The Operation Concept of the Soreq Applied Research Accelerator Facility

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Topics of the Talk

- The facility operation program
- The planned operation group
- Location and layout of main control room
- Architecture of main control system
  - Safety
  - Applications

The SARAF Operation Program

Operation Concept

- Facility is ‘multi-user’ but not ‘multi-tasking’
  - Irradiation will be ‘one target at a time’
  - During irradiation, appropriate shielding will enable preparation at other target stations

The SARAF Operation Program

Available Beam Time

- Maintenance hours (Annual of 4 wks, Quarterly of 2 wks and Monthly of 48 hrs) leave 6700 hrs per year over ~40 wks
- For these weeks we define a 4-week cycle (~670 hrs) of which we plan ~600 hrs (90% availability), for a total of 6000 hrs per yr
- The planned ~600 hrs include 28 hrs per wk 'beam-off' periods on Weekends

The SARAF Operation Program

A Sample operation plan for a typical week

Subject	Beam on Target (hr)	Beam tune (hr)	Beam off (hr)	Ion	Energy (MeV)	Current (mA)
Radio-Pharma	36	~3		d	17	2
Neutrons	4	~3		d	40	2
Basic Research	27	~3		d	20	2
Basic Research	16	~3		d	40	2
Radio-Pharma	8	~3		p	18	0.2
Radio-Pharma	14	~3		p	29	0.25
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- Accelerator will not operate on Weekends

- Total BOT for this week = 105 hr
- Total Beam available = 151 hr

The Planned Operation Group

- SARAF will be a small facility, on the border between ‘Commercial’ and ‘Government Laboratory’
  - Each operator will be on a supervisor/Engineer level
  - They will be ‘Jacks-of-all-Trades’
  - Each operator will have one ‘Primary’ and one (or more) ‘Secondary’ and ‘Tertiary’ expertise
- As the facility matures, non-expert operators may be added
- While facility in operation, two operators per shift

* Concept and definitions inspired by Nigel R. Stevenson, ‘The Organizational Structure of Operations Groups in a Commercial Accelerator Facility, WAO2001 Proceedings, p. 69.

The Planned Operation Group

- Anticipated expertise
  - High Power RF and High DC Voltage, Current
  - Electronics, Computers, Control, Instrumentation
  - High Vacuum
  - Cryogenics (Liquid Helium Refrigerator)
  - Beam Dynamics
  - Radiation Safety

The Planned Facility Group

	Design	Design & Construction	Commissioning Phase I	Construction & Commissioning Phase II	Start operation
	2001-5	2005-7	2006-8	2009-12	2012▯
Management & Researchers	5.5	5.5	5.5	6.5	5.5
Engineers	2	5	5	5	4
Technicians	1.5	1.5	1.5	4	6.5
Total	9	12	12	15.5	16

Operators will come mainly from Engineers and Technicians groups

The Main Control Room (MCR)

General Layout

- Comfortable size for all monitors and controls
- Easy access to all monitors and controls
- House two permanent operators + few more in special occasions
- Similar to other facilities (Don’t invent the wheel – read WAO proceedings)

MCR size of 5×10 m^2, with an adjacent 15 m^2 servers and controllers room

The Main Control Room (MCR)

Location and Safety Zone

- Prefer proximity to frequently visited systems during shifts
- Central position, near main entrance
- Position enables enlargement
- External walls with windows
- Minimization of Safety Zone change procedures
  - Red (Restricted when beam on), Yellow (Controlled), Green (Free)

The Main Control Room (MCR)

- We analyzed the visit probability to each of the facility systems (Low, Medium, High)
- Probability depends on:
  - Project stage (Phase I-II transition, Young Phase II, Mature Phase II)
  - Facility status (operation, maintenance)
- Wrote down the safety zone for each system
  - Red (restricted when beam on)
  - Yellow (controlled)
  - Green (free access)

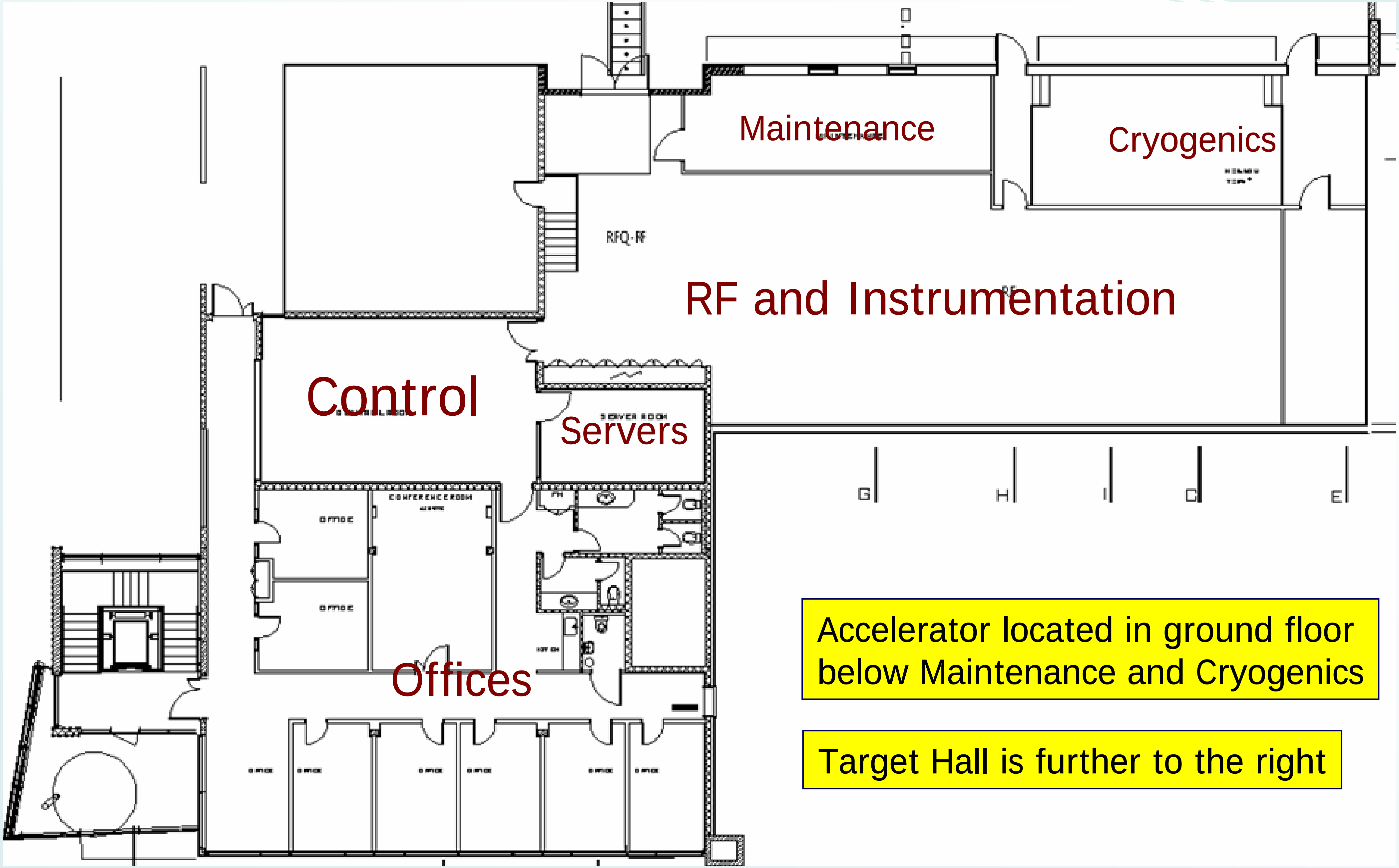
The Main Control Room (MCR)

			Visit Probability		Figure of Merit			Average
System	Floor	Safety Zone	Beam On	Maintenance	2005-2009	2010-2014	2015-2024	
Accelerator (Accelerating Modules)	0	R	1	3	2.5	1.8	1.4	**1.78**
Accelerator (Instrumentation and Control)	1	G	3	3	3	3	3	**3.00**
Cryogenics (Cold box, Local control)	1	G	3	2	2.25	2.6	2.8	**2.61**
Cryogenics (Valve Boxes)	0	R	1	2	1.75	1.4	1.2	**1.39**
RF Systems	1	G	3	2	2.25	2.6	2.8	**2.61**
Building + General Safety	0+1	R+Y+G	2	3	2.75	2.4	2.2	**2.39**
Radiation Safety	0	R+Y	2	1	1.25	1.6	1.8	**1.61**
Beam Lines	1*	R+Y	2	2	2	2	2	**2.00**
Applications	1*	R+Y	1	1	1	1	1	**1.00**
* Systems are in Ground Floor but								
entrance will probably be from 1st floor		G = Green	1 = Low					
		Y= Yellow	2 = Medium					
		R = Red	3 = High					
Ground (0) Floor Systems					5.5	4.8	4.4	**4.78**
Ground + First Floor Systems					2.75	2.4	2.2	**2.39**
First (1) Floor Systems					10.5	11.2	11.6	**11.23**
Red Systems					4.25	3.2	2.6	**3.16**
Red+Yellow Systems					4.25	4.6	4.8	**4.61**
Red+Yellow+Green Systems					2.75	2.4	2.2	**2.39**
Green Systems					7.5	8.2	8.6	**8.23**

Operation Mode		2005-2009	2010-2015	2015-2024
Beam On Fraction		0.25	0.6	0.8
Maintenance Fraction		0.75	0.4	0.2

