ИНСТИТУТ ЯДЕРНЫХ ИССЛЕДОВАНИЙ
РОССИЙСКОЙ АКАДЕМИИ НАУК
INSTITUTE FOR NUCLEAR RESEARCH
OF RUSSIAN ACADEMY OF SCIENCES

Operation and Research Activities at the INR Accelerator Complex

Leonid V. Kravchuk

RUPAC, 30 September 2008

High Intensity Proton Linacs

Linac	Pulse length(ms)	Rep. rate(Hz)	Pulse curr.(mA)	Av. cur-rent (mA)	Energy (MeV)	Power (MW)
LANSCE	0,625	60	16	1,0	800	0,8
INR	0,1	100	50	0,5	600	0,3
SNS	1,0	60	38	1,4	1000	1,4
J-PARC	0,5	25	50	1,25	400/600	1,0(RCS)
ESS SENER	1,2	50	107	3,85 0,125/0,5	1300 50/400	5,0 1,0
CERN SPL(La4)	0,4	50	40	1,0 0,1	3500-5000 160	4,0
FNAL		10		0,25	8000	2,0
PEFP	1,33	60	20	1,0	100/1000	0,9
C SNS	0,2	25	15/30/40	76/151/3I5	81/132/230	0,5(RCS)
ADS EU,USA, Japan, Korea, India …	--	CW	10 - 20	10 - 20	600 -1000	~10 ÷ ÷100

The Spallation Neutron Source, ORNL, USA

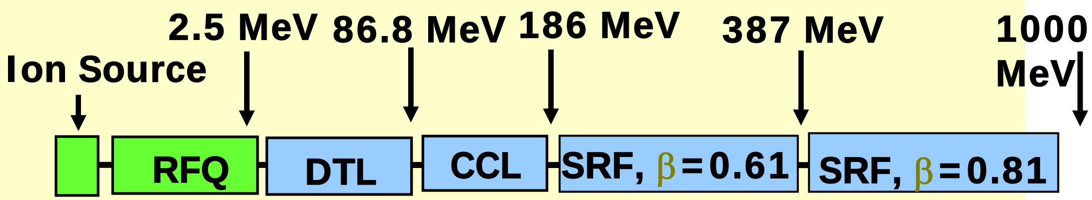
- The SNS construction project has been conclude in 2006
- At 1.4 MW it will be ~8x ISIS, the world's leading pulsed spallation source
- The peak neutron flux will be ~20-100x ILL
- SNS will be the world's leading facility for neutron scattering
- It will be a short drive from HFIR, a reactor source with a flux comparable to the ILL

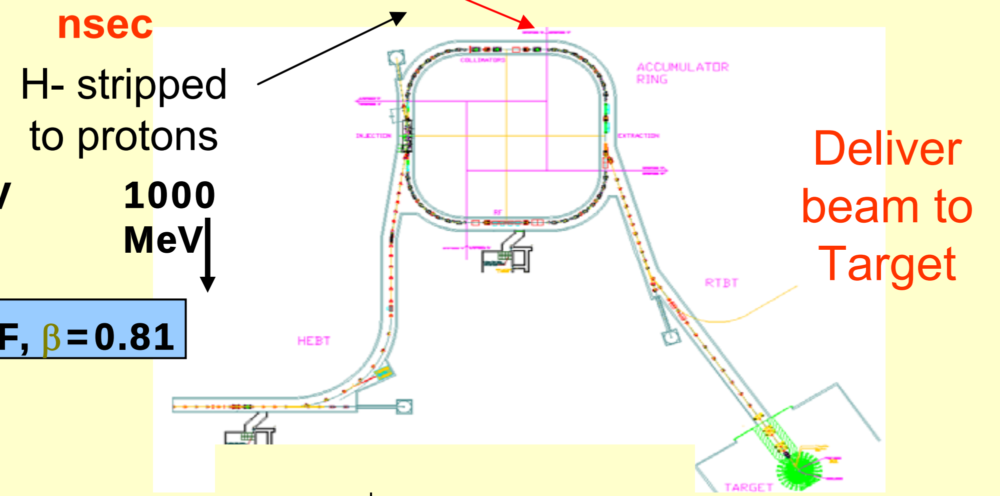
SNS Accelerator Complex

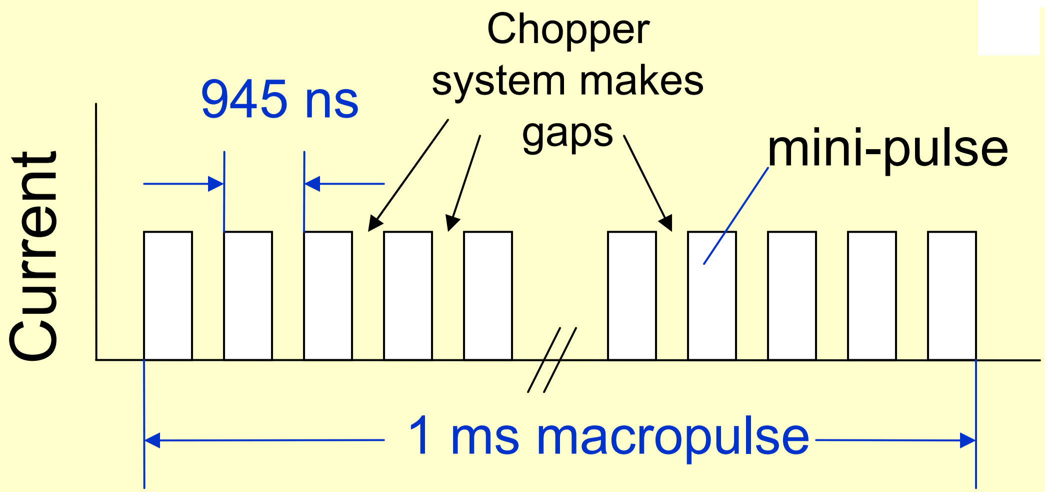
Front-End:
Produce a 1-msec long, chopped, low-energy H- beam

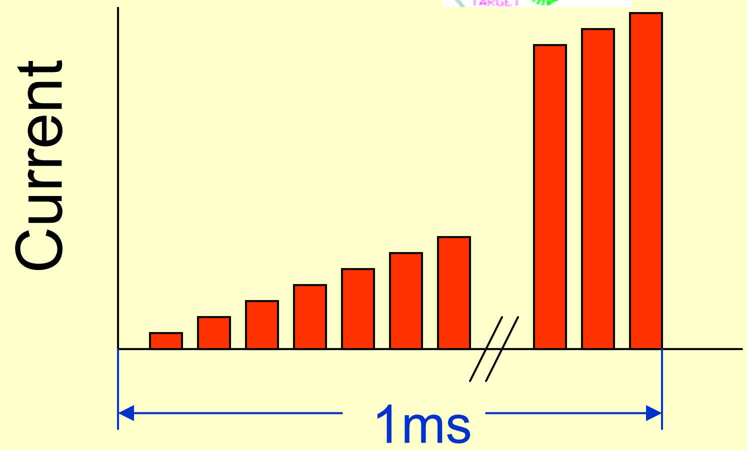
LINAC:
Accelerate the beam to 1 GeV

Accumulator Ring:
Compress 1 msec long pulse to 700 nsec



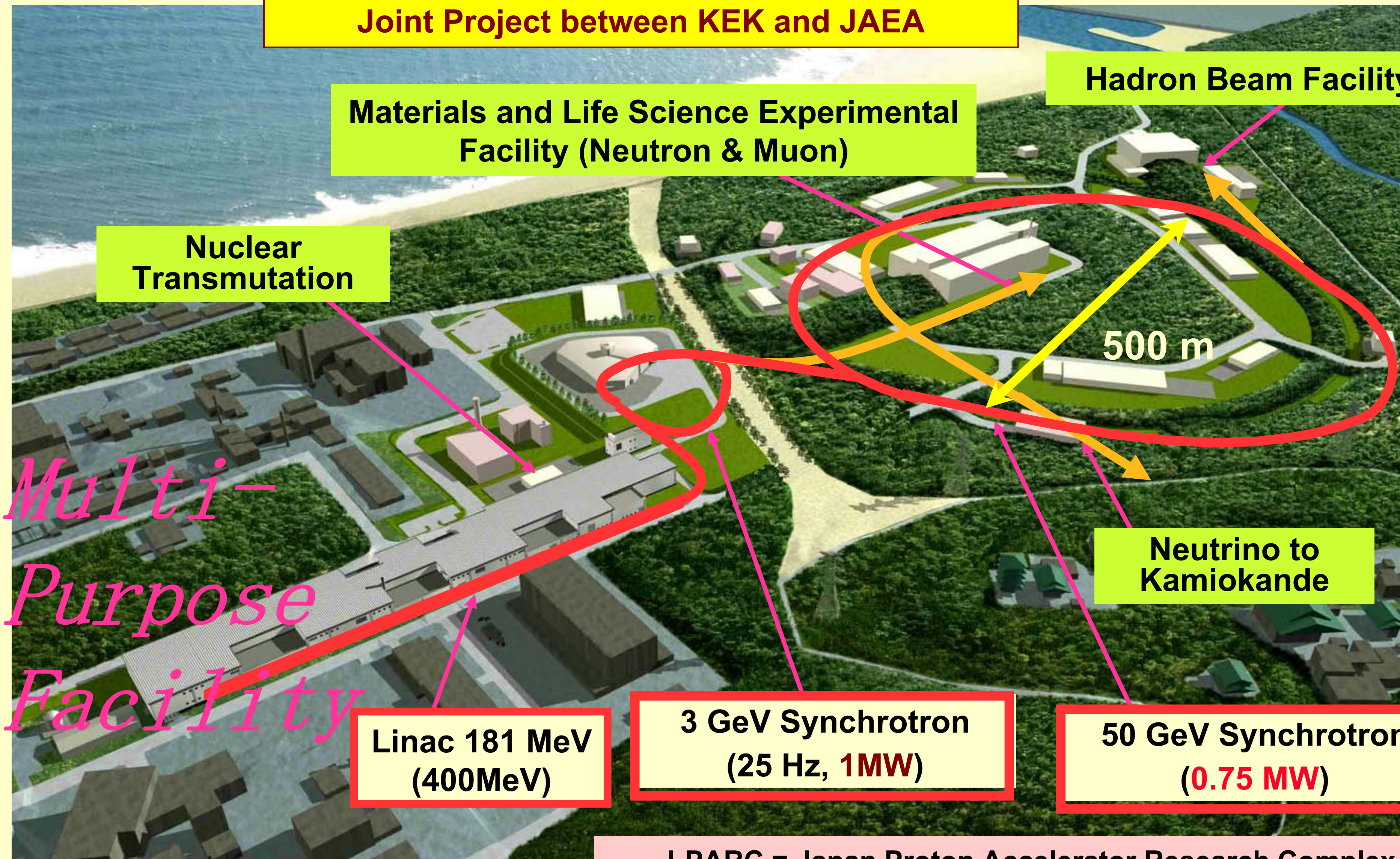






J-PARC Facility Layout

J-PARC
at Tokai, JAEA Site



J-PARC = Japan Proton Accelerator Research Complex

J-PARC LINAC

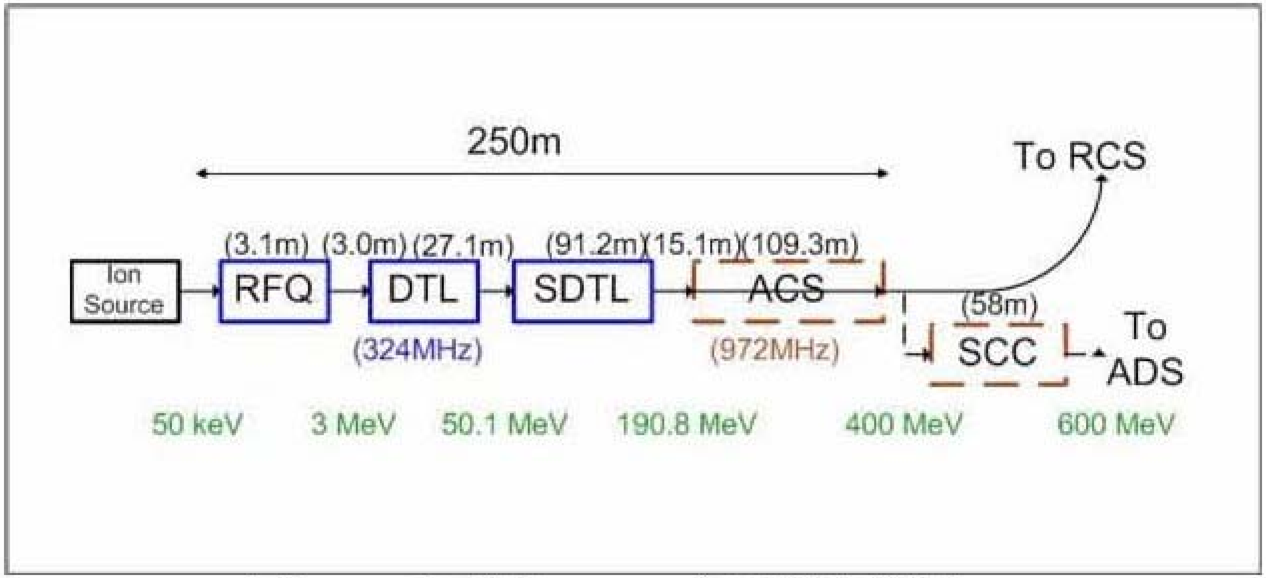


Figure 2: Scheme of J-PARC Linac.

