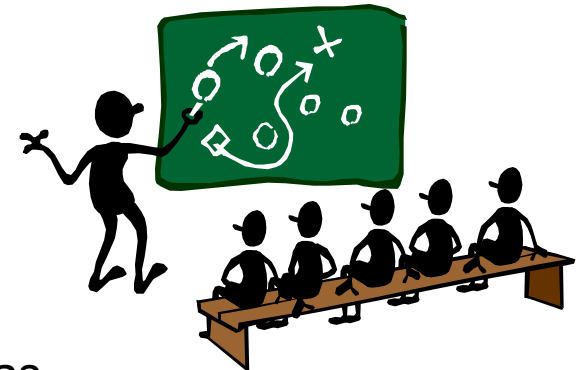


# Radiation Safety Issues in the SPS Experimental Areas

## Outline

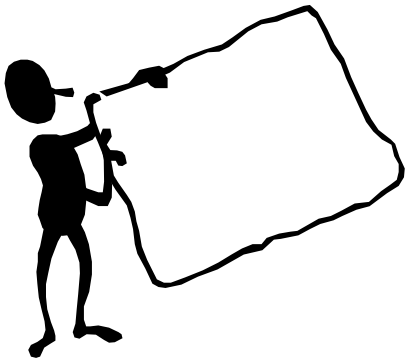
- Radiation issues in the beam lines
  - glossary
  - beam induced radiation
  - radiation incidents
- Marking – Warning signs
  - measuring devices
  - RP Central Data Acquisition System
- Additional radiation sources in the areas
- Classification of Radioactive Areas
- Dumps and fences



# Disclaimer

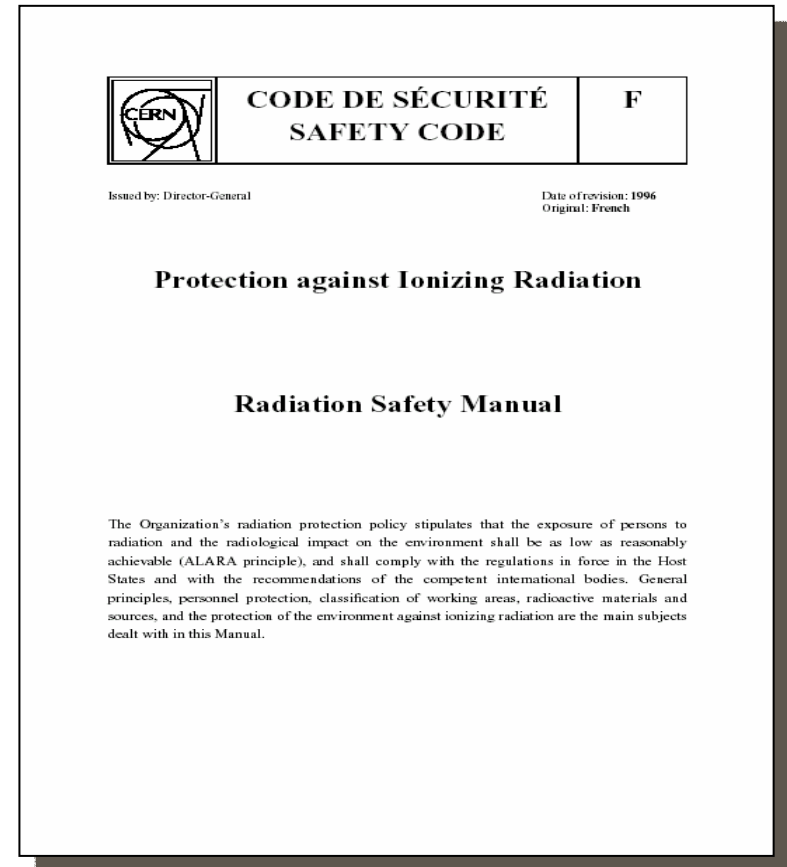
- This is NOT a radiation safety course!
- Not complete, focused in EA problematic
- Contact the experts (TIS/RP) for more detailed information
- If interested, we could organize a dedicated RP course