Location – 1st floor
Safety Zone - Yellow

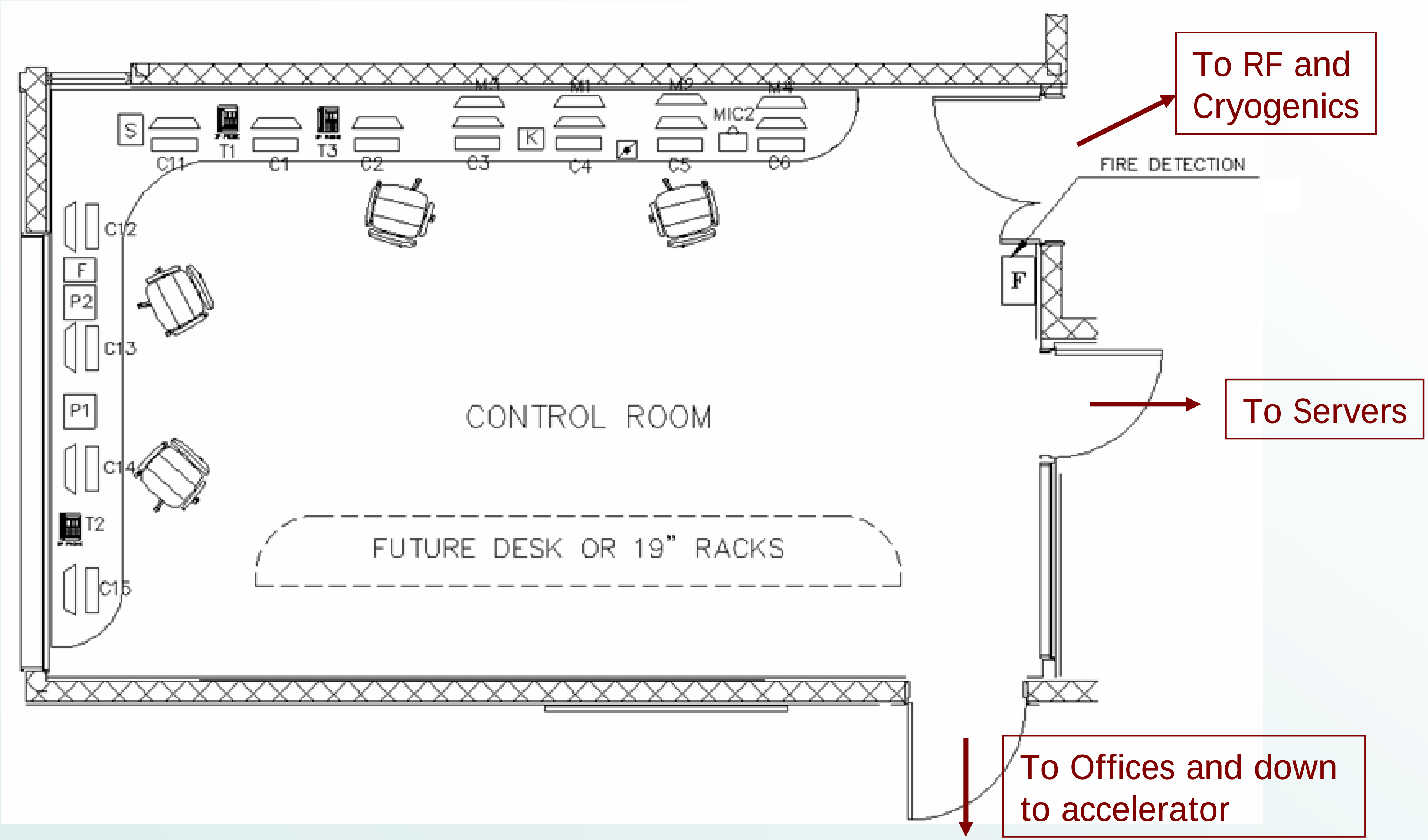
Accelerator Building - 1st Floor Layout



Accelerator located in ground floor below Maintenance and Cryogenics

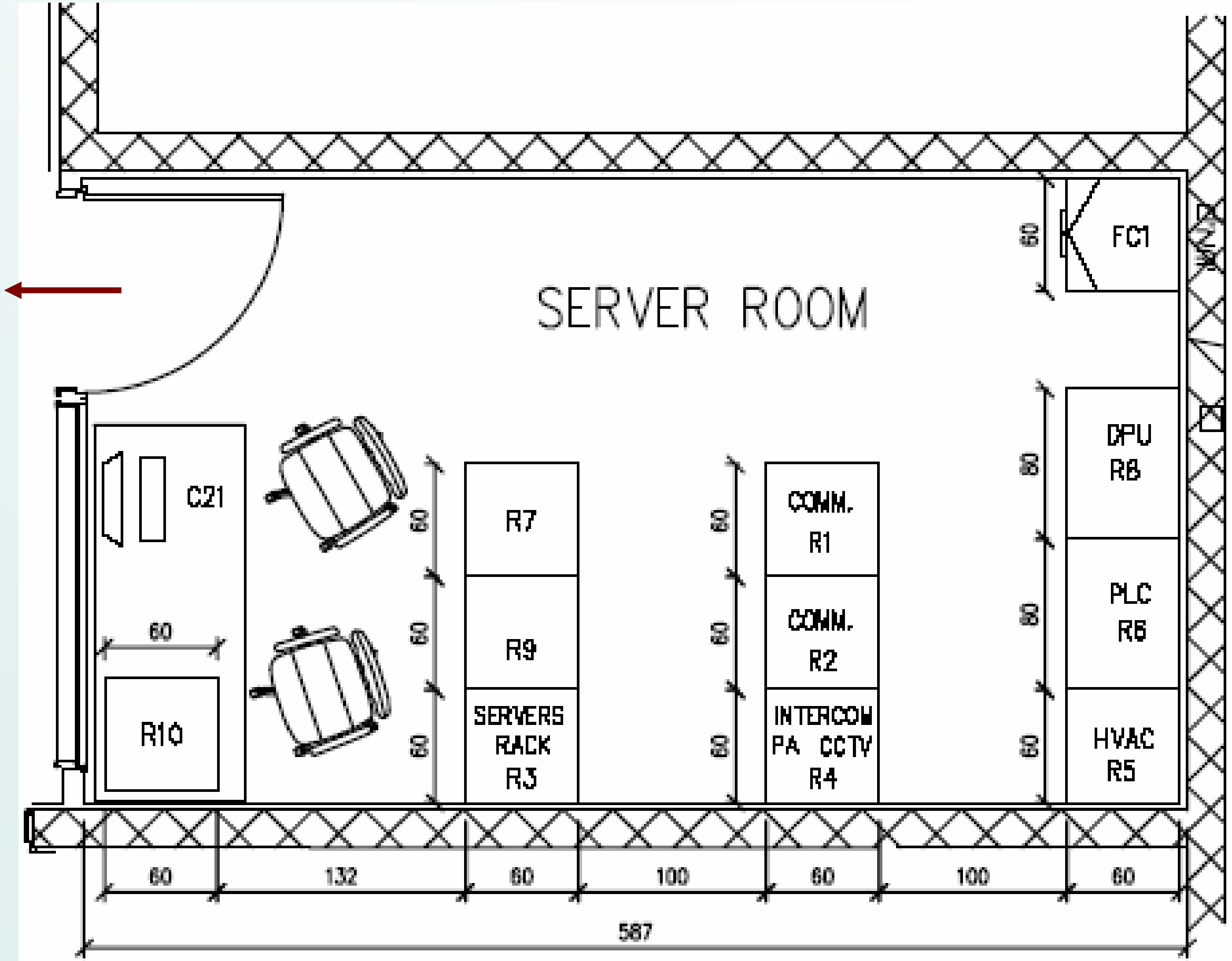
Target Hall is further to the right

Main Control Room Layout



Servers Room Layout

To Control



Main Control System (MCS)

Realization Guidelines

- Choose Commercial Software
  - Established companies
  - Widely used software
  - No need to write custom drivers
- Choose Commercial Hardware
  - Hardware incorporating OPC standard
  - Companies that produce both hardware and software
- Minimize types of Hardware and Software
  - Optimize with sub-contractor constraints
  - Settle for several types if inter-communication possible

Main Control System (MCS)

Realization Guidelines (2)

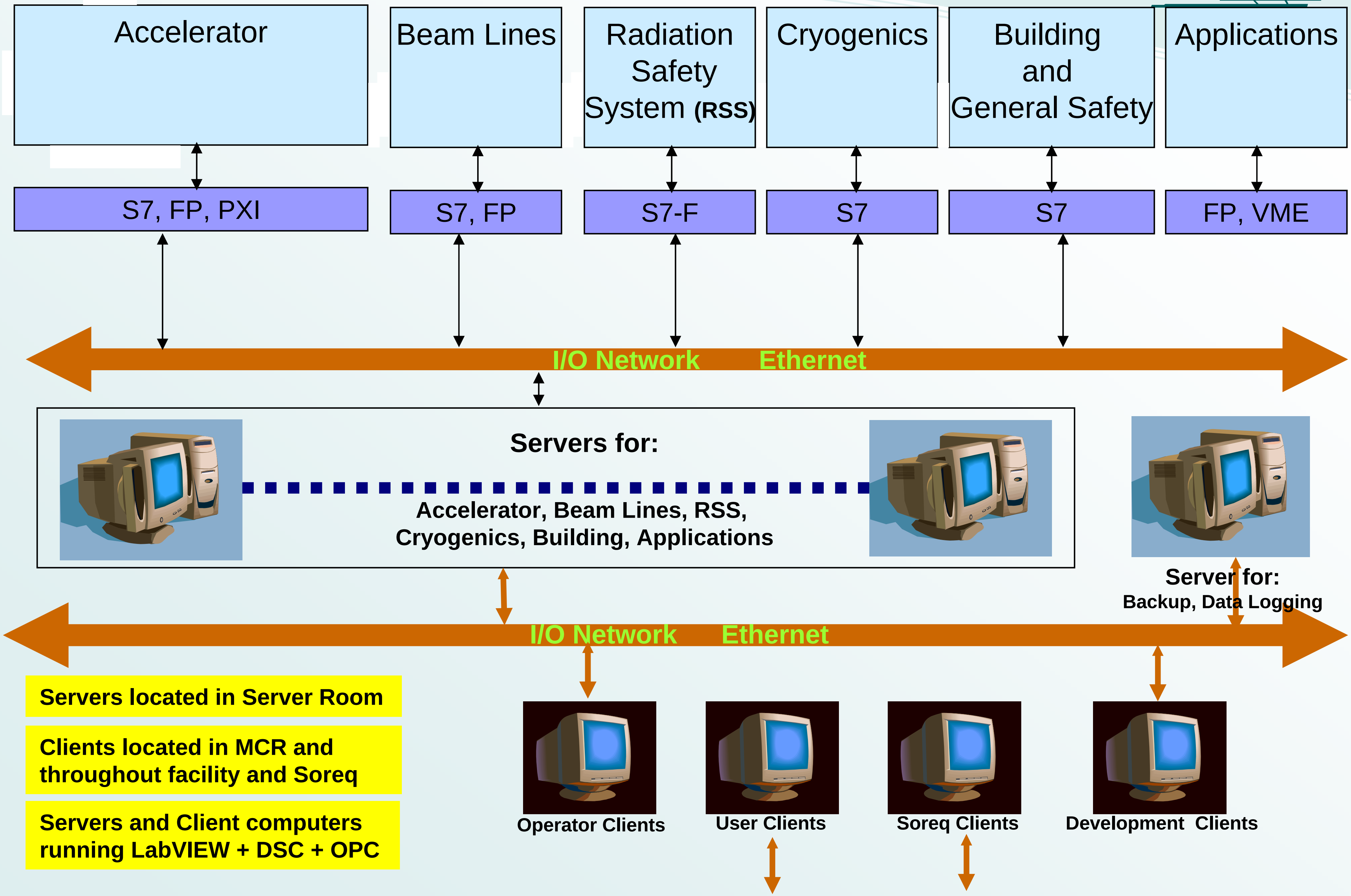
- Choose Server-Client architecture
  - Improves reliability
  - May provide redundancy
  - Consider backup server with a smooth automatic transition in case of main server crash
  - Client crash should not affect server or other clients
- Computers and Hardware networked
- Use Fiber Optics in EM-noisy environments

Main Control System (MCS)

Realization Decision – Go commercial!