Accelerator Driven Systems

1. Overall purpose

- Reduce the nuclear waste radiotoxicity & volume before underground storage
- 2500 tons of spent fuel are produced every year by the 145 EU reactors

2. Available strategy

- Partitioning : chemical separation of Pu, MA & FP
- Transmutation : use of the waste as a fuel in dedicated transmuter systems

3. The ADS transmuter system

- A subcritical reactor (k<1), in which the chain reaction is not self-sustained
- An intense spallation source, that provides the "missing" neutrons

From ETWG Report, 2001

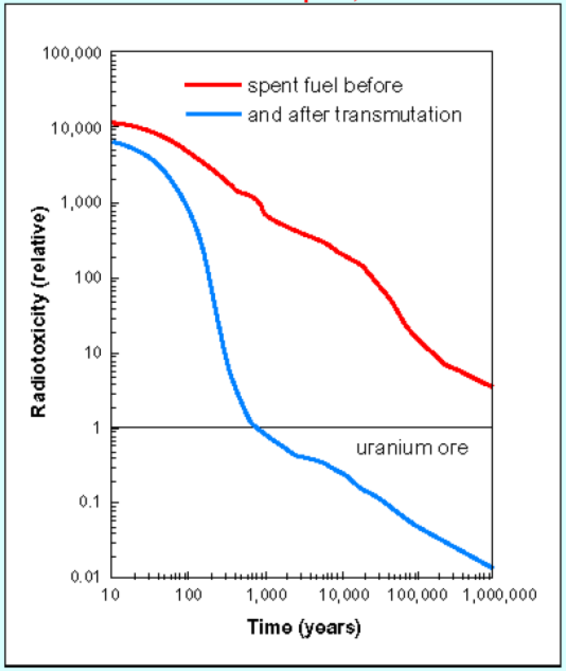
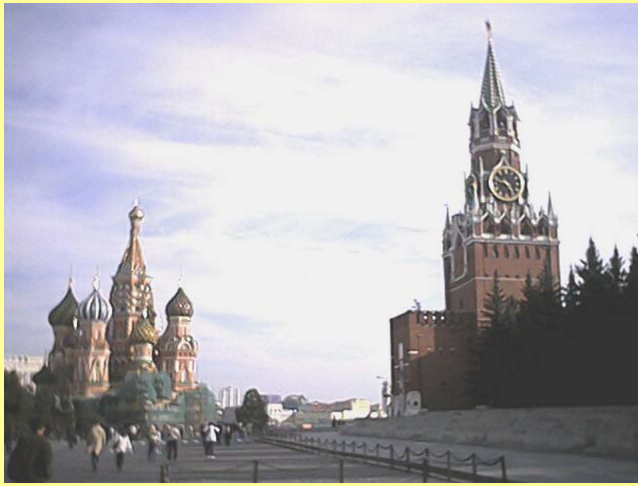


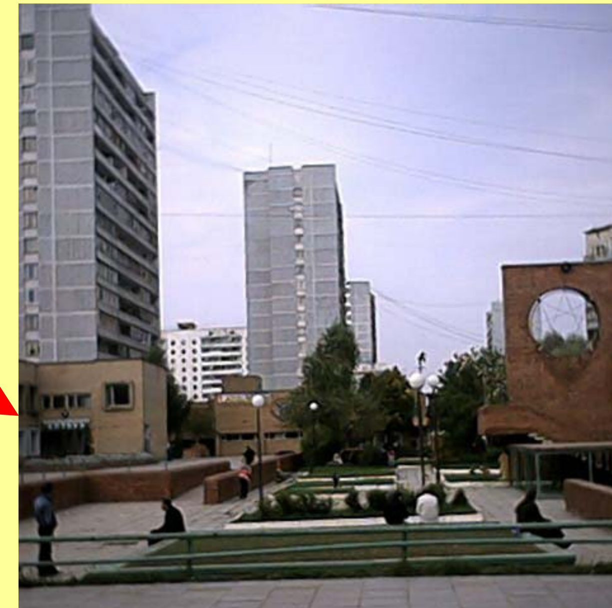
Fig. 1 – Ingestion radio-toxicity of 1 ton of spent nuclear fuel. With a separation efficiency of 99.9% of the long-lived by-products from the waste, followed by transmutation, reference radio-toxicity levels can be reached within 700 years

MOSCOW



20 km

TROITSK



1 km

INR Accelerator (MMF)

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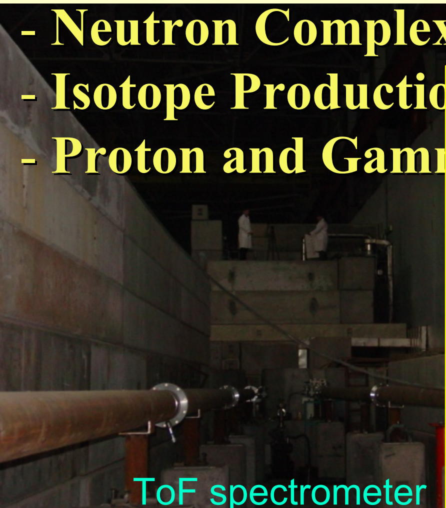
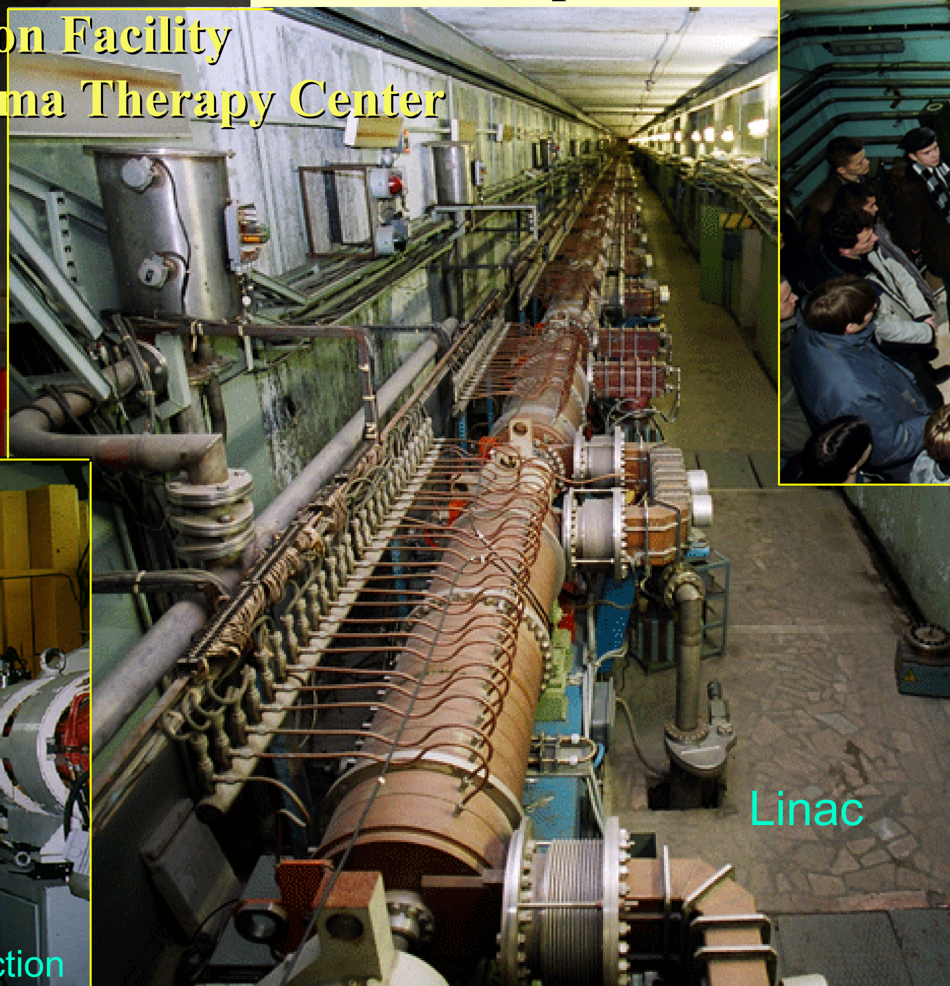
Moscow Meson Factory

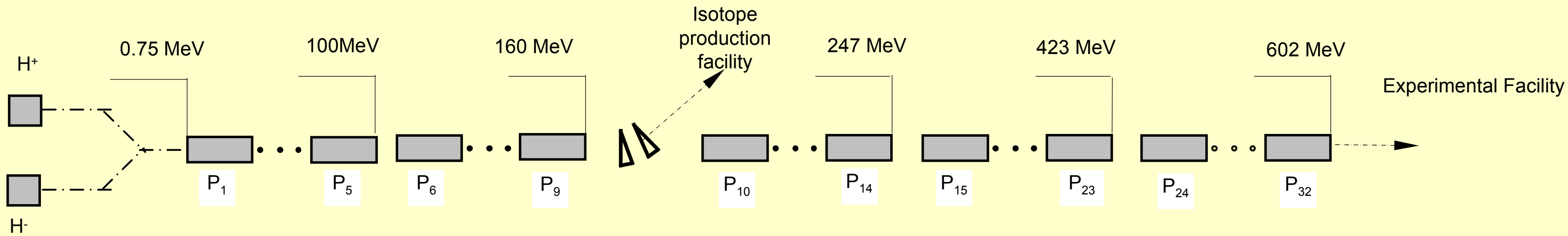
(Troitsk, Moscow region)

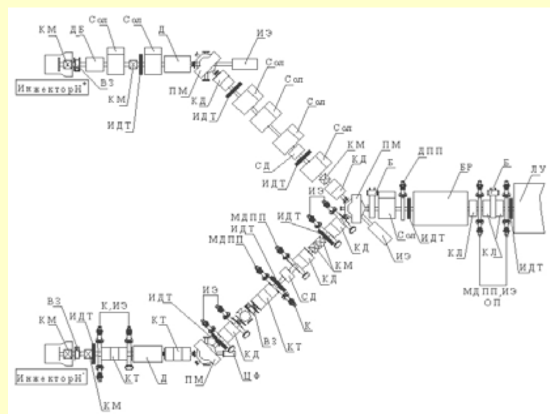
- High intensity proton and H- ion Linac
- Neutron Complex (IN-06, RADEX ToF Spectrometers, Lead Cub)
- Isotope Production Facility
- Proton and Gamma Therapy Center





Linear Accelerator





Proton Injector

Injection Lines

Low energy Part of INR Linac (100 MeV)