Lot of material was found and copied from the TIS/RP web pages



## Useful links for further reading

- <http://tis-div-rp.web.cern.ch/tis-div-rp/document/document.htm>
- [http://tis-div-rp.web.cern.ch/tis-div-rp/document/list\\_prp.htm](http://tis-div-rp.web.cern.ch/tis-div-rp/document/list_prp.htm)
- <http://tis-div-rp.web.cern.ch/tis-div-rp/training/training.htm>



# Radiation issues in the beam lines

- External radiation
  - radiation from sources outside of the body
- Sources of radiation in EA
  - accelerator and beam
    - direct in-beam exposure
    - induced radioactivity to shielding or detector/beam line equipment
  - radioactive sources used by experiments
- Types of radiation:

the **ALARA** Principle  
 "As Little As Reasonably Achievable"

<b><math>\gamma</math>-radiation</b>	photons of high-energy, X-rays	long-range, penetrating
<b>n-radiation</b>	elementary particle	long-range, penetrating Wide range of energies → wide range of effects
<b><math>\beta</math>-radiation</b>	electrons	relatively short range, modestly penetrating easy to shield
<b><math>\mu</math>-radiation</b>	muons ("heavy electrons")	penetrating, impossible to shield
<b><math>\alpha</math>-radiation</b>	He nuclei, decay of heavy nuclei	short range, not penetrating very easy to shield

# Glossary

## Dose [Gray]

- Corresponds to an energy absorption of 1 J/kg
  - $= 6.24 \times 10^{12} \text{ MeV kg}^{-1}$  of deposited energy

## Equivalent Dose [Sievert]:

- Corresponds to the dose multiplied by a factor which depends on the dE/dx spectrum of the radiation
  - this factor is mainly valid for long-term exposure and not for accidental, exposures
  - $1\text{Sv} = \text{absorbed dose in gray} \times \omega_R$

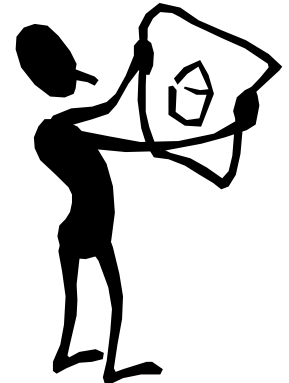
Radiation		$\omega_R$
X- and g- rays, all energies		1
Electrons and muons, all energies		1
Neutrons	<10 keV	5
	10-100 keV	10
	>100 keV to 2 MeV	20
	2-20 MeV	10
	>20 MeV	5
Photons (other than recoils) > 2 MeV		5
Alphas, fission fragments, & heavy nuclei		20

## Activity [Becquerel]:

- Denotes the number of disintegrations per second
  - old unit: [Curie =  $3.7 \cdot 10^{10} \text{ Bq}$ ]

## Dose and Biological effects

- Basically due to ionization  $\rightarrow$  damage cells
- Immediate biological effects (high doses)
  - erythem, headache, sickness, immunodeficiency
- Stochastic biological effects
  - damage to the DNA
  - possible mutation of cell
  - cancer



## ... Glossary

### Dose equivalent limits

- Switzerland 20 mSv/year
- CERN 15 mSv/year
- Most of EU 50 mSv/year

### Everyday dose examples

- X-ray shot of thorax 0.3mSv
- Cosmic radiation (GVA) 0.8mSv/year
- Computer tomography 10-30mSv