- ***Software*** - LabVIEW with DSC module and OPC server
  - LabVIEW is widely used, is flexible and scientific oriented
  - Client licenses low cost and do not depend on amount of I/O
  - Hardly any need to write custom drivers
- ***Hardware*** – FieldPoint, PXI (NI) and S7, S7-F (Siemens)
  - All types are chosen due to sub-contractor constraints
  - All types are OPC compatible
  - S7-F compatible with international safety standards
- ***Network and Buses*** – Ethernet
- ***Platforms*** – PCs running Microsoft Windows

SARAF Main Control System (MCS) – General Architecture



The Personal Safety System

Safety Statuses

- Regarding entry to the accelerator area (Red Zone) there are three Safety Statuses
  - Closed (Red) – Access restricted, accelerator might be on
  - Controlled (Yellow) – Access controlled, accelerator is off
  - Free (Green) – Free access
- Safety Status displayed by colored ‘Traffic Lights’ and on Main Control screens

*The Personal Safety concept of SARAF is strongly inspired by the PSI architecture

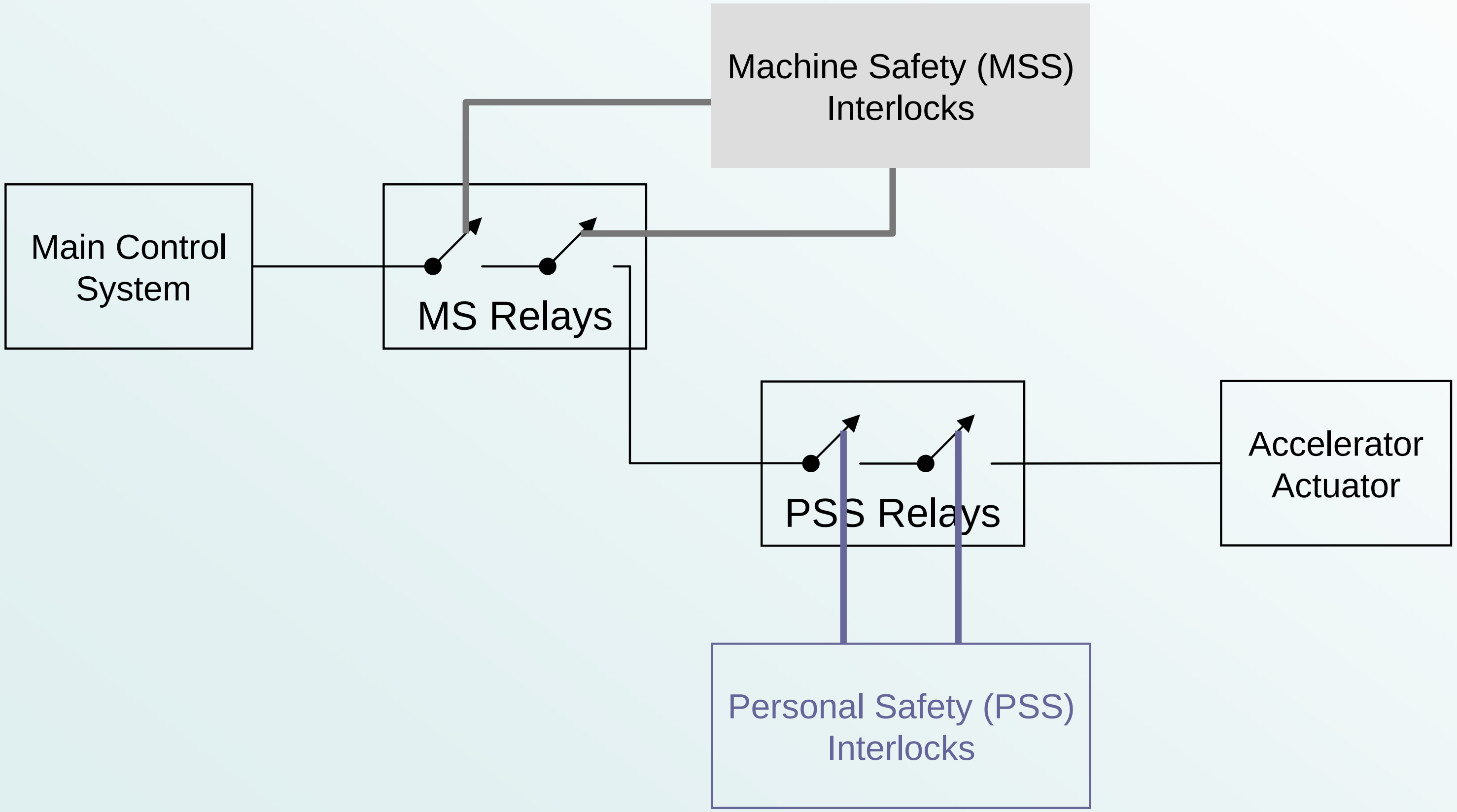
The Personal Safety System

Accelerator Area Entry Procedures

- While in Yellow Status, entry procedure is:
  - User approaches area door and takes one Safety Key (A total of Six keys) from its socket
  - User talks with Operator in MCR via intercom. Operator can see user via video camera
  - Operator releases the electric lock in the door
  - User enters
- While in Green Status, entry is not monitored and number of entries is unlimited

Interface of the MCS with Safety

Beam can be on only if Machine Safety System and Personal Safety System provide a 24V ‘Enable’ signal

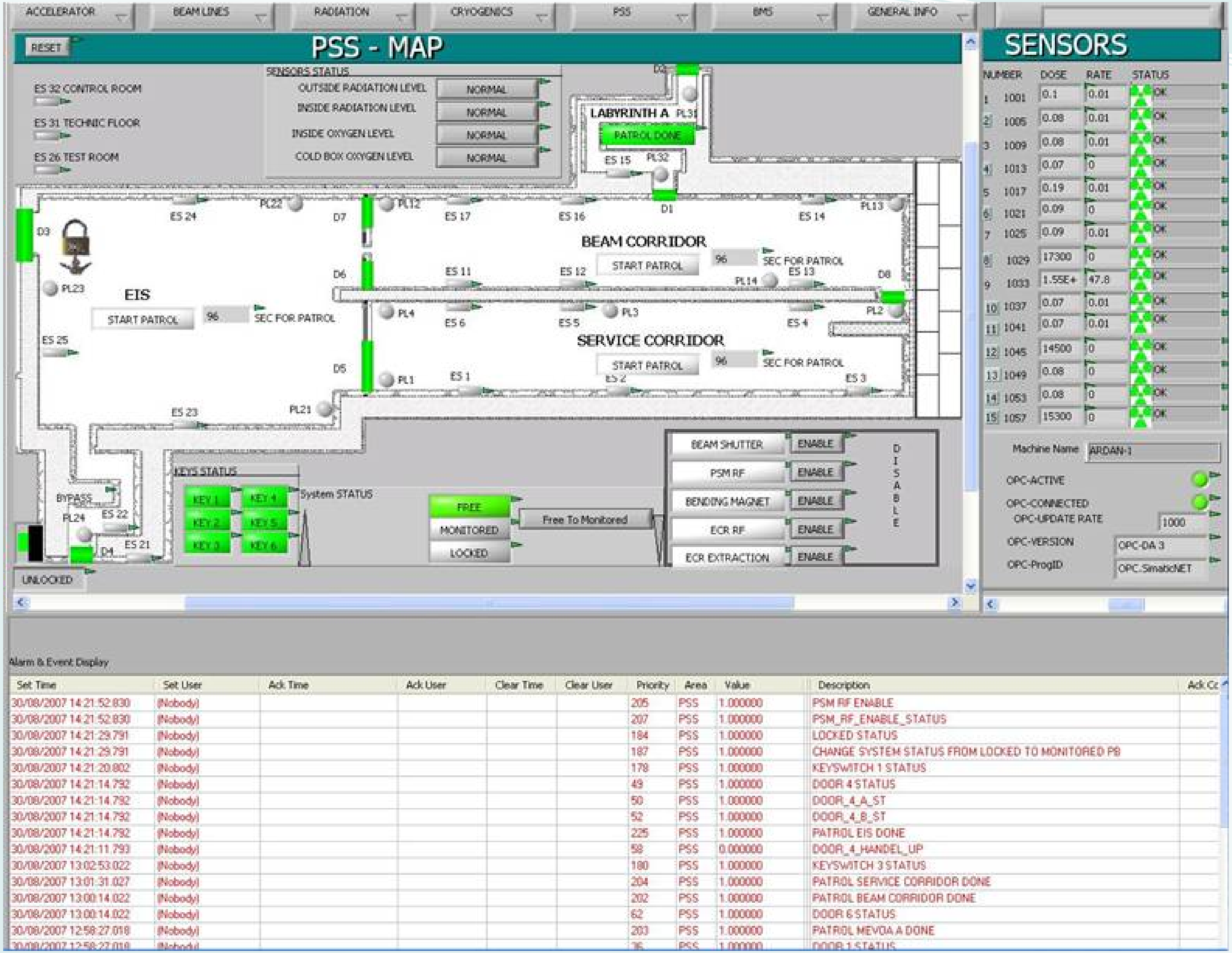


The Personal Safety System

Emergency Shutdown Scenarios

- Safety ‘Enable’ signal is dropped when:
  - One of the accelerator area external doors is opened
  - One of the emergency buttons has been pushed
  - One of the Safety Keys has been removed from its socket
  - The operator requested it via the control system
- Radiation readings above threshold do not drop the ‘Enable’ signal, but generate an alarm