	20 MeV	49 MeV	74 MeV	94 MeV	100 MeV
	Tank 1	Tank 2	Tank 3	Tank 4	Tank 5

5 drift tube cavities

Frequency – 198.2 MHz

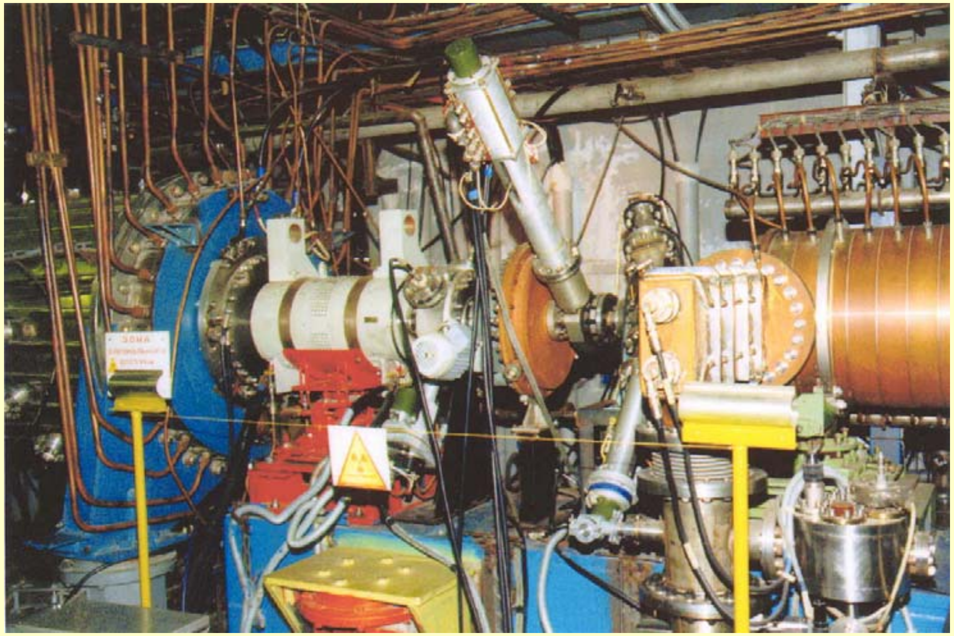
Output energy - 100 MeV

High Energy Part of INR Lnac (100-600 MeV)

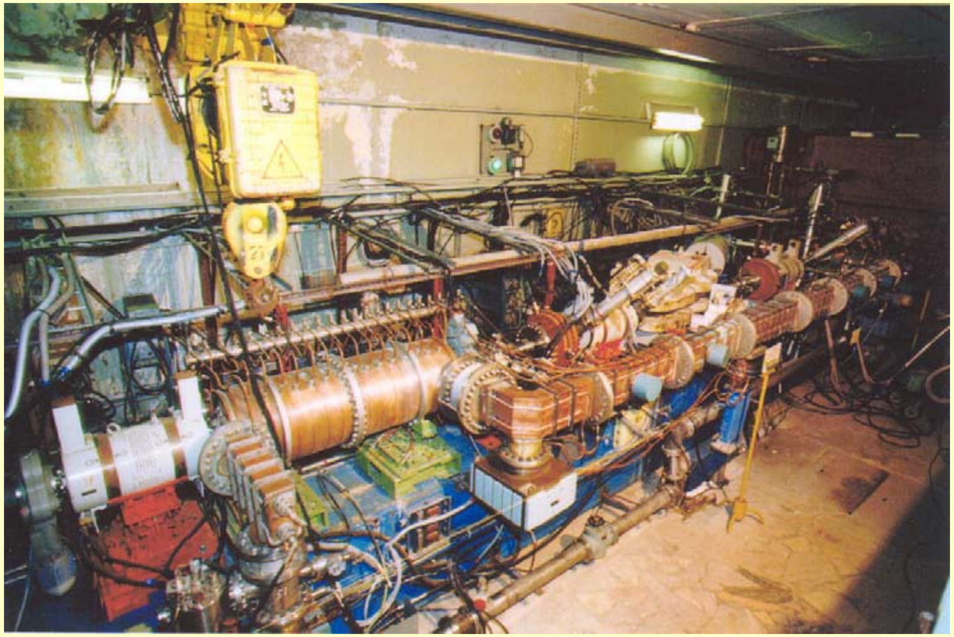
27 four-section disc and washer cavities operating at 991 MHz.

Accelerating cavities of high energy part of accelerator

RF gallery



Transition Region from DTL to D&W (100 MeV)



Intermediate Extraction Region (160 MeV)

Accelerator Control Room

Accelerator Parameters

Parameter	Design	Obtained	Status April 2008
Particles	H^+, H^-	H^+, H^-	H^+
Energy, MeV	600	502	209
Pulse Current, mA	50	16	12
Repetition rate, Hz	100	50	50
Pulse duration, μs	100	200	0,28…200
Average current, μA	500	150	120

Operation efficiency – 90%

Operation of Accelerator

1993 – Beginning of regular accelerator operation

From 1993 till April 2008 - 79 runs, total duration 32436 hours

Including: 2000 – 1800 hours (8 runs);

2001 – 2400 hours (7 runs);

2002 – 1400 hours (6 runs);

2003 – 2400 hours (7 runs);

2004 – 2200 hours (7 runs);

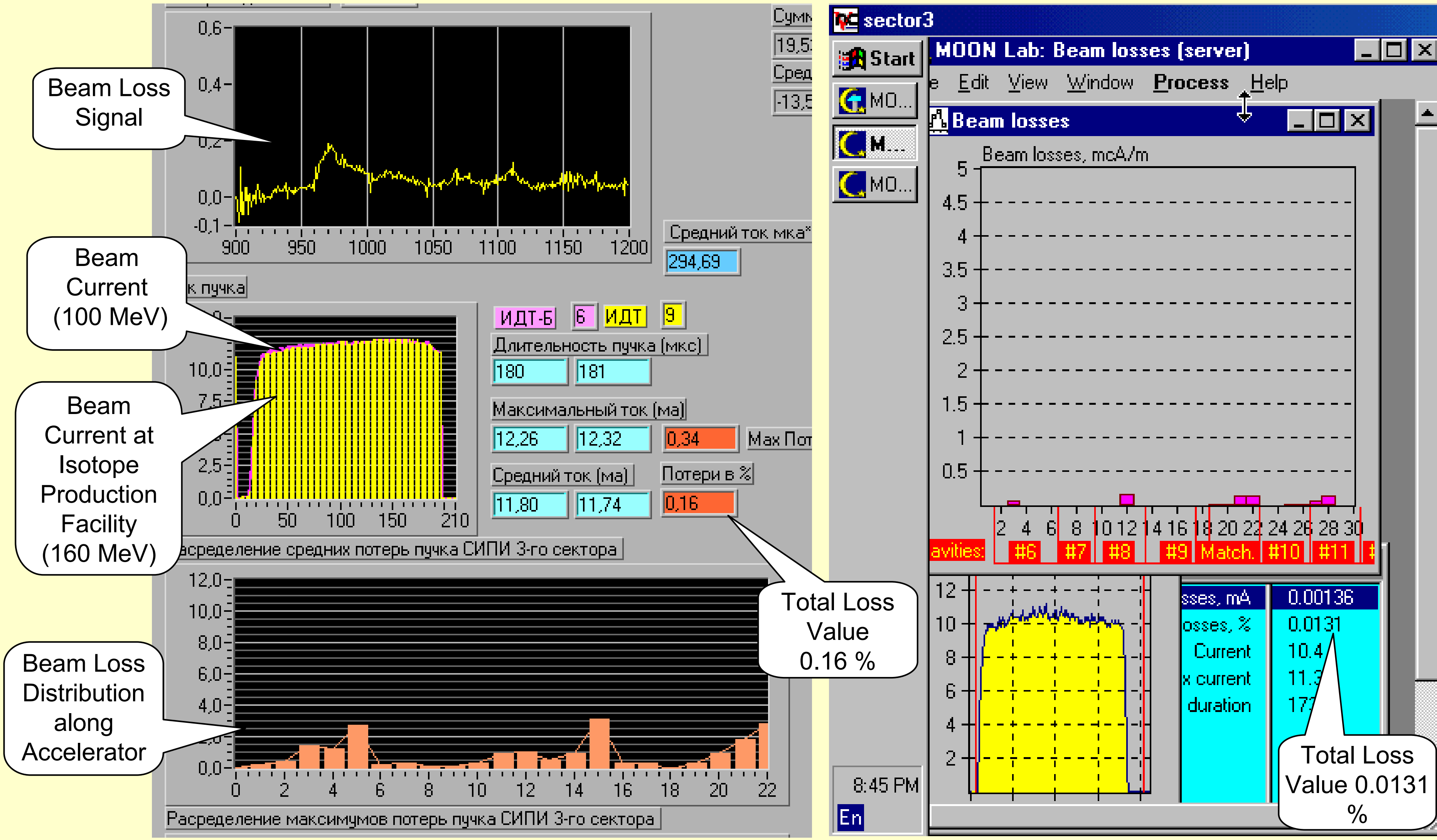
2005 – 1900 hours (6 runs);

2006 – 2250 hours (7 runs);

2007 – 2040 hours (7 runs);

2008 (January-April)– 644 hours (3 runs);

Beam Loss as a Criteria for Correct Accelerator Tuning



Operation For Isotope Production

Operation For Experimental Facility

INR Proton Linac main users

1. Isotope production facility
2. Multi-purpose Neutron complex
3. Proton Therapy Complex
4. Others

The features of accelerator operation

Isotope production (high intensity, about 100 μA).

Multi-purpose neutron complex (short beam pulses 0.3 - 60 μs, high intensity).

Problems :

- Beam diagnostics;
- Stabilization of phases in phase reference lines
- Stabilization of accelerating fields, transient processes.

Proton Therapy Complex (small pulse current, about 1 μA).

Problems:

- Beam diagnostics;
- Stabilization of phases in phase reference lines.

Other problems

Shortage of klystrons КИУ-40

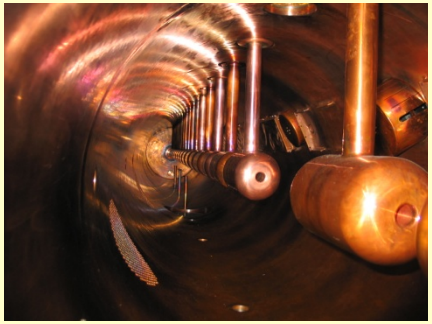
Stopping of RF and modulator tubes production. Replacement

ГИ-54А→ГИ-71А

ГИ-51А→ГИ-57А

ГМИ-44А→???

Death of drift tubes. Replacement



The nearest tasks

- Completion of H-minus injector and H-minus injection line.
- Bringing the process of two beam acceleration (protons and H-minus) to a routine operation.
- Modernization of 160 MeV intermediate extraction region. Installation of kicker magnet. Providing of flexible distribution of beams between experimental and isotope production facilities..
- Modernization of RF system of low energy part of accelerator.
- Doubling of repetition rate to 100 Hz.
- Increasing of energy as new klystrons become available.

Upgrade possibilities

Proceedings of the 1999 Particle Accelerator Conference, New York, 1999

UPGRADE STUDY OF INR PROTON LINAC FOR PRODUCTION OF 3 MW BEAM

L. V. Kravchuk[#] and P. N. Ostroumov
Institute for Nuclear Research RAS, 117312, Moscow

Abstract

There are many proposals for the construction of proton linacs with beam power up to 200 MW for various applications (energy production, nuclear waste

purpose is to confirm beam performance parameters, demonstrate an operation of SRF cavities and identify component failure modes.

The main task for the 3 MW linac is the development of transmutation technologies. After this problem will be

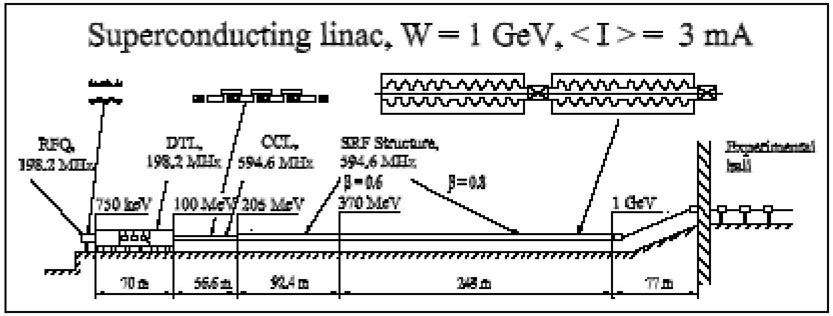


Figure 2: General layout of the 3 MW linac to be located in the MMF.