### Natural annual background

- ~(0.4-4) mSv
- Can range up to 50 mSv in certain areas

### Good working practices

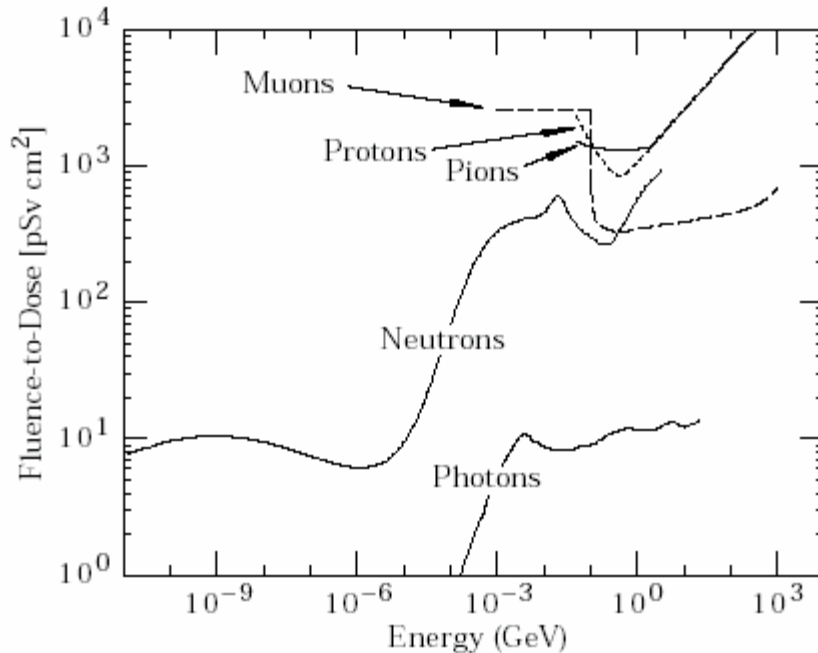
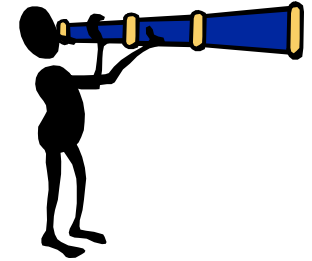
- Reduce exposure/occupancy time
  - Dose = Dose rate  $\times$  time
- Keep your distance
  - Doserate  $\propto$  distance<sup>-2</sup>
- Use shielding

$\alpha$ -particle	thin layer of foil
$\beta$ -particle	cm-thick plastic
$\gamma$ -radiation	several cm to m of heavy metals
neutron-radiation	one to several m of concrete and iron

- Controlled areas
  - keep them clean
  - no food/drinks allowed
  - signal unknown doubtful material

# Beam induced radiation

## Fluence to dose equivalent conversion factors for various particles



- Assuming uniform flux without any cascading of a secondary pion beam of 300 GeV/c
  - $10^8$  ppp, 250 pulses/hour
  - corresponds to **~500 mSv/h**

## Watch out! - Muons

- Leptons, "heavy electrons",
    - $m=105$  MeV,  $\tau=2.2\mu\text{s}$
  - Produced in the decay of pions and kaons
    - directly in the beam
      - $\sim 1\%$  of total hadron flux in a  $10 \times 10 \text{ cm}^2$  surface
      - and another  $\sim 1\%$  in a  $\sim 100 \times 100 \text{ cm}^2$  surface
    - or in cascades of high energy hadrons
    - or high-energy hadron-nucleus interactions
  - Weakly interacting particles
  - Mainly lose energy by ionization
    - $\langle dE/dx \rangle \cong \sim 3.8$  MeV/g  $\text{cm}^2$
  - Muon shielding is important for high energies
    - muons of  $>2-3$  GeV can penetrate Fe dumps of 1-2m, typically used in the Exp. Areas to stop the pions/hadrons
  - Assuming a uniform flux in a  $10 \times 10 \text{ cm}^2$  surface (a typical scintillator counter) :
    - $3.8$  [MeV  $\text{g}^{-1} \text{ cm}^2$ ]/ $100$  [ $\text{cm}^2$ ] =  $38$  [MeV  $\text{Kg}^{-1}$ ] -->  $\sim 6 \times 10^{-12}$  Gy
- $10^6$  muons/pulse =>  $6 \mu\text{Gy/pulse} \rightarrow 1.5 \text{ mGy/h}$**