PSS visualization screen



PSS interface with the accelerator

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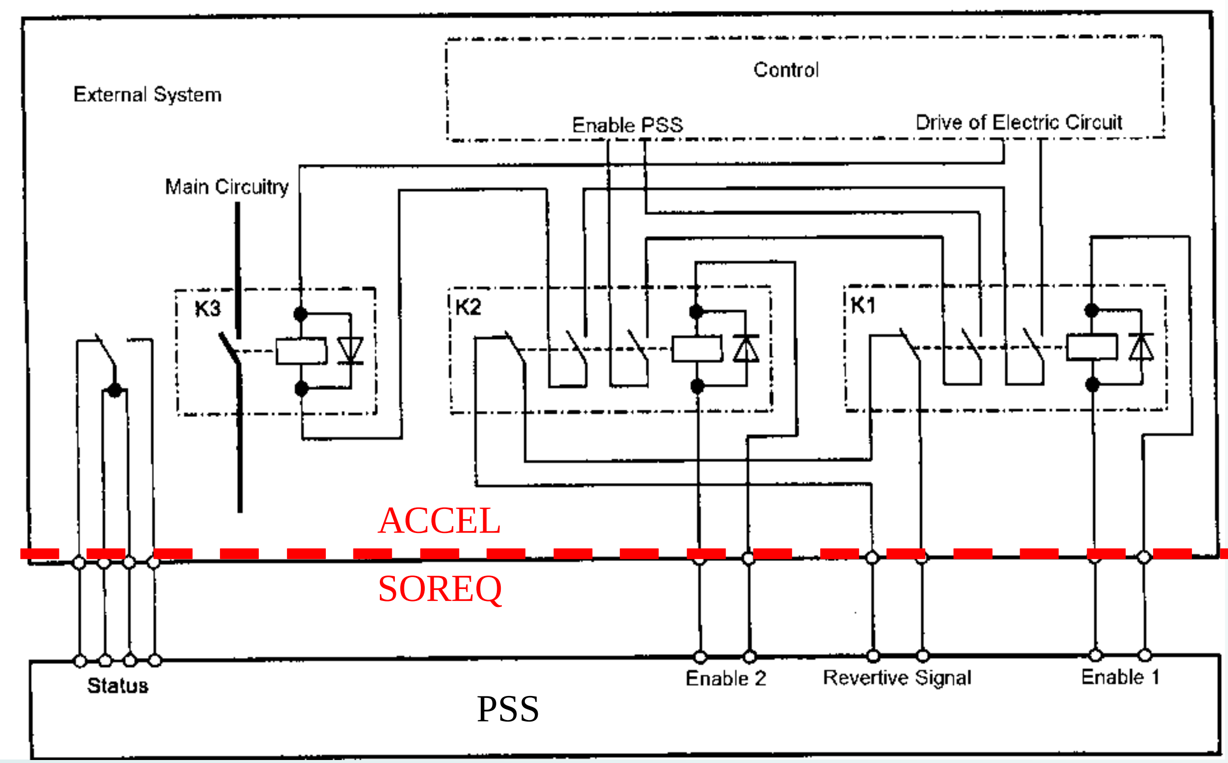
Schematic of each of 5 PSS interfaces



PSS interface implementation

PSR – Phoenix Safety Relay
PSR-ESA2_B

– Emergency stop/safety door monitoring
– Safety Category 4, EN 954-1
– Plug-in screw-cage or spring-cage terminal blocks
– One-channel circuit
– Basic insulation
– Housing width 22.5 mm (0.886 in.)
– Four enable contacts
– One signaling contact
– Approvals: LISTED

Actuator	Status Signal
LEBT Beam shutter	Micro switches (safe)
ECR extraction RF	Safety sump switch (safe)
ECR RF	Control system (regular)
LEBT bending magnet	Control system (regular)
RF for RFQ and SC cavities	Control system (regular)

PSS in the MCR

Overview of the SARAF Main Control Room

PSS Station at the Main Control Room

PSS control of personnel entrance

Interface of the MCS with Applications

Signals from Application to MCR

- Status of last Faraday Cup
- Application ready for beam
- Application at standby
- Beam current at application
- Emergency accelerator stop

Signals from MCR to Application

- Accelerator on/off
- Accelerator beam ready
- Beam to application ready
- Ion type
- Beam current at last FC
- Beam energy at last diagnostic
- Last FC is in/out of beam

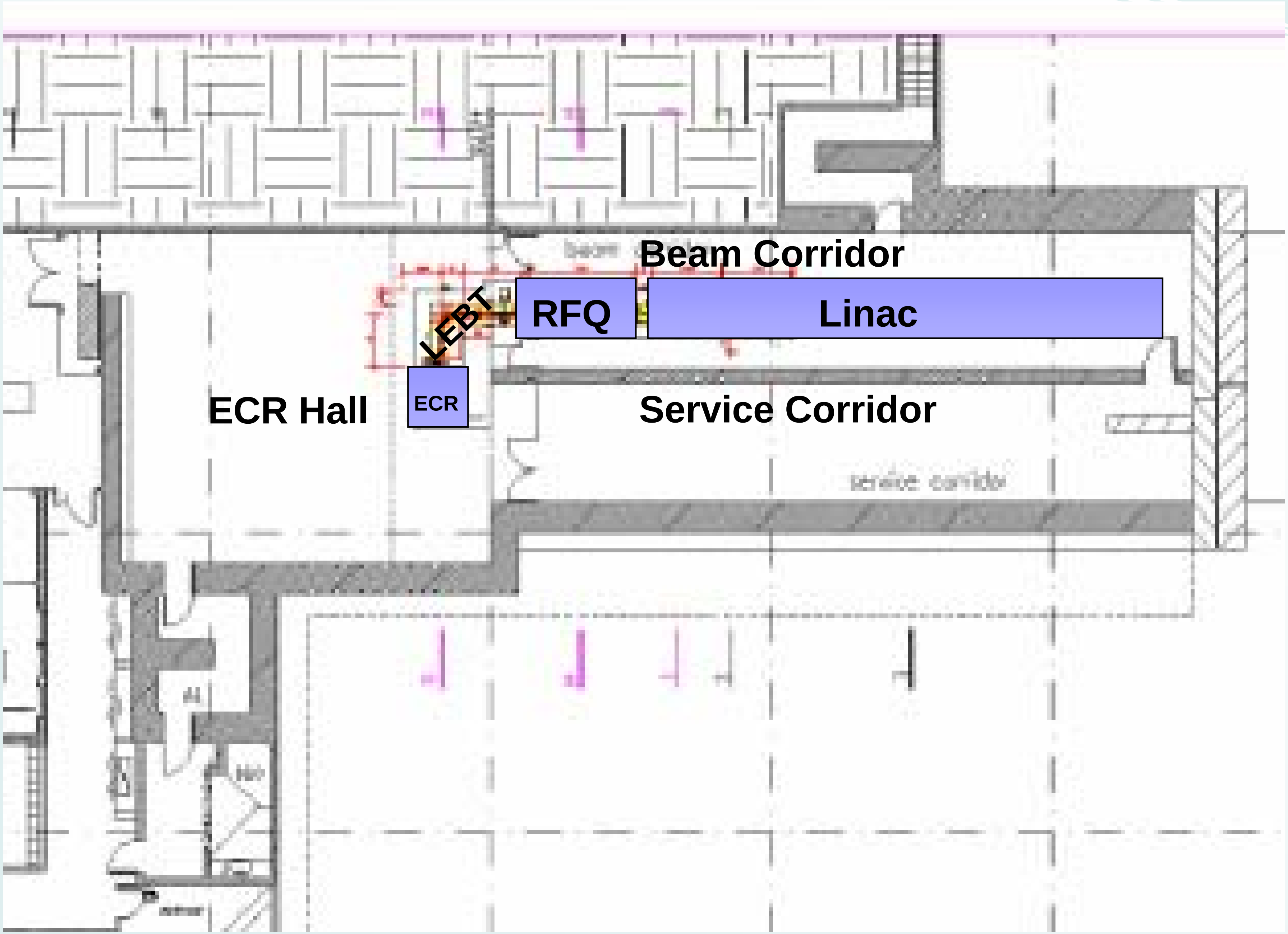
Feedback Mechanisms

Set energy and current to certain values and have the control system keep them within a given range