MMF Experimental Area

The Experimental Area

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- Proton beam transport lines
- Multi-purposes neutron complex
- Storage ring (not completed)
- Channels for secondary beams

Size: 60×130 m^2

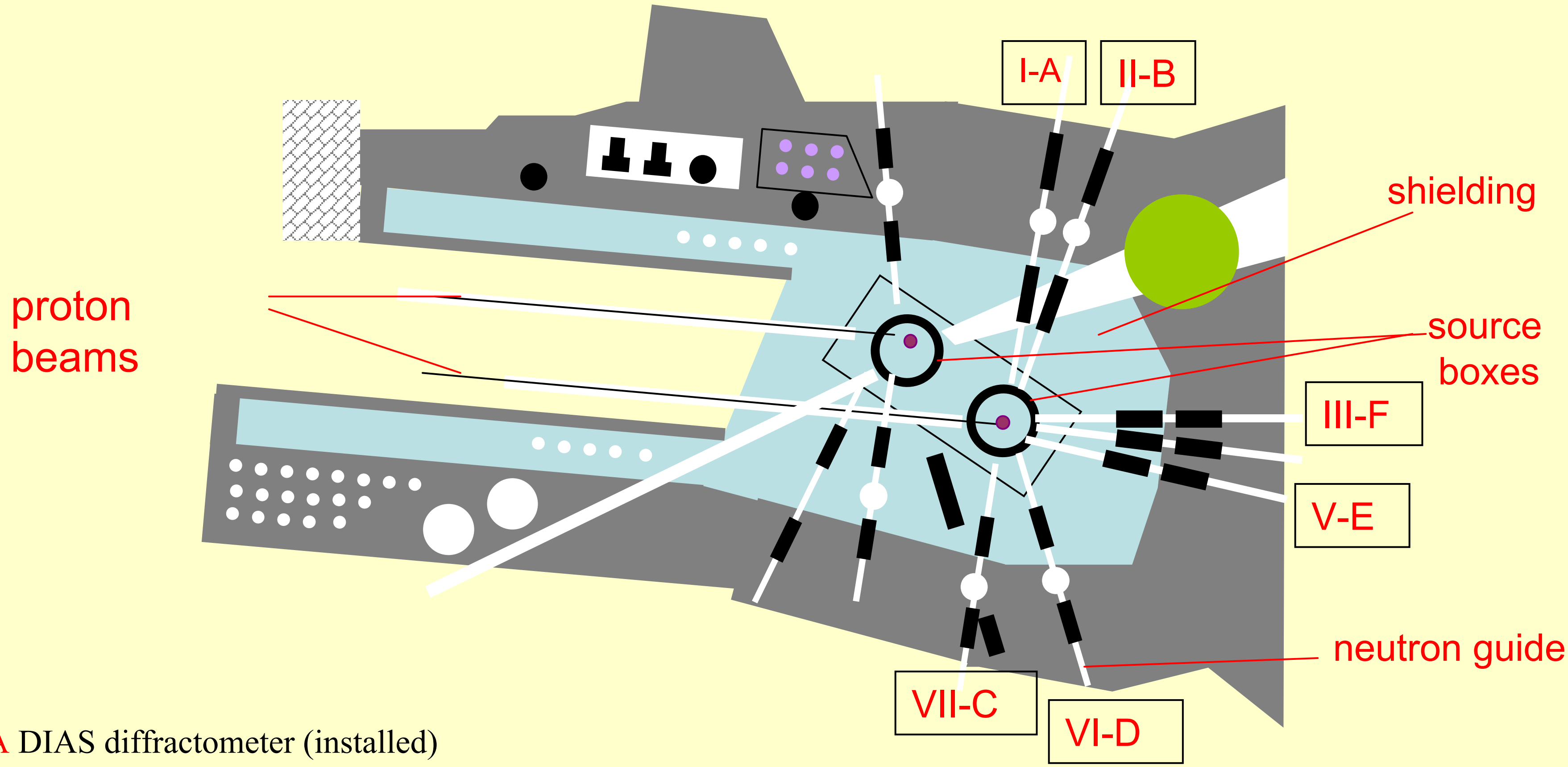
Research directions:

Nanomaterials structure/Condensed matter physics by neutron scattering; Nuclear physics; Astrophysics; Nuclear energy; Bio/Medicine; Components proton irradiation etc.

Experimental Possibilities of the Neutron Complex

- The spallation neutron source IN-06 with a number of multipurpose instruments
- The 100-tons spectrometer on neutrons slowing-down in lead LNS-100
- The RADEX facility (modified beam stop) with neutron guides and stations for TOF spectrometry

Neutron source facility



A DIAS diffractometer (installed)
B MNS multifunctional spectrometer (partially installed).
C Reflectometer «Horizon» (construction in progress).
D Hercules neutron physics facility (constructed).
E Inelastic scattering spectrometer of straight geometry (project).
F Small-angle scattering diffractometer (project).

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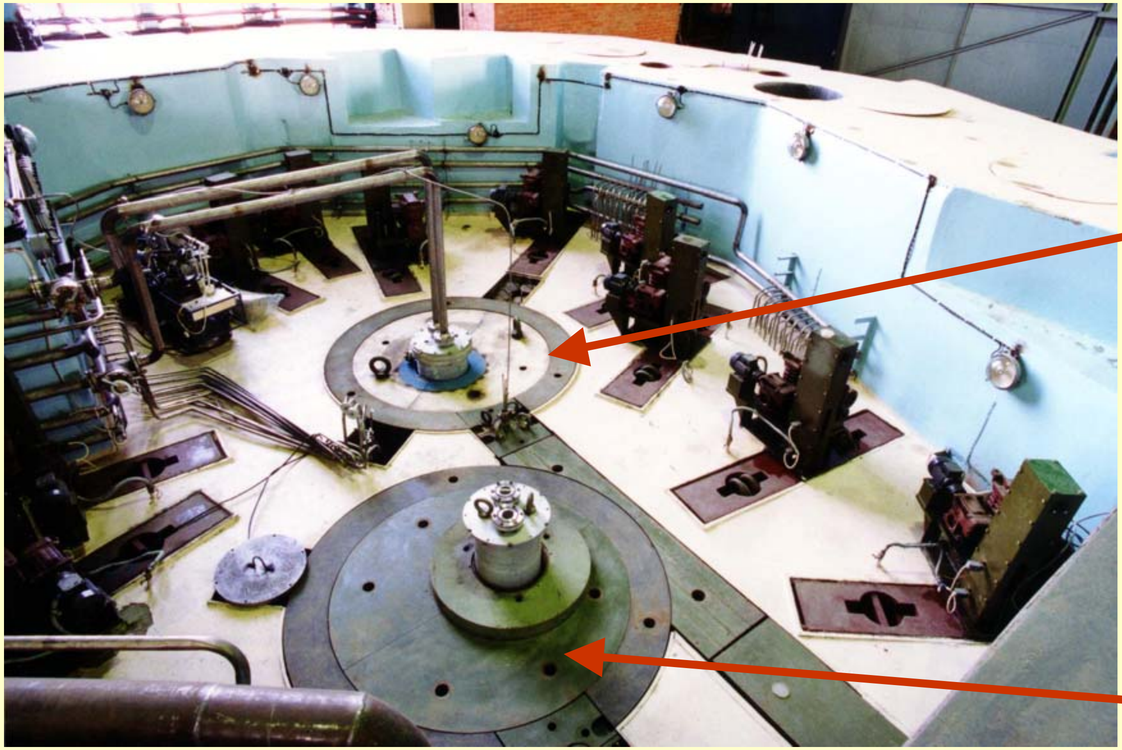
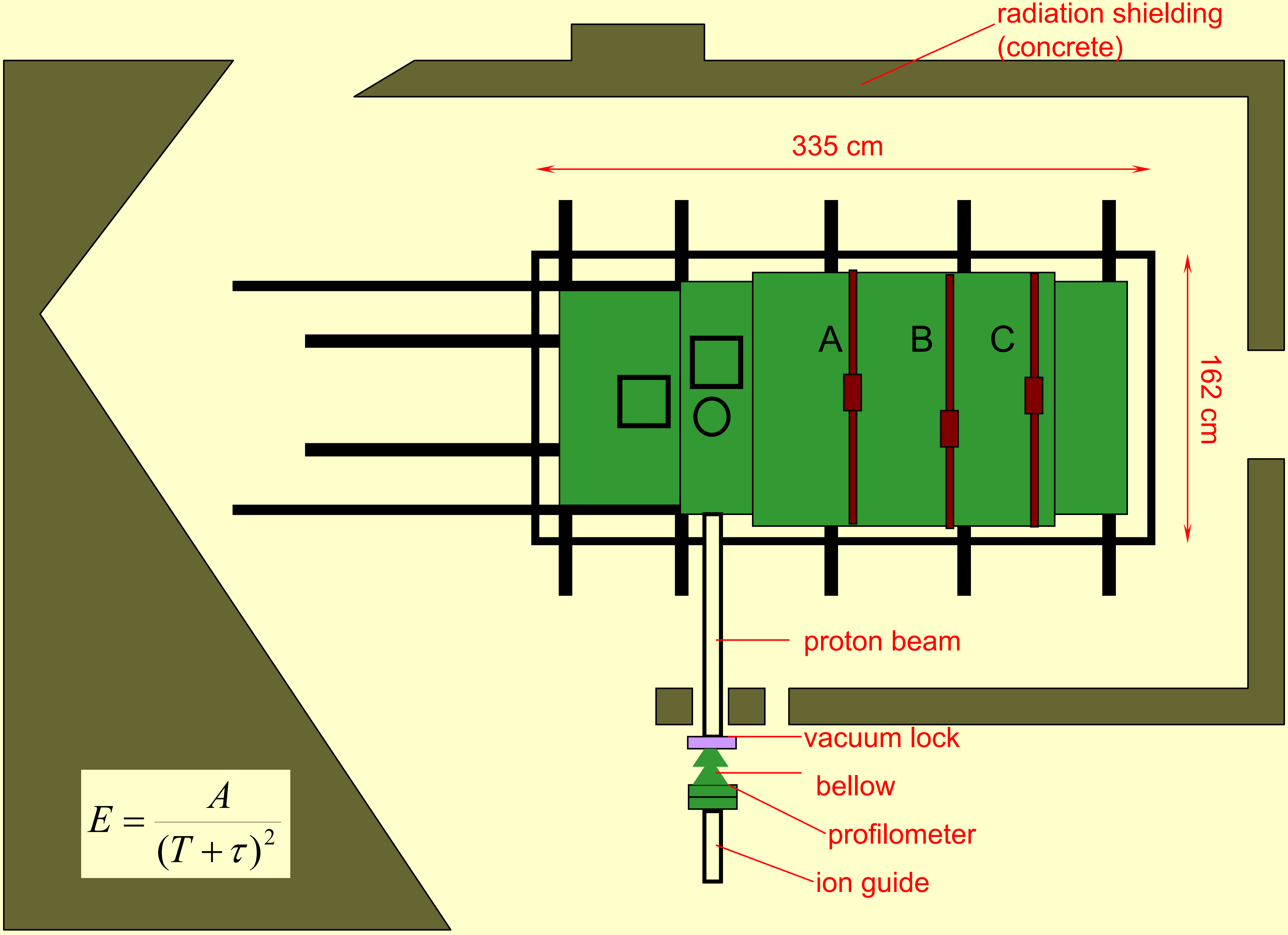
IN-06 top view



The tungsten target

The second box (for ADS or Ultra-cold neutrons)

Lead neutron spectrometer (100 tons)