## ... Beam induced radiation

### Heavy Ion beams

- The stray radiation in relativistic heavy ion beam rises proportional to the number of nucleons in the projectile nucleus
- Therefore the dose rates of Pb-ion beam are about 200 times higher than a secondary particle beam of the same intensity
  - a Pb-ion beam of  $10^6$  ions is equivalent to a "normal" proton beam of  $2 \times 10^8$  particles

in addition

- From the Bethe-Bloch formula:  $dE/dx \propto q^2$ 
  - the MIP energy loss rate of muons(protons)  $\sim 3.8 \text{ MeV/g cm}^2$
  - the MIP energy loss of Pb nucleus:  $82^2 \times 3.8 \text{ MeV/g cm}^2 \rightarrow \sim \mathbf{25 \text{ GeV/g cm}^2}$
- Moreover, the ion energy deposition is distributed over a much larger surface along the ion direction compared to the protons

### Ion beams can become very dangerous

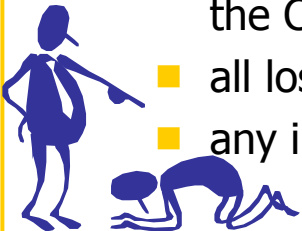
- Compared to the hadron/muon case:
  - $1.5 \times 10^4 \text{ lead-ions/pulse} \rightarrow (\times 82^2 =) \sim 10^8 \mu/\text{pulse}$

# ... Beam induced radiation

## Summary

**Direct in-beam exposure should be avoided at all cases!**

- Hadron or electron beams containing **>10<sup>8</sup> particles/burst** are dangerous
  - should be always dumped in special (thick) dumps (controlled losses)
    - serious irradiation to persons standing close to unshielded loss points
    - unshielded loss points will cause excessively high radiation levels in the experimental hall and cause dose rate limits at the CERN boundaries
  - any in-beam exposure for even one pulse will cause observable biological damage
  - beam line & areas should be completely shielded
- Hadron or electron beams containing **>10<sup>6</sup> particles/burst** should be treated with respect
  - unshielded loss points will cause limiting radiation levels in the experimental halls and at the CERN boundaries
  - all loss points must be completely shielded (dumps)
  - any in-beam exposure is still serious and will cause significant administrative actions





# ... Beam induced radiation

## Summary ...

- Hadron or electron beams containing **<math>10^4</math> particles/burst**

  - could be allowed to travel in open areas
  - still in-beam exposure should be avoided

  
- **Heavy ion beams** of any intensity

  - cannot be allowed to travel through open areas
  - accidental in-beam exposure is dangerous and must be completely avoided

# What you should do in case of a radiation incident

## Radiation alarm due to high beam-rate

- Frequent case during beam tuning
- Identify the source/beam line and check beam status (counters, collimators)
- Try to reduce the rate by closing the acceptance collimators
- Contact the experiment
  - find out if they were trying to do something and if there were/are people or material in danger
- If you have any doubt stop the beam
- Continue with further checking and reload known beam conditions

Don't panic!



## Exposure to Radiation (serious!!)

- Emergency-stop button of a beam line or door was pressed
- If not the case already, stop the beam
- Record beam conditions and parameters and condemn the beam until the investigation is complete and the cause of the incident removed. Do not let anyone do anything
- Contact the experiment. Visit the area and find out the origin of the event
- If there were people involved in the incident that could have been exposed to the beam calm them down and call TIS/RP
- Call the RSO
- Get the user account of events and document them

# Marking – warning signs

- Controlled areas are marked by warning signs indicating the risk of exposure to ionizing radiation
- Wearing a film badge is compulsory



- Radioactive components are clearly marked with warning labels and panels
- Typically the labels show the dose rate at 10cm distance and the date of the measurement



# Measuring devices

## Individual monitoring

- Film badge ( $\gamma$  and neutron radiation)