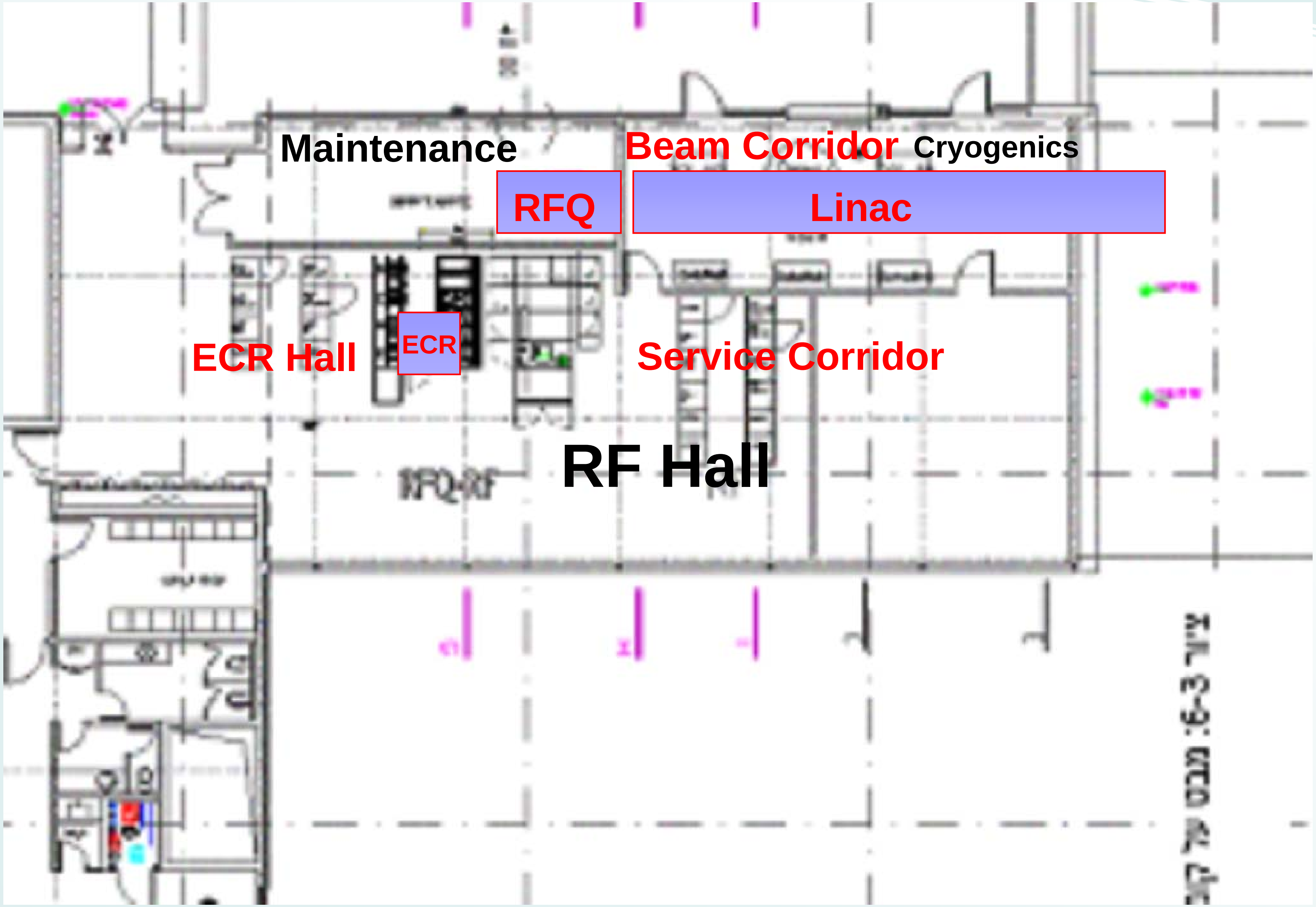
SARAF Shielding Calculations

Presentation based on calculations performed by Arnold Pernick

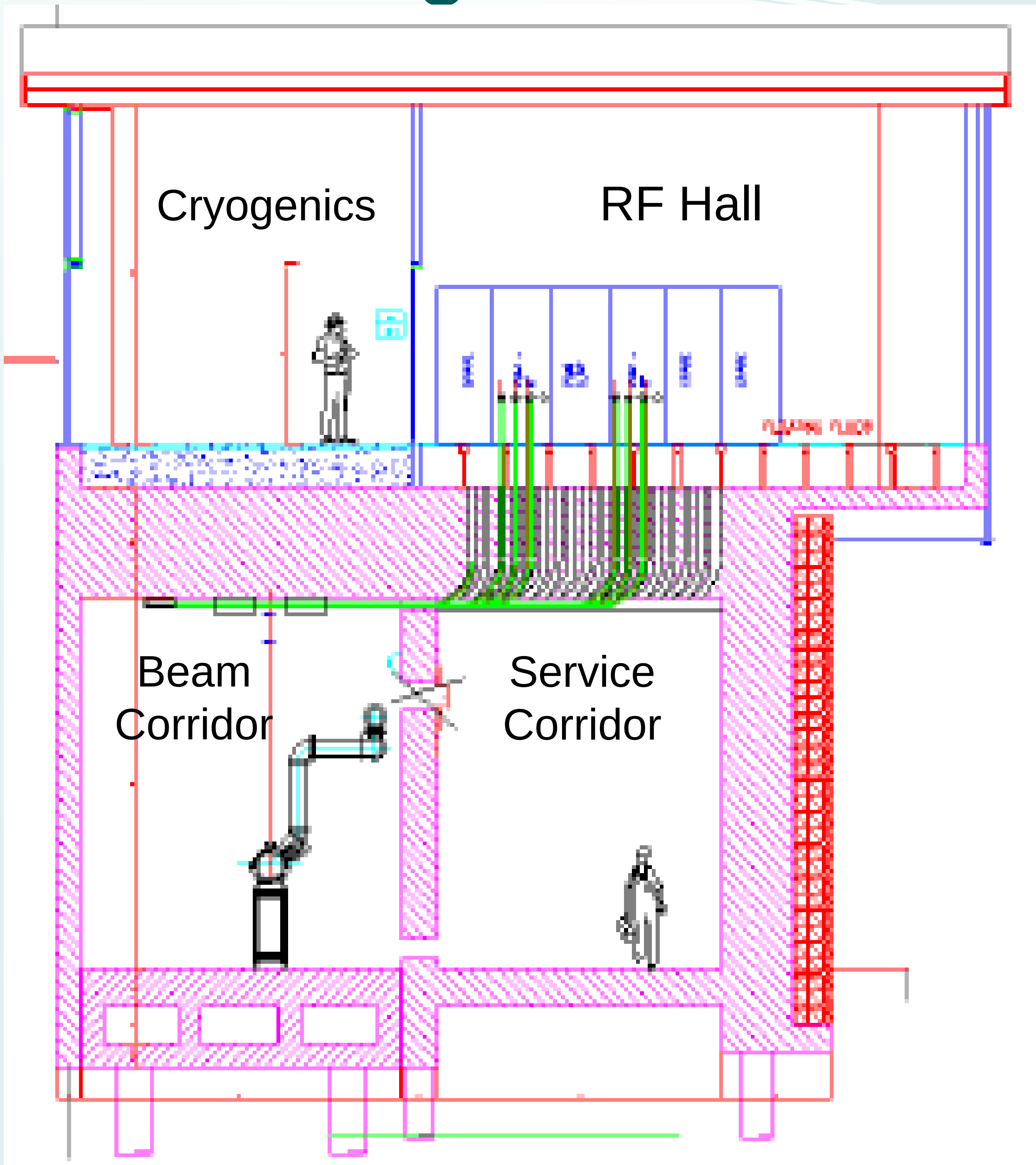
Accelerator building – ground floor



Accelerator building – 1st floor



Accelerator building – Vertical cut



Guidelines for shielding calculations

- Shielding is against prompt neutrons and secondary radiation (gammas and secondary neutrons)
- Goal of shielding is to reduce dose rate behind it to 0.1 mrem/hr
- Only deuteron beams are considered, as they generate more neutrons then protons
- When exact information is not available, use strict and conservative assumptions regarding energy, cross sections, distributions, materials, etc.

Linac calculation method and assumptions (1)

- Beam loss is **uniform** along the linac and the neutron emission rate is:

$$S_n\,(n/s) \;=\; I \cdot f_{bl} \int_0^{25} N_n(x)\; dx$$

  - $S_n(n/s)$ = neutron emission rate [n/s]
  - I = deuteron rate = 6.25×10^{25} d/(s·mA)·4mA
  - f_{bl} = beam loss fraction = 2.0×10^{-7} m^{-1}
  - dx = differential linac length, from 0 to 25 m
  - $N_n(x)$ = neutrons per deuterons factor, which includes the direct neutron reactions, depending on deuteron energy and irradiated materials [n/d]

Linac calculation method and assumptions (2)

- The neutron per deuteron factor is defined as:

$$N_n(x) = 0.6 / A \sum_i n_i \int_0^{E_d} \sigma_i(E)\,(dy/dE)\,dE$$

  - $\sigma_i(E)$ = cross section for reaction i [barn]
  - dy/dE = reciprocal of linear stopping coefficient of deuterons in the irradiated material [$gr/cm^2/MeV$]
  - A = Atomic weight [gr]
  - n_i = number of neutrons generated in reaction i
  - E_d = deuteron initial energy (before penetration of material) [MeV]

Linac calculation method and assumptions (3)

- The linac is made of uniform slabs of Niobium (Nb) and Stainless Steel (taken as **^{56}Fe**, since it is the dominant component and most prolific neutron generator)
- The maximal beam energy is **50 MeV** (as opposed to the final design of **40 MeV**)
- The linac is a thick target – the deuterons loose all their energy
- The cross sections in $N_n(x)$ were extracted from data and (where there is no data) calculated with **ALICE**. Results were bench-marked against Cu(d,xn) data
- Emission rate was calculated for 10 discrete sections (Δx) defined by the energy gain. The energy of a section was the maximal energy in that section

Linac calculation method and assumptions (4)

- The neutron energy spectrum, as a function of deuteron energy, was approximated by experimental distributions given for several materials
  - E_d = 1 – 20 MeV : N_n decreases continuously with E_d
  - E_d = 20 – 50 MeV : N_n is peaked at approximately $E_d/2$
- The neutron angular distribution is assumed to be uniform. This is conservative for the perpendicular dose, since most neutron generating reactions are forward peaked

Linac calculation method and assumptions (5)

- The dose rate perpendicular to the linac as a function of the concrete shielding thickness was calculated with **MCNP4B**
  - Reaching the required dose rate of 0.1 mrem/hr requires a "deep shielding" calculation
  - Therefore, variance reduction methods were used
    - 'Splitting' with weighting towards irradiation target
    - Applying 'Russian Roulette' to backward particles
  - Accuracy of 10% at reasonable computation times was achieved

Linac calculation results

- Concrete walls thickness should be
  - **<u>55 cm</u>** at beginning of linac (E_d = 3 MeV)
  - **<u>120 cm</u>** at end of linac (E_d = 50 MeV)
- Due to an **<u>executive decision</u>**, all linac walls were built **<u>150 cm</u>** thick
- Concrete ceiling (above which the RF hall resides) thickness should be
  - **<u>150 cm</u>** throughout the linac