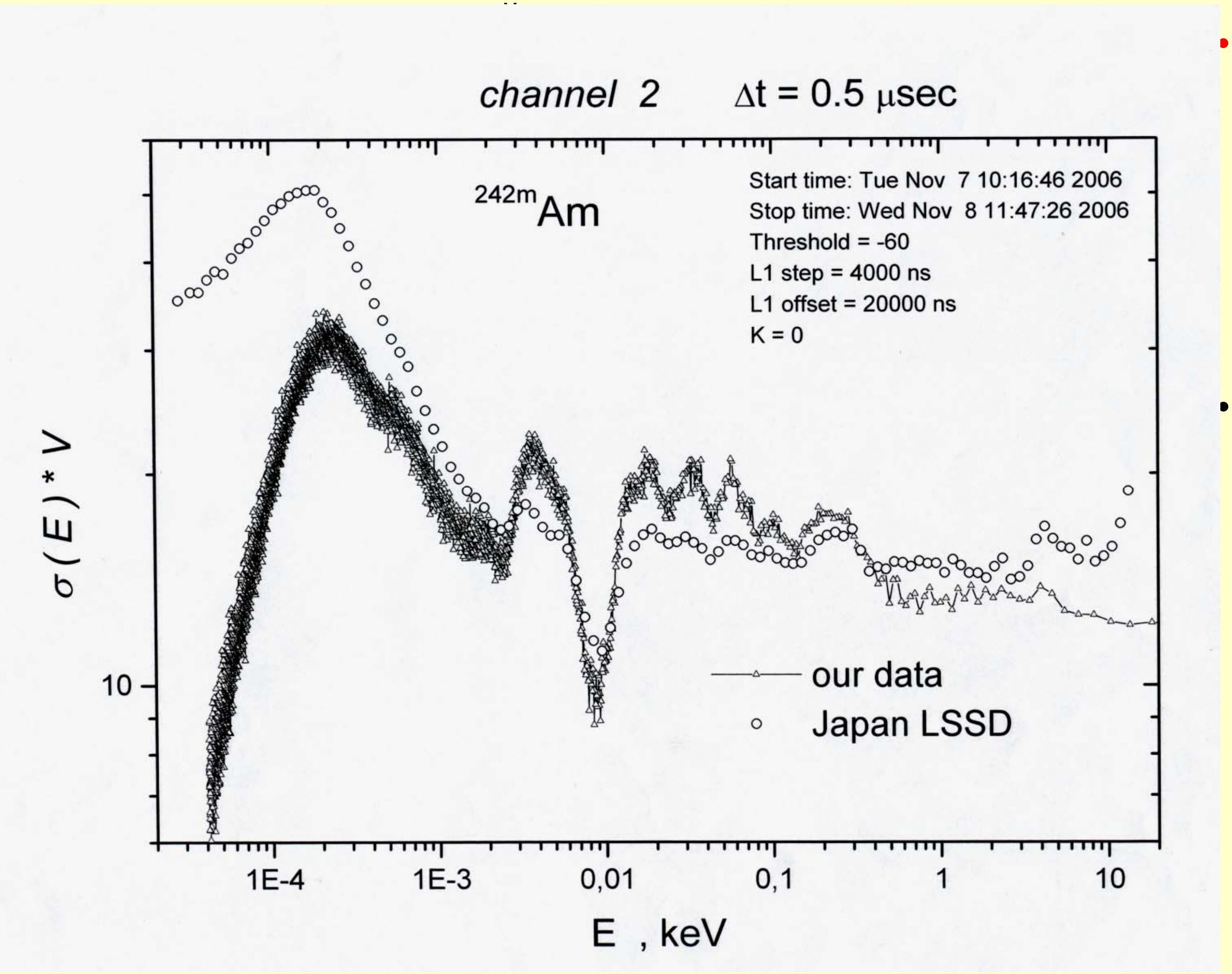


$$E = \frac{A}{(T+\tau)^2}$$

TOF RADEX spectrometer

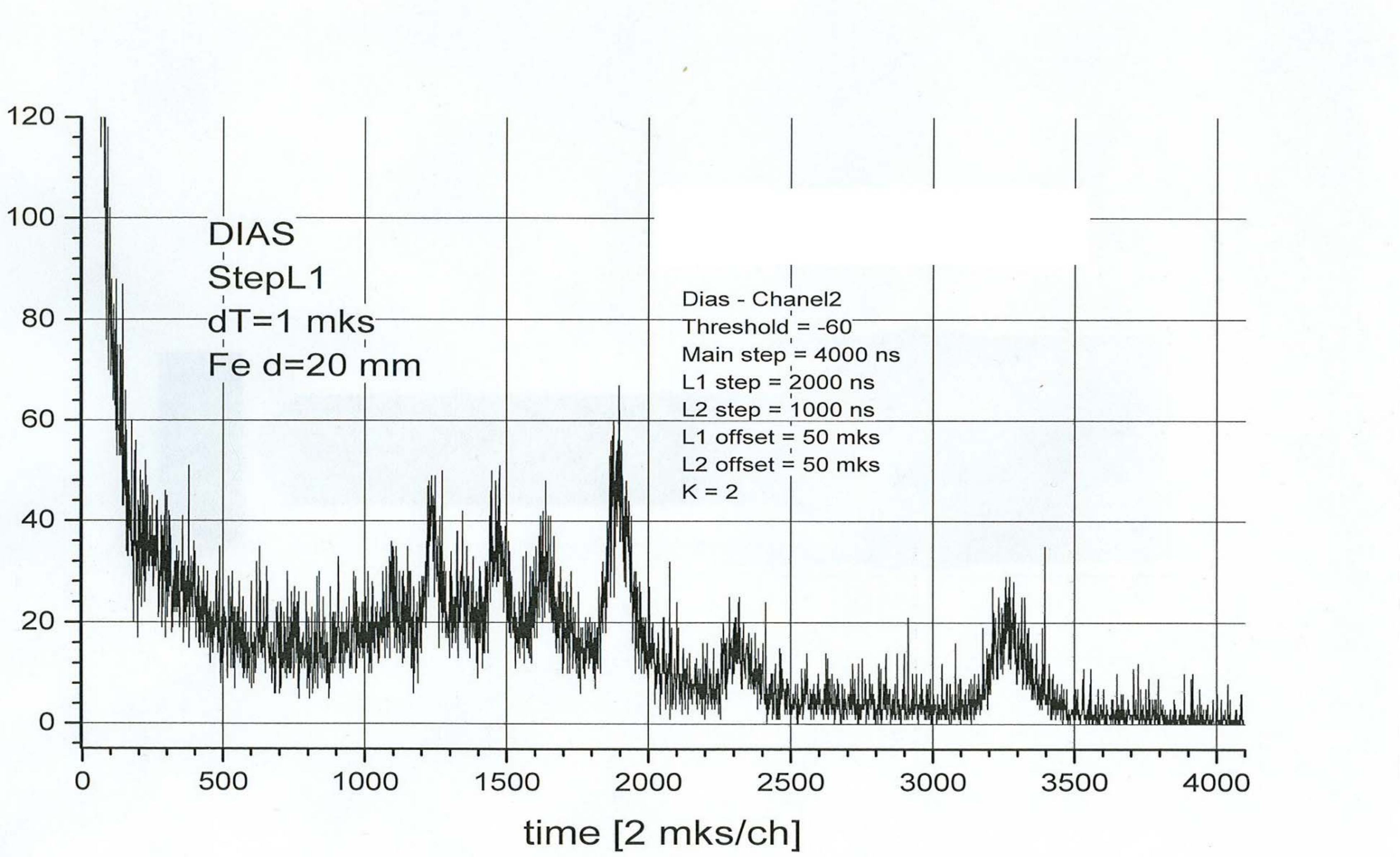
- The modified tungsten target of the installation RADEX is optimized for absorption of the proton beam with energy 250 MeV and average current up to 150 μA.
- The horizontal and vertical vacuum neutron guides give a possibility to realize the time-of-flight experiments on a base till 50 m. For pulse length variation from 0.25 μs to tens of microseconds neutron fluxes are 4×10^{12}… 1.2×10^{15} n/s with energy resolution (0.15…2.0) %.

Данные измерений (ноябрь 2006 г.) на *спектрометре по времени замедления в свинце* (СВЗ-100) сечений деления долгоживущих актинидов, необходимых для решения экологических проблем



- Сечения деления метастабильного долгоживущего Америция 242m, полученные на спектрометрах СВЗ в Японии и на СВЗ-100 в ноябре 2006г.
- *Видно существенно лучшее разрешение на СВЗ-100, обусловленное высочайшей чистотой свинца – 99,996%.*

Нейтронограмма поликристаллического железа полученная на импульсном источнике нейтронов РАДЭКС-ИЯИ РАН с помощью времени пролета с использованием макетного варианта спектрометра . (27 Апреля 2007г.)



DETERMINATION OF nn-SCATTERING LENGTH FROM DATA ON nn- FINAL STATE INTERACTION IN n+d→p+n+n REACTION

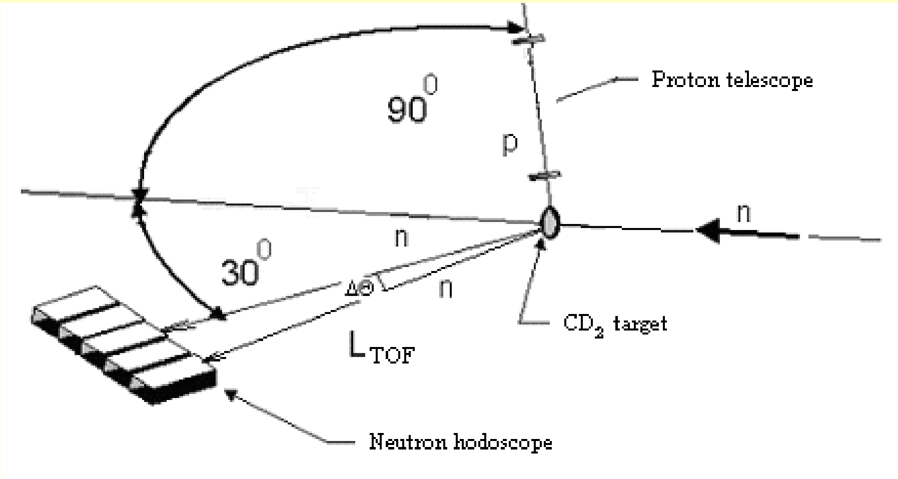
One of the most fundamental evidence for Charge Symmetry Breaking in nuclear physics is the difference between nn and pp scatterings lengths. This difference is small and precise data are needed.

The results obtained by now testify significant uncertainty of a_{nn} values which are clustered near -16.1±0.4 (Bonn) and -18.5±0.3 fm (TUNL, LAMPF), so there is even uncertainty about the sign of this difference

Proposed experiment – n+d→p+n+n reaction.

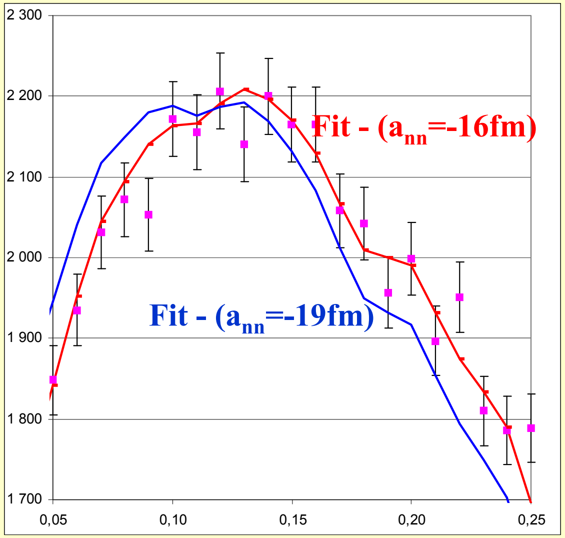
The nn scattering length will be determined from the dependence of the yield of nd breakup reaction on the relative energy of two neutrons.