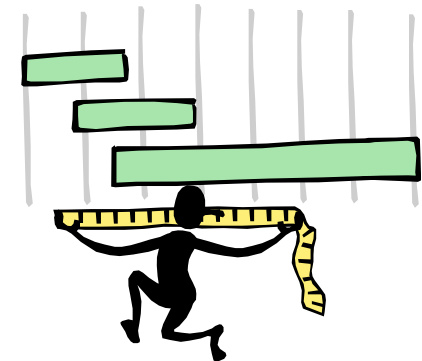
## Personal monitoring

- Stylodosimeters, electronic pocket dosimeters



## Area monitoring

- Ionization chambers
  - 20 atm H- or Ar- filled, air-filled, plastic

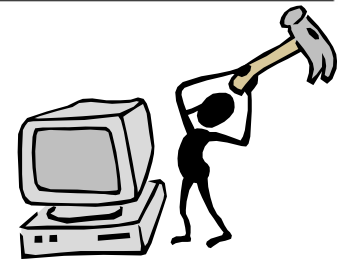
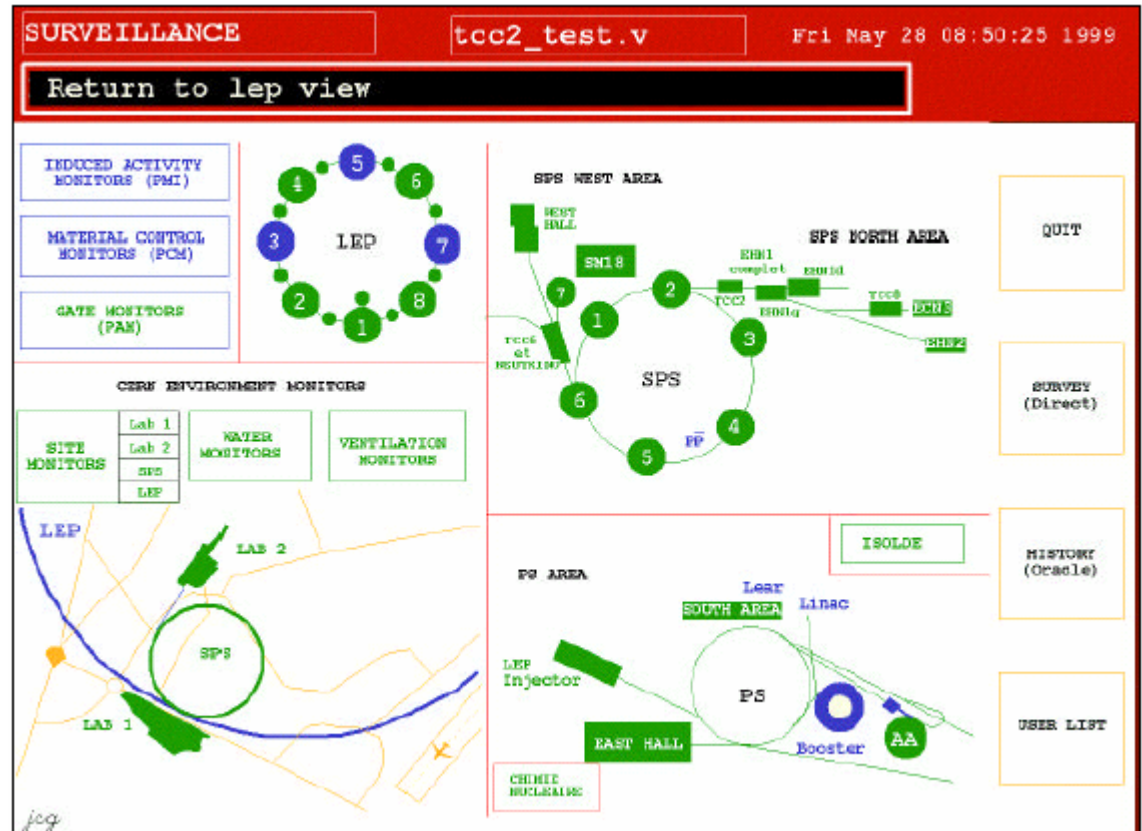