RFQ calculation method and assumptions

- E_d = 3 MeV throughout the RFQ
- f_{bl} = beam loss fraction = 0.1
- Deuterons are irradiating a cylindrical Copper (Cu) cavity 100 cm long and with diameter 50 cm (RFQ wall is a thick target), which represents the downstream side of the RFQ
- Neutrons are generated by the reactions $^{63}Cu(d,n)^{64}Zn$, $^{65}Cu(d,n)^{66}Zn$. Their cross sections were taken from experimental data and compared with **ALICE**

RFQ calculation results

- Dose rates were calculated 30 cm behind a concrete wall with several thicknesses, which is 200 cm away from the RFQ
  - Thickness of **85 cm** gives 0.06 mrem/hr, which is satisfactory
  - Thicker than 55 cm required for beginning of linac because of 10% beam loss in RFQ
  - Ceiling thickness
    - **150 cm** above RFQ downstream (beam corridor)
    - **65 cm** above RFQ upstream (ECR hall)
    - **50 cm** above ECR (ECR hall)

Prompt neutron production in LEBT

- Beam deuterons are implanted on the Faraday Cup at the end of the LEBT
- Prompt neutrons are generated via the reaction $D(d,n)^3He$, with $E_n = 2.45$ MeV
- The neutron rate was scaled down from a calculation done for IFMIF (95 keV, 125 mA)
- The planned **65 cm** ceiling is enough to reduce to dose rate to below 0.1 mrem/hr
- **Measured** neutron rates at SARAF are lower than the estimates (details later)

Additional calculations

- Dose rates behind all the walls and ceilings about the beam corridor and ECR hall were calculated
- For each case, a certain wall thickness was suggested based on simple assumptions, and the abovementioned method was then applied
- The thicknesses were adjusted according to the results

Entrances to accelerator area

- Personnel entrances are through mazes
- Mazes were designed in a way that dose rate at their far side (near external door) is below 0.1 mrem/hr
  - Calculation results implied maze designs with **100 cm** wide walls and **150 cm** wide corridors
- Accelerator components enter through a thick concrete door, far upstream of RFQ
  - Calculations implied a door thickness of **75 cm**
  - Contribution of linac is higher than of RFQ, due to high energy neutrons from high energy side of the linac

Ground floor – Shielding dimensions

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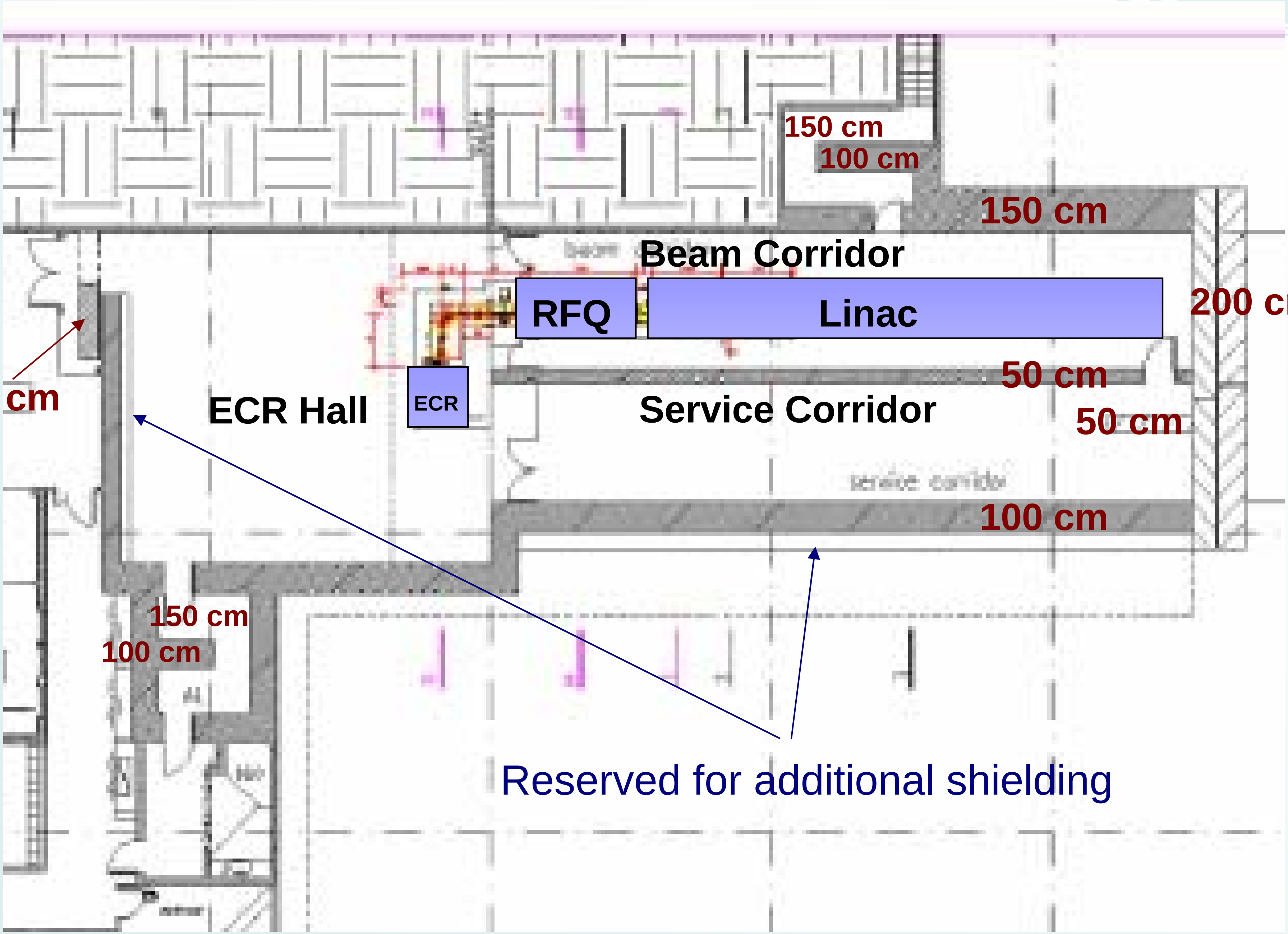
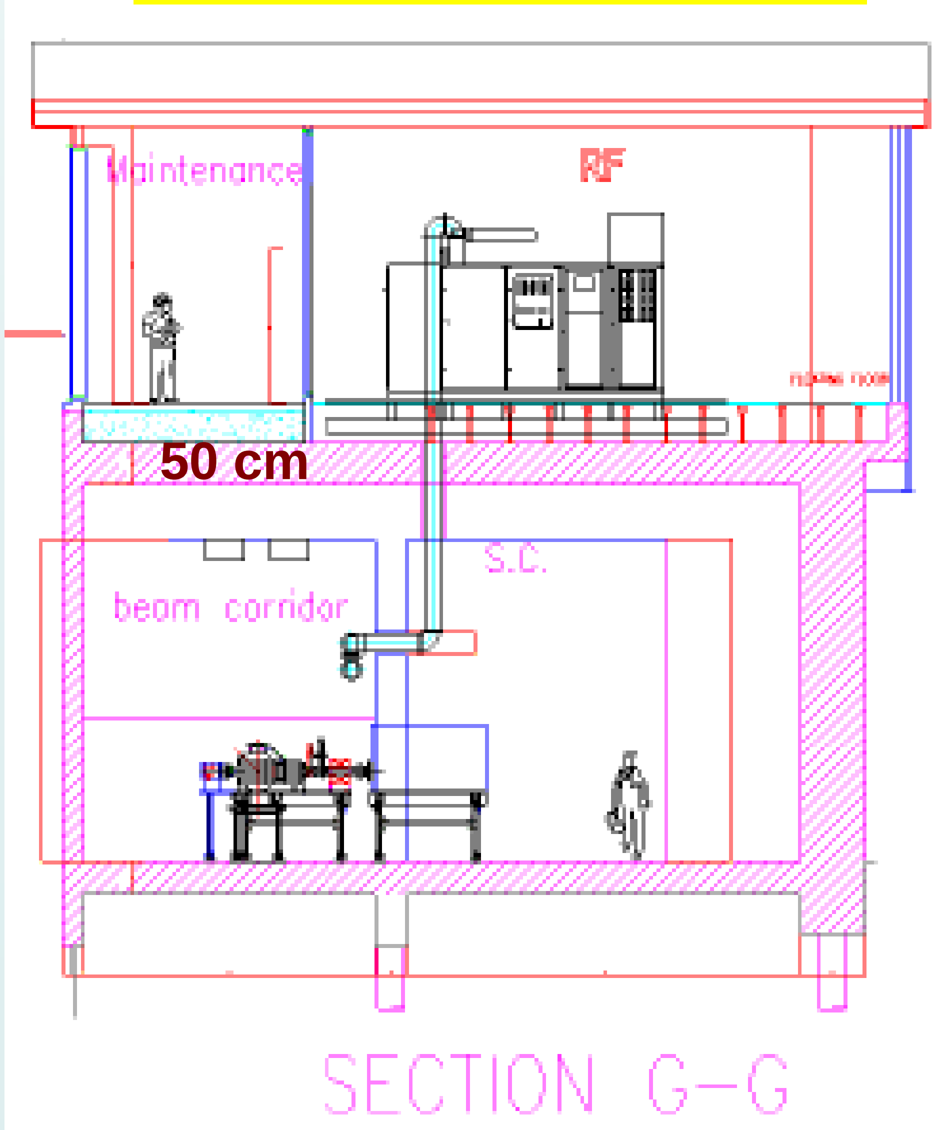
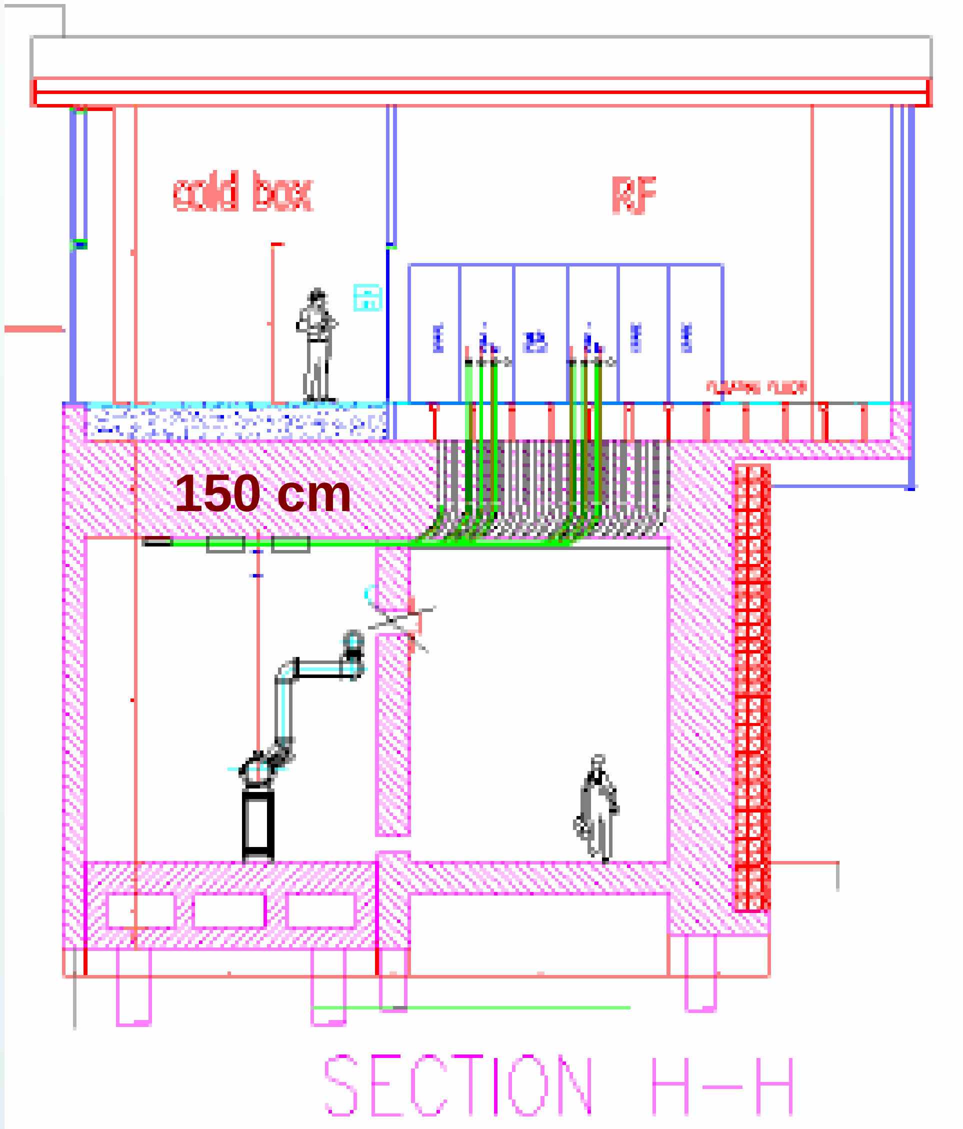