EXPERIMENT

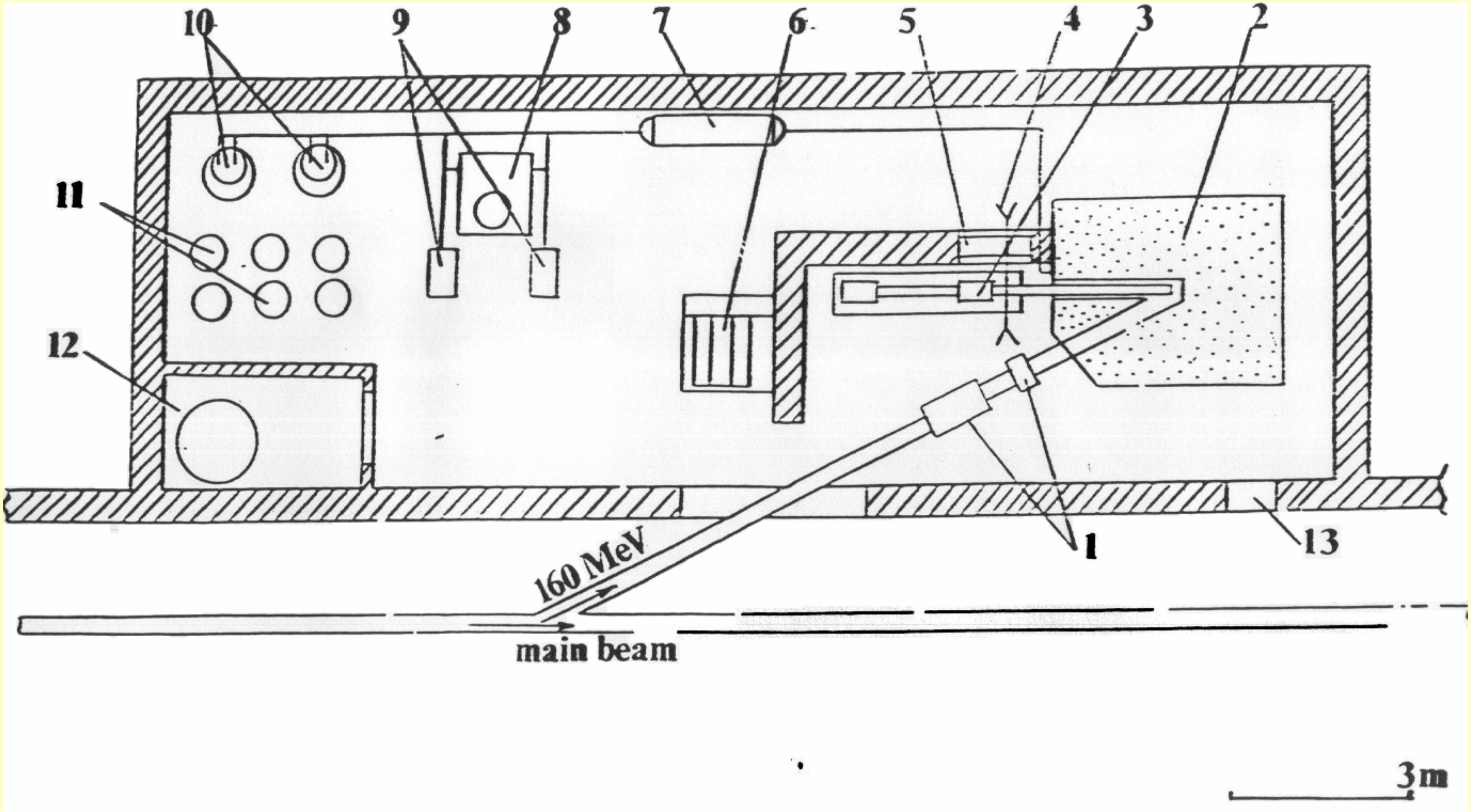


SIMULATION

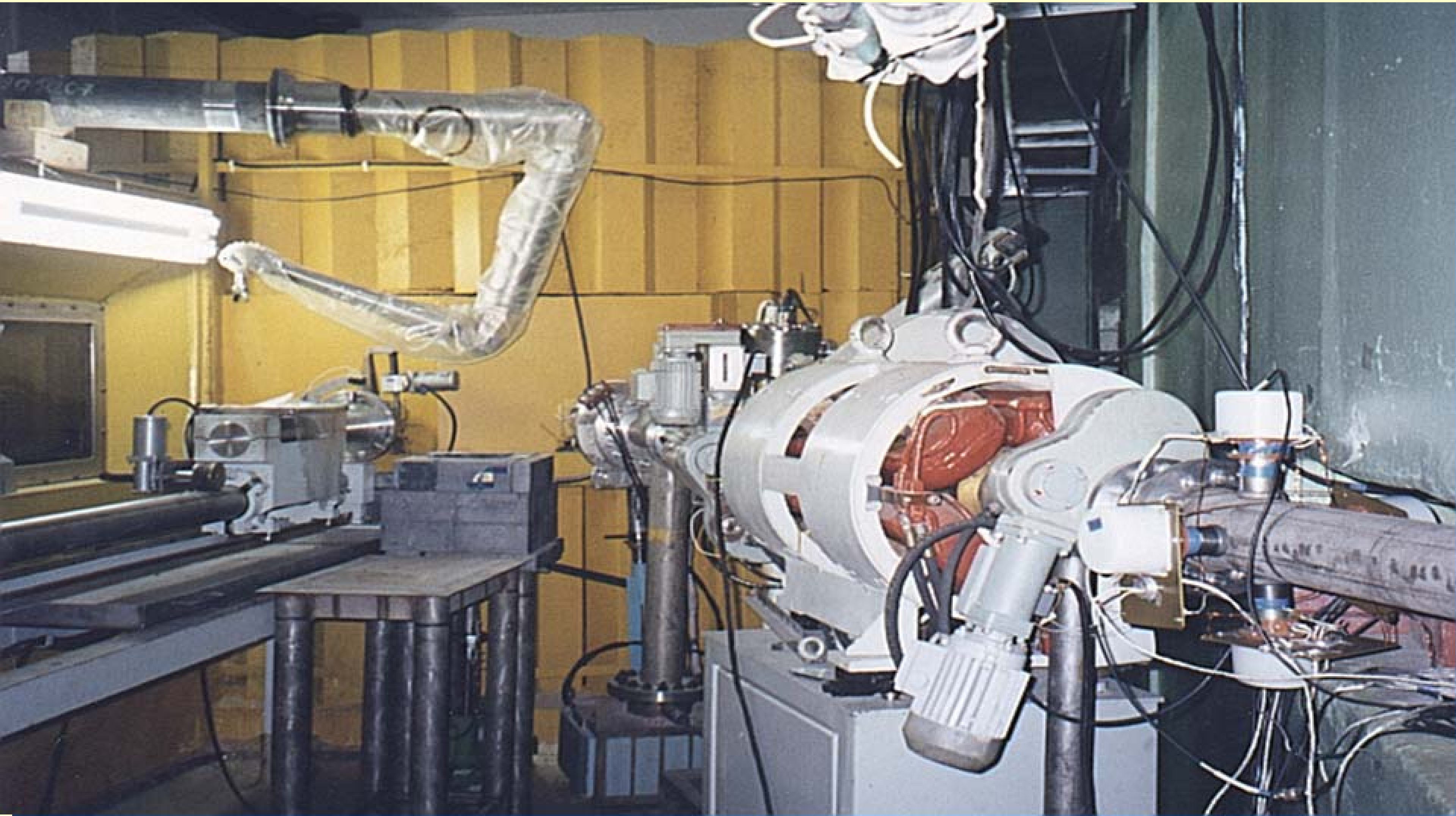
Input – (a_{nn}=-16fm)