# RP Central data acquisition system

- All installed radiation alarm monitors can be read remotely
- Data are stored in a database for further retrieval
- The parameters for each monitor are accessible
  - can only be set/modified by authorized persons (TIS/RP)

```

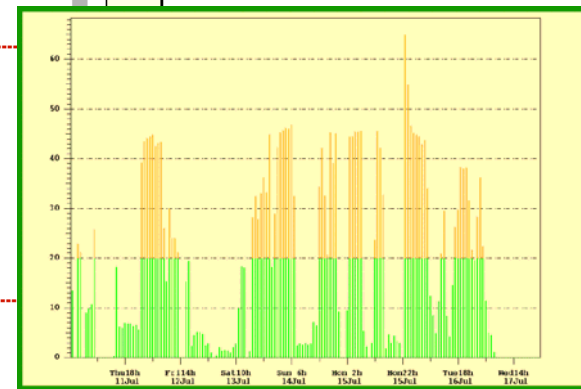
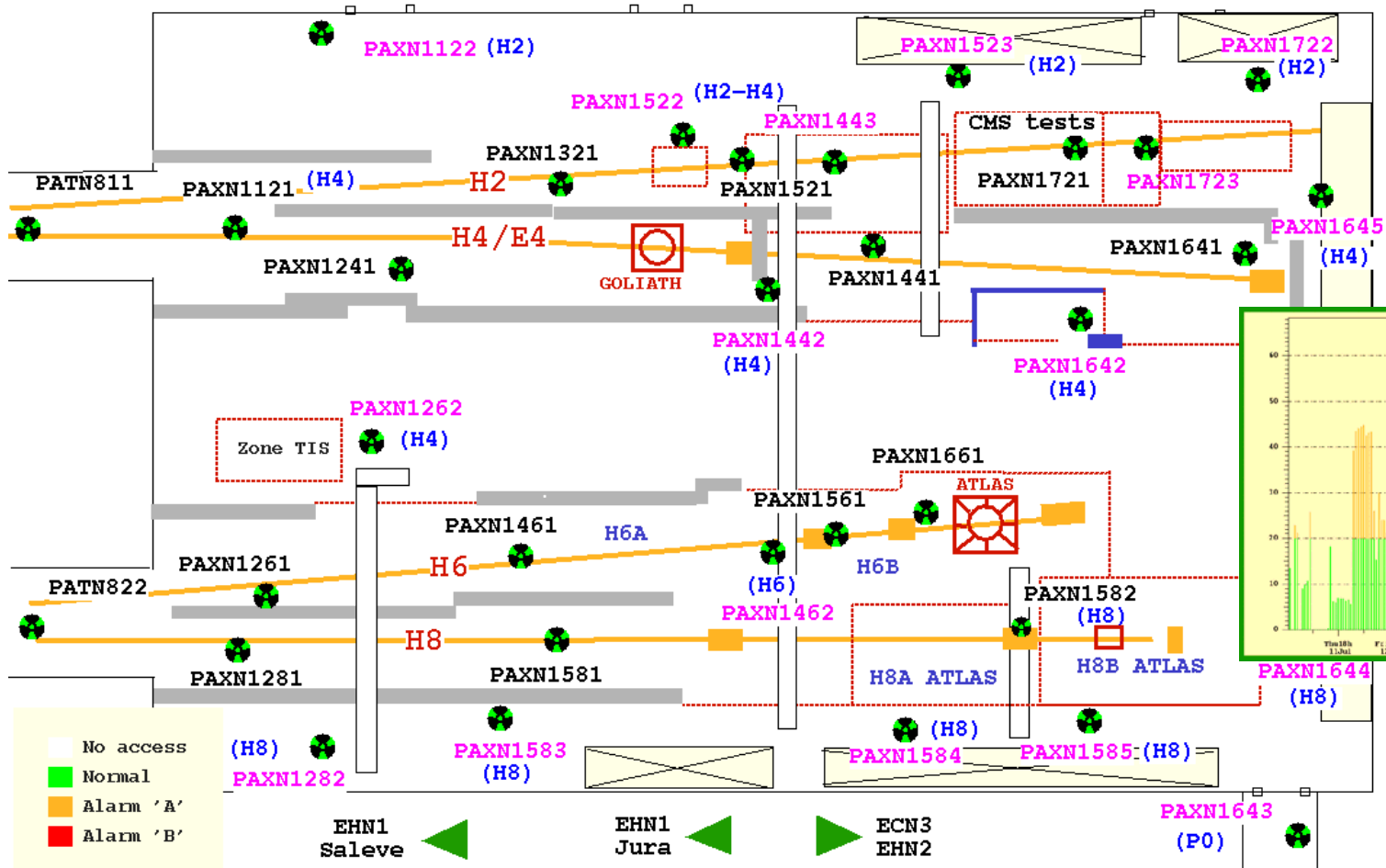
Mnemonic           : PAXN1661
Input Number       : 42
Monitor Type       : H-20
Incm               : 4362
Calibration Factor : 18.80n
Field Factor       : 1.00
Rate Time Constant : 900.00m
Zero Offset        : 0.00
Unit of Measurement : Sv
Measurement Type   : Integral
No. of Rate Alarms : 0
No. of Integral Alarms : 2
Status             : Inhibited
  