Ground floor – Shielding dimensions

Cut in ECR Hall through ECR

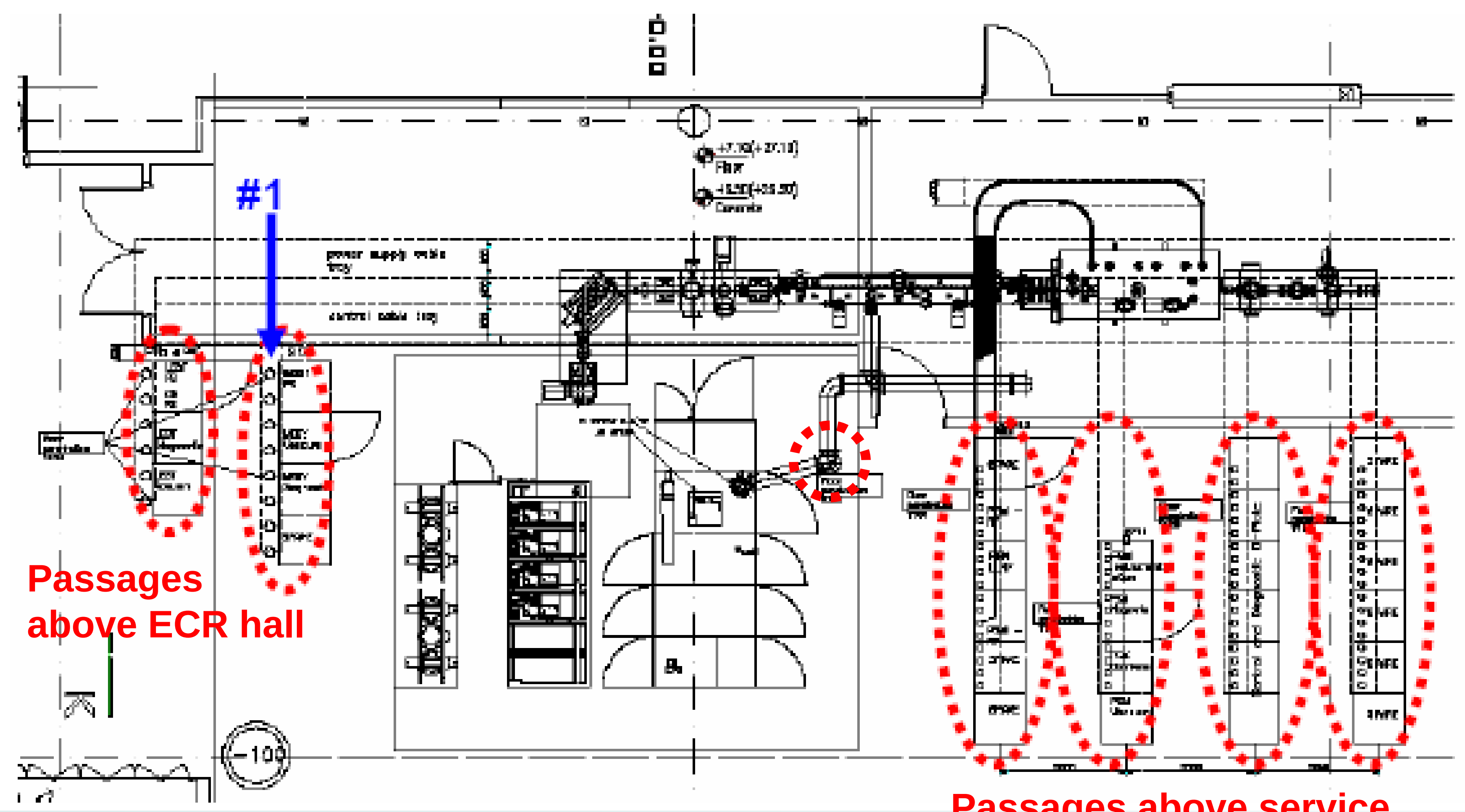


Cut in Beam Corridor through RFQ



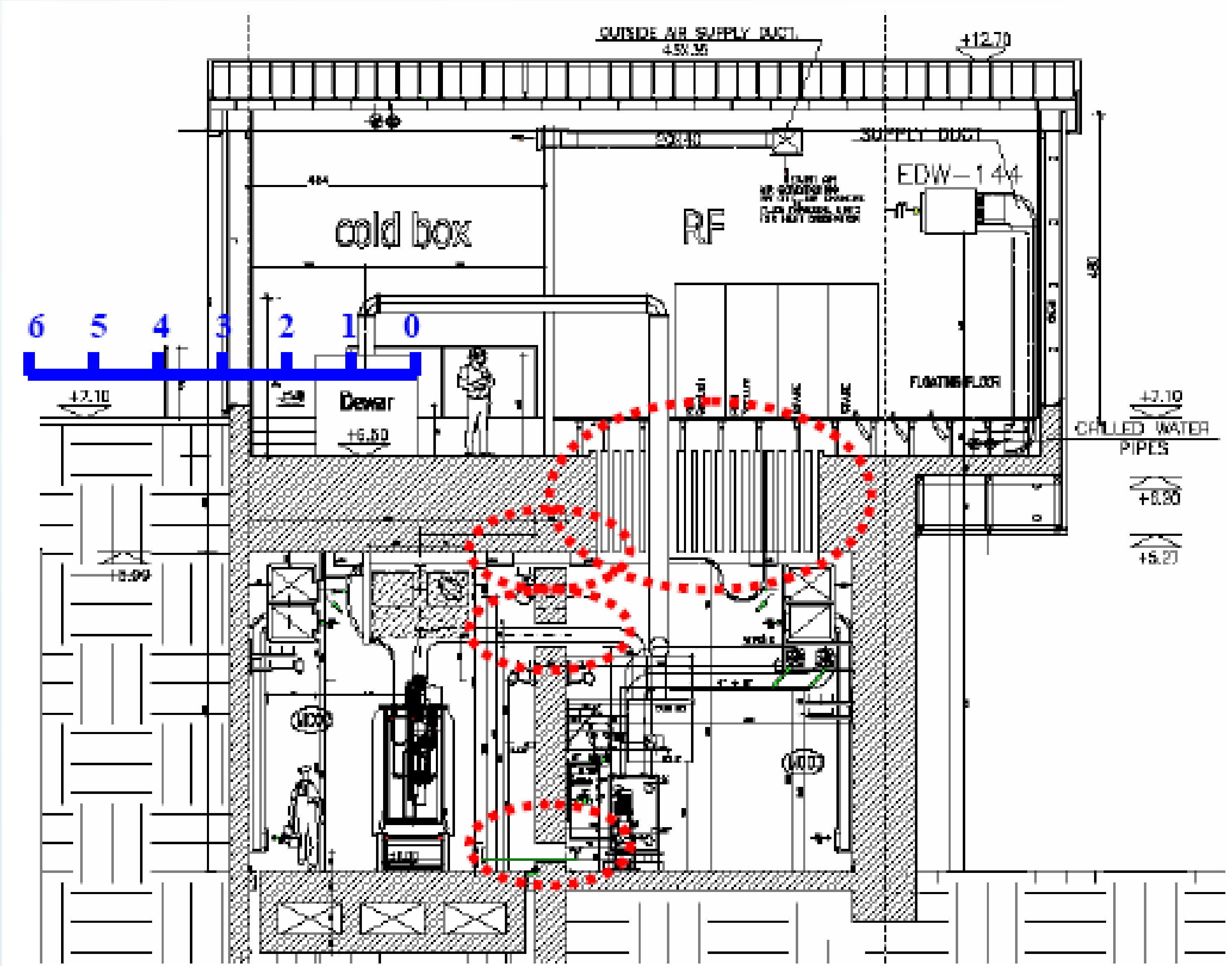
Passages for RF, power and control cables (1)