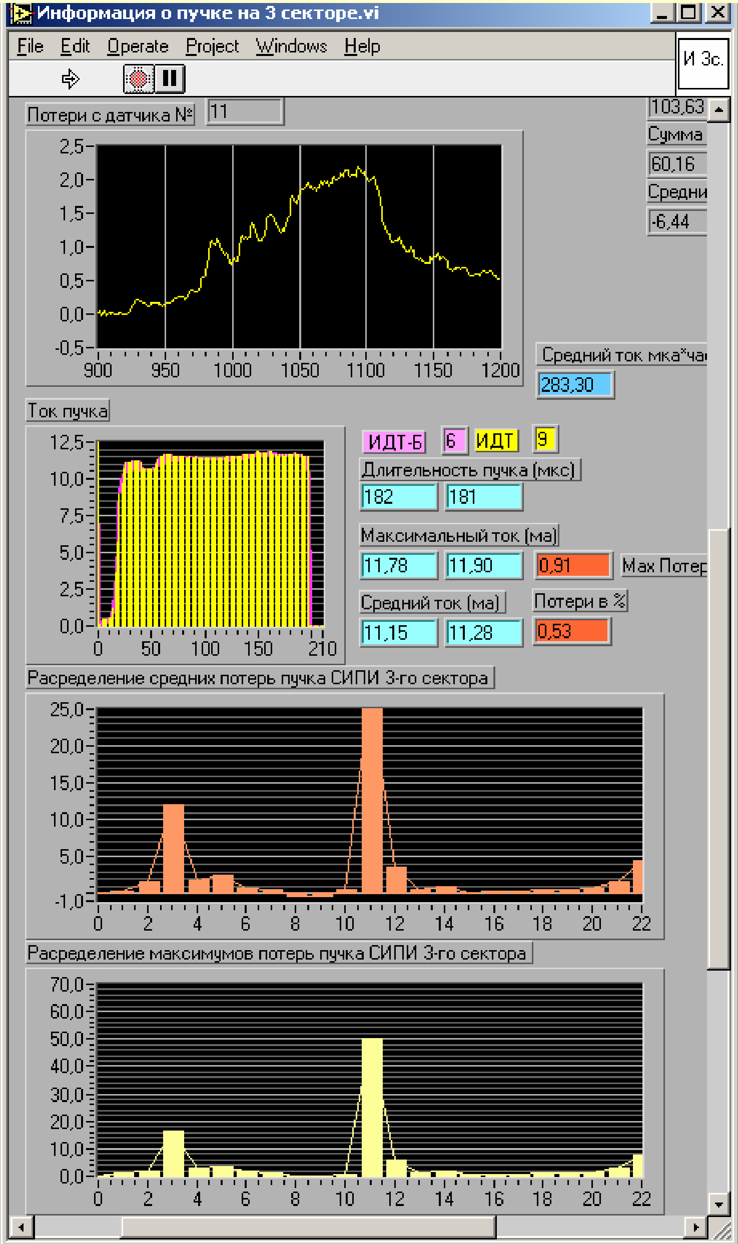


Floor Plan of INR Isotope Production Facility

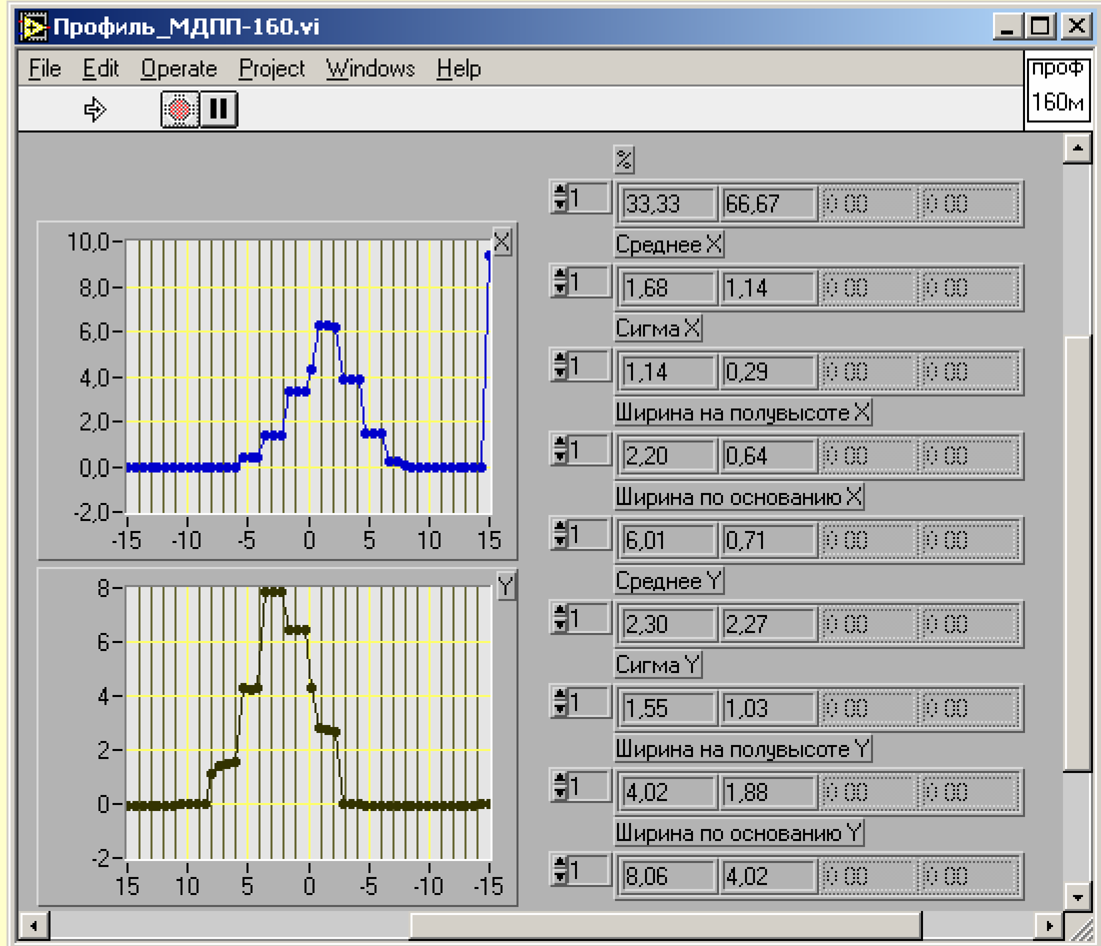


INR Isotope Production Facility

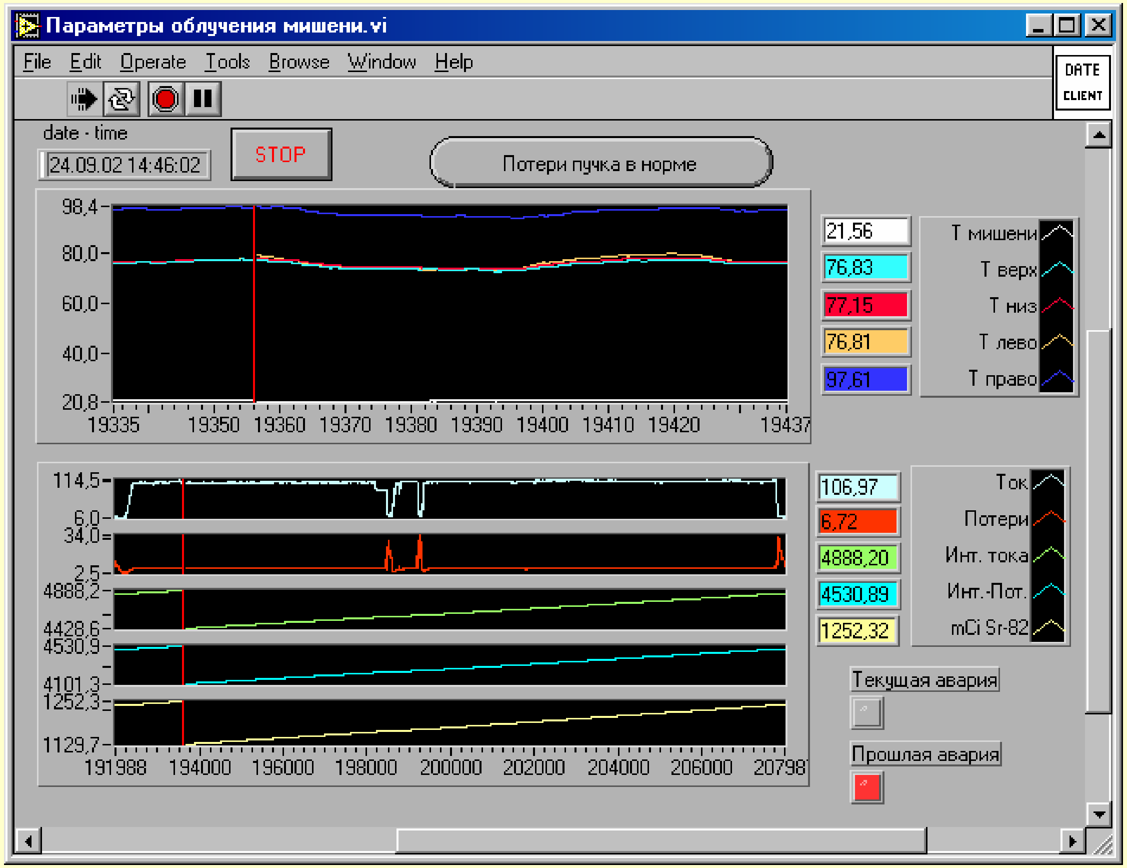




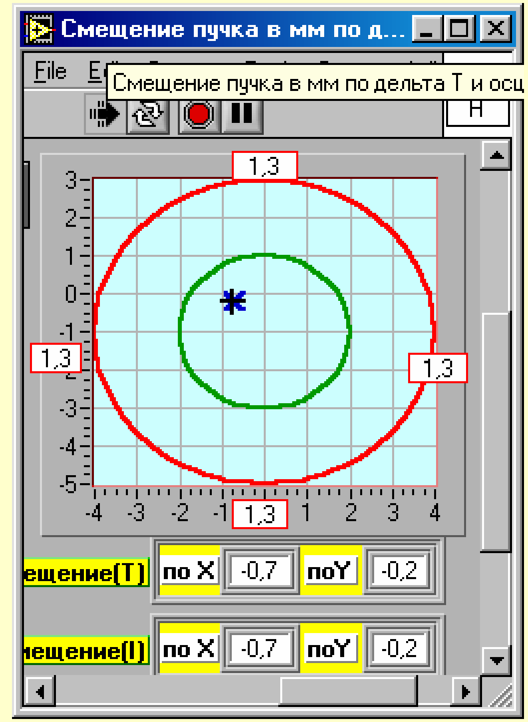
Beam Loss Information



Beam Profile at Isotope Production Facility



Target irradiation parameters



Finding of beam position on the target using temperatures of target and collimators

- **Routine production**

  Sr-82, generator Sr/Rb-82, Na-22, Cd-109

- **Technology design ready to use**

  Sn-117m, Ge-68, Se-72, Pd-103

- **Design in progress**

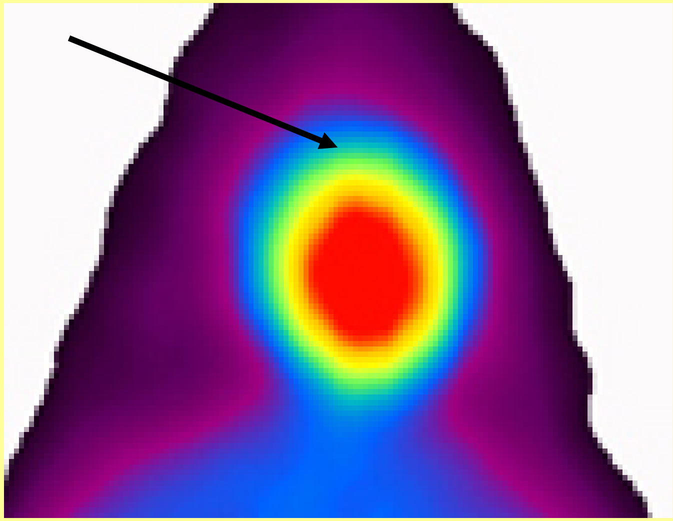
  Ac-225, Cu-64 and 67, As-76,
  generator Se/As-72

- **Others**

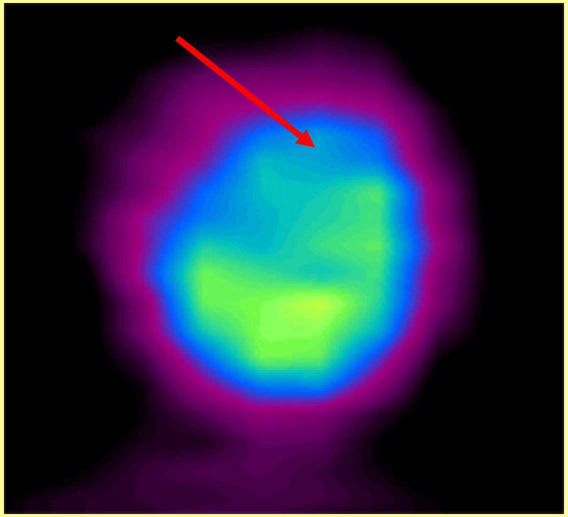
  Tl-201, I-123 и 121, Mo-99, F-18, Ti-44, Co-57

PET- grams of rabbit heart obtained with the present Russian Sr/Rb-82 generator

(Frontal slices)



Healthy rabbit heart
Heart is shown with the arrow



Infarcted rabbit heart
Infarct area is shown with the arrow

INR Beam Therapy Center (Troitsk)

The primary goal:

irradiation of malignant tumors by protons only or in a combination with irradiation by photons.

Basic facilities:

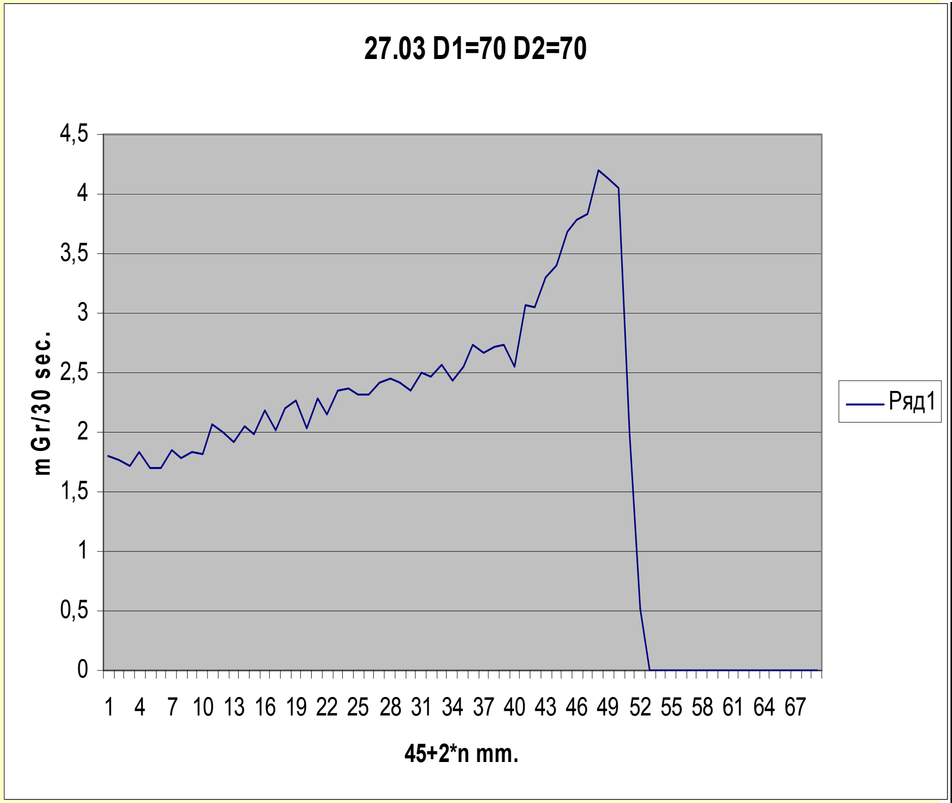
- The proton linac (energy 74 – 247 MeV),
- The linear electron accelerator SL-75-5-MT (energy up to 6 MeV).