```



# ... RP Central data acquisition system

SPS NORTH AREA : EHN1

SPS NORTH AREA  
SITE MONITORS



Radiation protection

# Additional radiation sources in the areas

## Radioactive sources

- Used by the experiments for their detector calibration
- Transport/installation under the TIS/RP responsibility
- Normally a garage position should be available
  - sometimes the source is in interlock with the area access system
- Warning panels at the door of the experimental area

## Lasers

- Used by the experiments for their detector calibration
- Normally setup certified by TIS/RP

## Radioactive detectors

- Uranium calorimeters (not anymore "a la mode"!)
- "hot" detectors after irradiation tests
  - transport/installation under TIS/RP supervision

## Note

- Setups are modified quite often by the users
  - it can happen that information on the changes arrives very late

# Classification of radioactive areas

Area	Dose rate limit ( $\mu\text{Sv/h}$ )		Remarks
	Average	Maximum	
<b>Non designated</b>	$\leq 0.15$	$\leq 0.5$	<ul style="list-style-type: none"> <li>No film badge required</li> <li>Public exposure &lt; 1mSv/year</li> </ul>
<b>Supervised</b>	$\leq 2.5$	$\leq 7.5$	<ul style="list-style-type: none"> <li>No film badge required</li> <li>Employees exposure &lt; 1 mSv/year</li> </ul>
<b>Simple controlled</b>	$\leq 25$	$\leq 100$	<ul style="list-style-type: none"> <li>Film badge required</li> <li>Employees exposure cannot exceed 15mSv/year</li> </ul>
<b>Limited stay</b>	$\leq 2 \text{ mSv/h}$		<ul style="list-style-type: none"> <li>Film badge and personal dosimeter required</li> <li>Work needs authorization of RP or RSO</li> </ul>
<b>High radiation</b>	$> 2 \text{ mSv/h}$ but $\leq 100 \text{ mSv/h}$		<ul style="list-style-type: none"> <li>Film badge and personal dosimeter required</li> <li>Strict access control enforced</li> <li>Access needs authorization of RP or RSO</li> </ul>
<b>Prohibited</b>	$\geq 100 \text{ mSv/h}$		<ul style="list-style-type: none"> <li>Access protected by machine interlocks</li> <li>Access needs authorization of division leader, medical service and RP group</li> <li>Access monitored by RP group</li> </ul>