1st floor, with accelerator superimposed



Passages for RF, power and control cables (2)

Vertical cut through PSM area



Effect of cable and pipe passages due to neutron streaming

- Passages between ground and 1st floors and are necessary for liquid helium, cooling water, electrical power, RF power, etc.
- Direct passages from beam corridor to 1st floor were not allowed – only via service corridor
- Dose rates calculated at RF hall openings
- As a conservative estimate, shielding effects of cables and pipes that fill the openings were ignored
- Openings dimensions were optimized to ensure dose rate below 0.1 mrem/hr

Dose due to full beam loss in beam corridor (1)

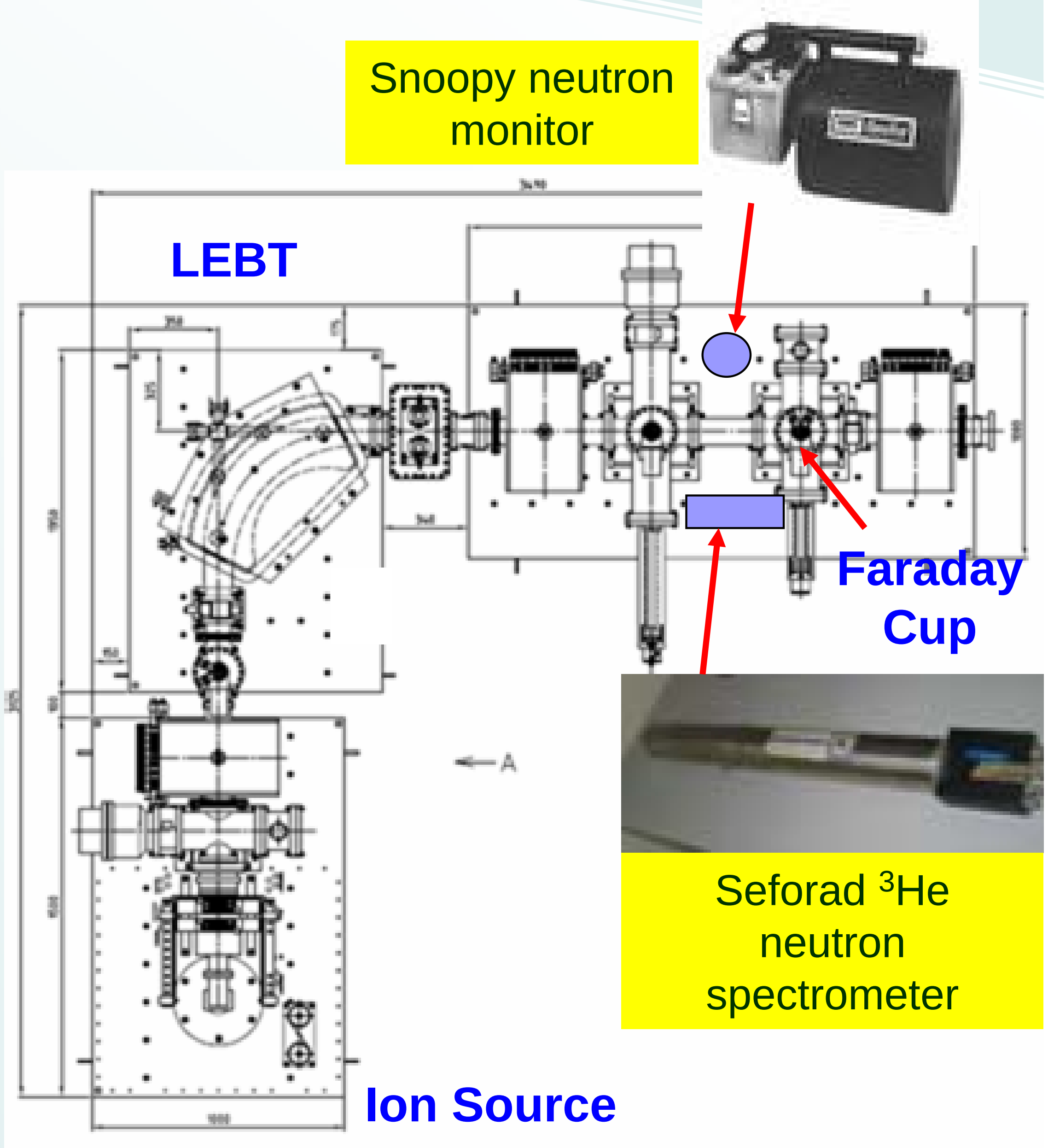
- Scenario is an incident that steers the entire beam through the beam pipe to the concrete wall
- Notice: at PSI, such an incident was defined as a “non issue”, and no calculations were made to estimate its effect
- We assumed
  - Machine safety systems will limit such an incident to 100 msec
  - If at all, there will be a few such incidents per year

Dose due to full beam loss in beam corridor (2)

- Dose rate was calculated in the cryogenics rooms, beyond the personnel entrances and in the test room upstream of the ECR hall
- Source was either 50 MeV deuterons at end of linac or 25 MeV deuterons at center of linac
- Dose rates reached 2-3 mrem/sec, which is much higher than limit
- However, integrated over 100 msec, the dose is about 1 mrem - negligible compared to the allowed 200 mrem/year (assuming only a few incidents per year…)

d(D,n)^{3}He nuclear reactions in the LEBT

- Even 40 keV deuterons generate nuclear reactions
- In our case, beam deuterons interact with deuterons that are adsorbed in the graphite Faraday Cup
- d+D $\rightarrow$ 3He+n (E_n=2.45 MeV)
- At 5 mA, neutron flux was measure to be 6.6×10^6 n/sec, corresponding to ~60 mrem/hr @ 45 cm
- Flux is about a factor of 10 less than original calculations which were the basis of the shielding design

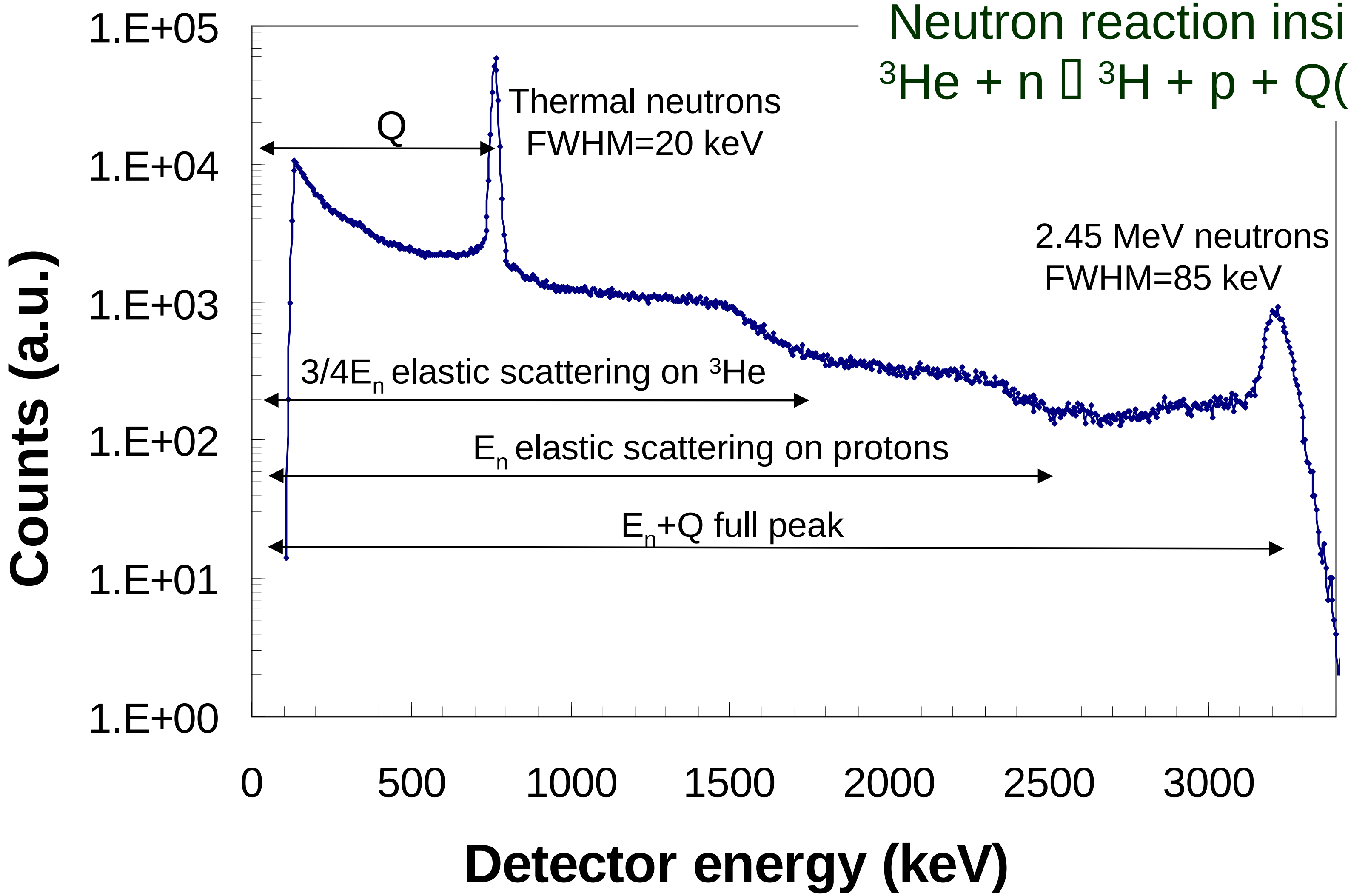


Dose rate is compatible with R. Gobin LINAC 2004

d+D nuclear reactions in the LEBT

Neutron reaction inside detector:

$^{3}He + n \rightarrow {}^{3}H + p + Q(764\ keV)$



Peak efficiency for 2.45 MeV neutrons is ~ $2.5\ 10^{-5}$

Full efficiency is ~ $1.5\ 10^{-3}$ (good agreement with *Beimer NIM A245 (1986) 402*)