARGON ▼</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M5: ▼</td>
<td>f4: 0.012827</td>
<td>M6: ▼</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>f5: ▼</td>
<td>f6: ▼</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>MAT-PROP</td>
<td>Type: ▼</td>
<td>Gas pressure:</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Ionization: 85.7</td>
<td>to Mat: ▼</td>
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<tr>
<td>Mat: AIR ▼</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### STERNHEI

- Cbar: 10.5961
- a: 0.10914

---

M. Benmerrouche, HSE Manager

http://www.lightsource.ca
### Usbdx Scoring

<table>
<thead>
<tr>
<th>USRBDFX</th>
<th>Type: ( \Phi, \text{LogE}, \text{Lin}\Omega )</th>
<th>Unit: 58 BIN ▼</th>
<th>Name: gb-fl</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Part: PHOTON ▼</td>
<td>to Reg: GBFL ▼</td>
<td>Area: 1.0</td>
</tr>
<tr>
<td></td>
<td>Reg: GBPOE ▼</td>
<td>Emax: 3.0</td>
<td>Ebins: 50.0</td>
</tr>
<tr>
<td></td>
<td>Emin: 1.0E-06</td>
<td>Qmax:</td>
<td>Qbins: 1.0</td>
</tr>
<tr>
<td></td>
<td>Qmin:</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>USRBDFX</th>
<th>Type: ( \Phi, \text{LinE}, \text{Lin}\Omega )</th>
<th>Unit: 58 BIN ▼</th>
<th>Name: gb-fl-iii</th>
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<tbody>
<tr>
<td></td>
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<td>to Reg: GBFL ▼</td>
<td>Area: 1.0</td>
</tr>
<tr>
<td></td>
<td>Reg: GBPOE ▼</td>
<td>Emax: 1.0E-03</td>
<td>Ebins: 100.0</td>
</tr>
<tr>
<td></td>
<td>Emin: 1.0E-06</td>
<td>Qmax:</td>
<td>Qbins: 1.0</td>
</tr>
<tr>
<td></td>
<td>Qmin:</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>USRBDFX</th>
<th>Type: ( \Phi, \text{LinE}, \text{Lin}\Omega )</th>
<th>Unit: 58 BIN ▼</th>
<th>Name: gb-fl-iih</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Part: PHOTON ▼</td>
<td>to Reg: GBFL ▼</td>
<td>Area: 1.0</td>
</tr>
<tr>
<td></td>
<td>Reg: GBPOE ▼</td>
<td>Emax: 3.0</td>
<td>Ebins: 100.0</td>
</tr>
<tr>
<td></td>
<td>Emin: 1.0E-03</td>
<td>Qmax:</td>
<td>Qbins: 1.0</td>
</tr>
<tr>
<td></td>
<td>Qmin:</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
set mxtics 10
set mytics 10
#set xtics ("-06" -pi/2, "-.45" -pi/4, "0" 0, "45" pi/4, "90" pi/2)
# Fraction of GB power exiting the GB flange
fr_fl = 5.6087328E-03/5.7574552E-03
print 1/fr_fl
# Fraction of GB power hitting the upper target in SOE
fr_Tg = 5.0434833E-03/5.7574552E-03
print 1/fr_Tg
#MATERIAL
#COMPOUND
#MAT-PROP
# Residual gas
z0 = 10.4502
# 20 = 10.3
# 20 = 9.4
# 20 = 10.2
a0 = 29.4454
print 10.45*(10.45+1.0)/(10.2*(10.2+1.0))
R0 = 1.225E-04
P0 = 0.1*1.01E+05
# ring energy
Ee = 2.9
# air target length (cm)
l0 = 600.0
# avogadro no
av = 6.022E+23
vol = 2.24E+04
# c = 4.0*al+re^2 with al=1/137 and re=2.82e-13 cm (classical electron radius)
c = 2.32E-27
cl(z) = c*tl(z)*(z+1.0)*(pa/1.01e+05)*(av/vol_N)
c2(z,a) = c*tl(z)*(z+1.0)*(av*tl0/a)
phi(x,z) = (1.0 + (1.0 - x/2)*2.0 - 2.0/3.0*(1.0 - x/Ee))*log(183.0/z**(1.0/3.0)) + 1.0/9.0*(
g(x,z) = x^*cl(z)*phi(x,z)
replot ng(x,20)/x w lines lt 10 lw 2 title "THEORY"
### Flair USBIN Plots/Analysis

**ambient dose**

**USBIN**
- **Type**: X-Y-Z
- **Part**: DOSE-EQ
- **Xmin**: 200.0
- **Ymin**: -150.0
- **Zmin**: 100.0
- **Unit**: 60 BIN
- **Xmax**: 1200.0
- **Ymax**: 150.0
- **Zmax**: 150.0
- **Name**: gde_in
- **NX**: 400.0
- **NY**: 100.0
- **NZ**: 100.0

**AUXSCORE**
- **Type**: USBIN
- **Part**: PHOTON
- **Det**: gde_in

---

**Plot**

**Title**: Photon Ambient Dose Equivalent

**File**: bl_gen_usbín_60_plot

- **Axes Labels**
  - **X**: Z (cm) [Beam Direction]
  - **Y**: X (cm) [Elevation]
  - **CB**: uSv/hr

- **Binning Detector**
  - **File**: bl_gen_usbín_60
  - **Title**: CLS B208 Beamline (IDEAS) POE/POE
  - **Cycles**: 7
  - **Primaries**: 70000000
  - **Weight**: 70000000.0
  - **Time**: ****** Sum file ******