# Dumps

- Used to orderly stop the hadron/electron beams
  - muons go through but undergo multiple scattering ==> larger cone
- Typically formed by
  - 2-3 m of iron with at least 80cm in each direction from the beam impact point
  - one or two concrete blocks (80cm each) in each direction
- Several dumps can exist in a beam line
  - provide separation between different experimental areas
    - motorized or build in
  - fixed dump at the end of each line

- For high intensity beams the dump is made re-entrant, the particles are dumped into a hole, in order to reduce the particle backslash



- For very high intensities or for special beams (neutrino or muon beams) the dumps consist of many meters of iron, concrete and/or earth shielding
  - examples: M2, P0/NA48, WANF, CNGS

# Motorized dumps

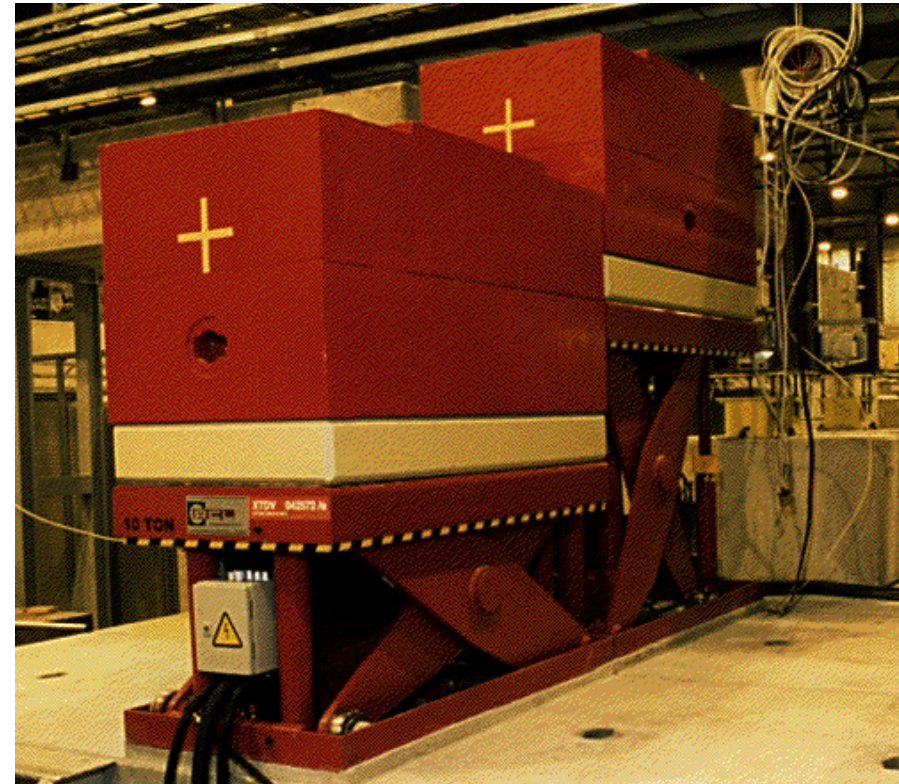
## XTDX – horizontal

- 2-3m of cast iron
- several blocks one next to the other
  - variable configuration
    - replace by concrete the last block for better neutron absorption
- No concrete shielding around it
  - reinforced shielding in the area



## XTDV – vertical

- 3.2m of cast iron
- Is embedded in concrete shielding
  - > 80cm in each direction



# Fences

- Used to mark the limits of the controlled areas
  - at least 2m height
  - should not be possible to climb over
  - no ladders allowed at any point against the fences
- At least 1-2 m away from the nominal beam axis
  - exact size/shape depends on the size of the experiment



## Modification to dumps or fences

- Can ONLY be initiated by the responsible physicist
- Have to be approved by TIS/RP and RSO
  - presented in AB Safety Committee for approval
- During SPS operation if for whatever reason the dumps or fences of the areas have to be modified, the MANUAL VETO of the beam line should be set