- **Binning Info**
  - **Det**: gde_in
  - **Type**: X-Y-Z
  - **Score**: DOSE-EQ
  - **Min**: 2.62916515E-08
  - **Max**: 0.0193166174
  - **Int**: 169.365624

- **Projection & Limits**
  - **X**: [200 .. 1200] x 400 (2.5)
  - **Y**: [-150 .. 150] x 100 (3)
  - **Z**: [-100 .. 150] x 100 (2.5)

---

**M. Benmerrouche, HSE Manager**

http://www.lightsource.ca
Photon Ambient Dose Profile
(6 m long straight)
Neutron Ambient Dose Profile (6 m long straight)

M. Benmerrouche, HSE Manager

http://www.lightsource.ca
**Comparison with earlier shielding Calculations for GB Only**

**Bending Magnet POE Shielding Requirements (GB Only)**

<table>
<thead>
<tr>
<th>Back-wall:</th>
<th>EGS</th>
<th>FLUKA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10 mm Pb</td>
<td>5 mm Fe</td>
</tr>
<tr>
<td></td>
<td>(+20 mm Pb locally)</td>
<td>(+25 mm Pb locally)</td>
</tr>
</tbody>
</table>

| Side-wall:       | 5 mm Pb              | 3 mm Fe                |
| Roof:            | 5 mm Pb              | 3 mm Fe                |

- EGS dose estimates based on energy deposited in water phantom while FLUKA uses AMB74 ambient dose equivalent.
- EGS results assumes 12 cm long straight (BM) while FLUKA are based on a 6m long straight – factor of about 50 reduction
- Both are for 500 mA stored current and 2.9 GeV electron energy.
- EGS assumes an effective z for residual gas to be 8.1 while FLUKA uses an effective z of about 10.5.
• Source parameters: $E=2.9$ GeV, $B=1.354$ T, 7.572 keV

• Use Spectrum generated by STAC8 as input for FLUKA simulations using source.f file
DO 2 I = 1, NPOINT
   READ(81,*,END=999) SR_E(I), SR_S(I)
   SR_E(I) = SR_E(I)*EFAC
   WRITE(LUNOUT,*)I,SR_E(I),SR_S(I)
  2 CONTINUE
999 CONTINUE
   SR_I(1) = ZERZER

Calculate the cumulative function
   DO I = 2, NPOINT
      SR_I(I) = SR_I(I-1) + HLFHLF*(SR_S(I)+SR_S(I-1))
      $      (SR_E(I) - SR_E(I-1))
      WRITE(LUNOUT,*) I, SR_E(I), SR_I(I)
   END DO
   SUM = SR_I(NPOINT)
   DO I = 2, NPOINT
      SR_I(I) = SR_I(I)/SUM
      WRITE(LUNOUT,*) I, SR_E(I), SR_I(I)
   END DO
END DO

* Push one source particle to the stack. Note that you could as well
* push many but this way we reserve a maximum amount of space in the
* stack for the secondaries to be generated Npflka is the stack counter: of course any time source is called it must be =0
RAN_E = FLRNDM(TKESUM)
ENERGY = ENMIN + (ENMAX - ENMIN) * RAN_E
DO 3 I = 1, NPOINT - 1
   IF(ENERGY .GT. SR_E(I) .AND. ENERGY .LE. SR_E(I+1)) THEN
      WEIGHT = SR_S(I) + (SR_S(I+1) - SR_S(I)) *
                    (ENERGY - SR_E(I))/(SR_E(I+1) - SR_E(I))
      GO TO 4
   END IF
  3 CONTINUE
  4 CONTINUE
   NPFLKA = NPFLKA + 1

* Wt is the weight of the particle
WTFLK (NPFLKA) = ONEONE
WTFLK (NPFLKA) = WEIGHT
WEIPRI = WEIPRI + WTFLK (NPFLKA)
Synchrotron Radiation Photon Fluence

M. Benmerrouche, HSE Manager

http://www.lightsource.ca
Conclusions/Remarks

• Need to understand the differences between EGS and FLUKA for the GB calculations
  – Run comparison using same input, target, geometry, etc...

• Radiation experiments have been conducted exposing Luxels to radiation inside a Bending magnet primary enclosure
  – Data is being analyzed
  – Compare results with FLUKA and STAC8 (SR Radiation)
Future Use of Fluka

- **Phase III Beamlines (CLS)**
  - Compare radiation measurements during beamline commissioning with Fluka predictions
  - Brochouse beamline shielding design
- **Top-up mode of Operation Radiation Analysis (CLS)**
  - Radiation analysis of Front-ends and beamlines
- **Medical Isotope Project (CLS)**
  - Low Energy High Power electron Linac (35 MeV, 35 kW) shielding
  - Activation of accelerator components, target, cooling water and surrounding air
  - Estimate of Mo-99 from Mo-100 target
- **Accelerator specific radiation analyses (CLS)**
  - Booster to Storage ring collimator and scraper
  - Revisit local shielding in the Booster injection area
- **Elinac project (Triumf)**
  - Collaboration with Anne Trudel and Mike Trinczek
Acknowledgment

- **Fluka:**
  - Fluka organization for providing the FLUKA Code

- **FLAIR:**
  - Vasilis Vlachoudis

- **SimpleGeo:**

- **STAC8:**
  - Yohishiro Asano for providing the STAC8 code
  - Developed by Y. Asano for shielding SR beamlines at SPring8
  - STAC8 Refs:

- **Radiation Measurements:**
  - Pavi Selvaraj and Lyndon Cowles for carrying out the radiation experiments on SXRMB bending magnet beamlime.