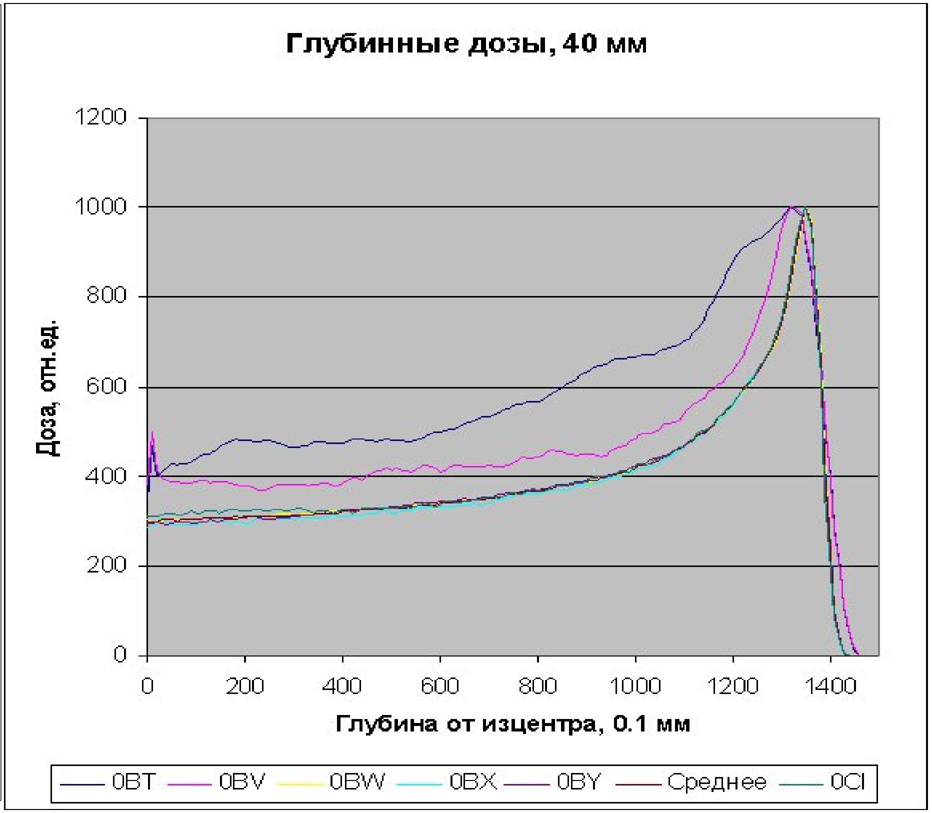
The Center also consists of:

- The proton-beam transport channel,
- 2 treatment rooms (protons and photons),
- The ambulatory for 30 patients per day,
- X-ray laboratory for topometry and therapy .

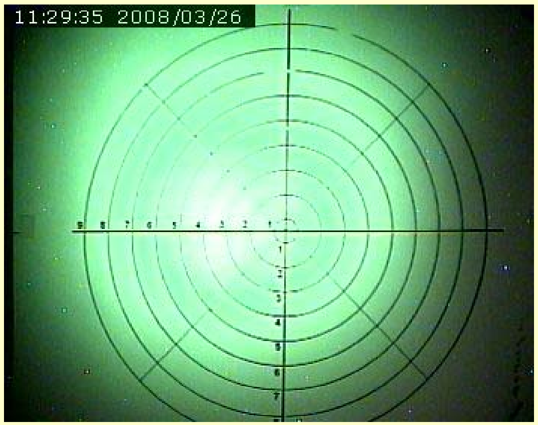
INR Beam Therapy Complex accepted by State Commission in 2007

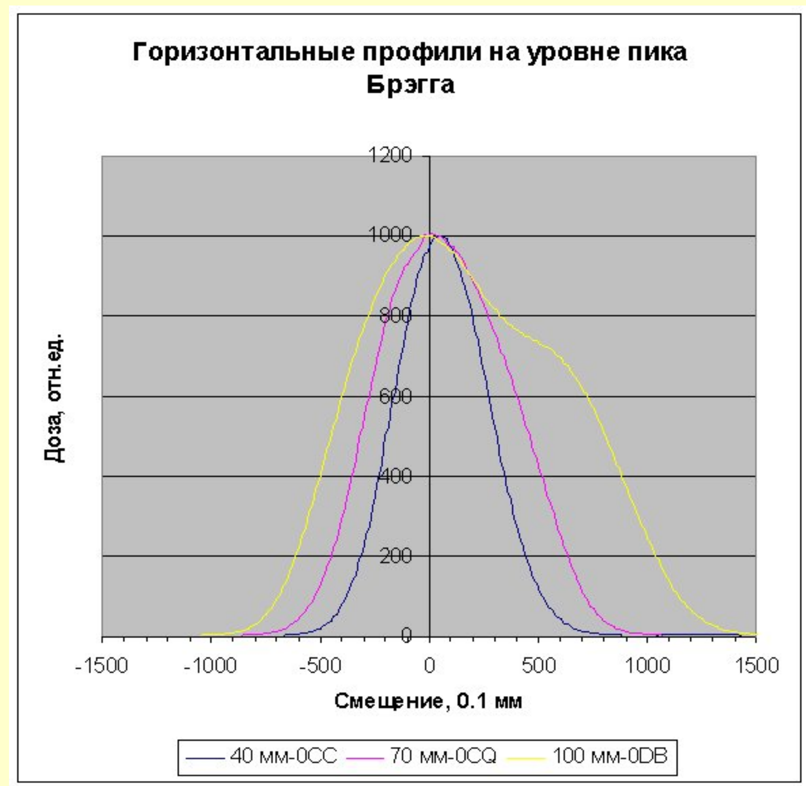
First phantom measurements





Beam position and shape





INR Participation in International Particle Accelerators Collaborations

1. **CERN – LHC (3 Addendums), Linac 4**
2. **DESY – S-band, TESLA, TTF, PITZ, XFEL (~30 contracts)**
3. **ORNL – SNS (~20 contracts)**
4. **KEK/JAERI – J-PARC**
5. **ILC**

TRIUMF, LANL, ANL, FNAL etc…

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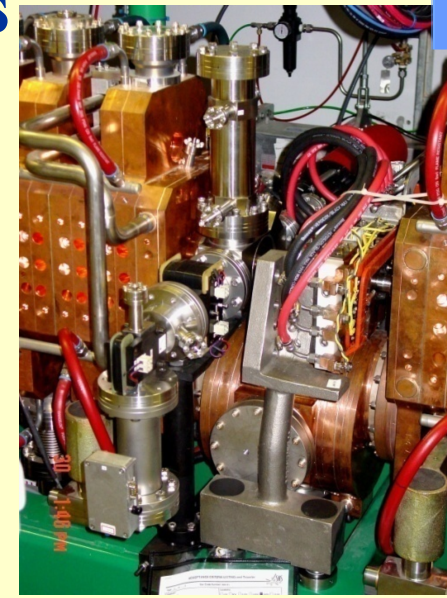
Addendum		Total value, kCHF	Status
D1	Inter-Tank Bunch Shape Monitors	360	Completed in 1999.
D2	Survey targets	1034.439	Completed in 2001
D3	Ceramic Pipes for Rotating Long Coils	529.800	Completed in 2003.
Total		1924.239	

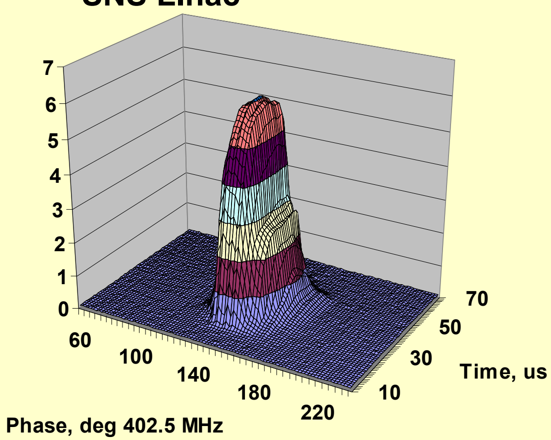
SNS Bunch Shape Monitors

BSM developed for
SNS LInac

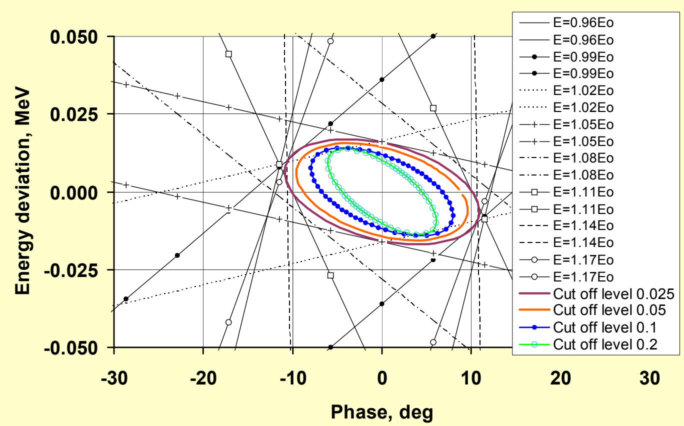
BSM
electronics



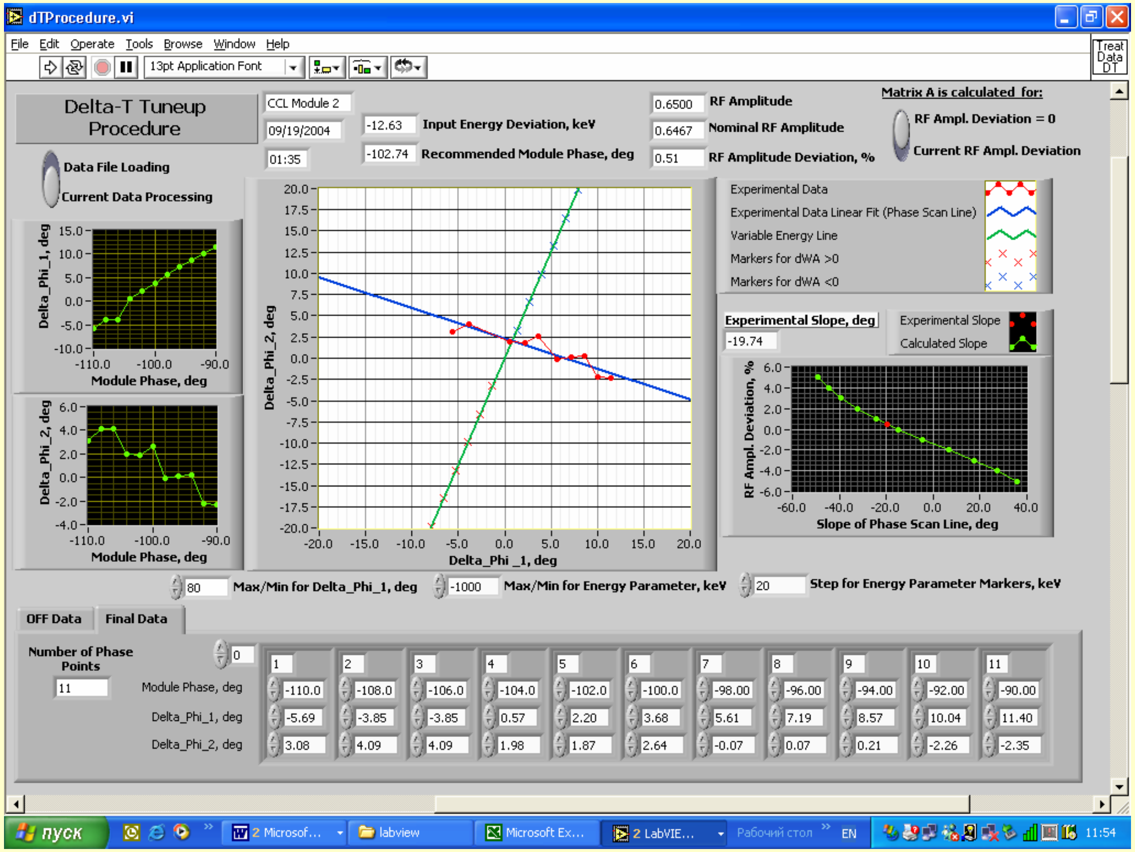
BSM in the inter
segment of the CCL
module of SNS linac



Evolution of longitudinal
distribution within the beam
pulse in SNS Linac



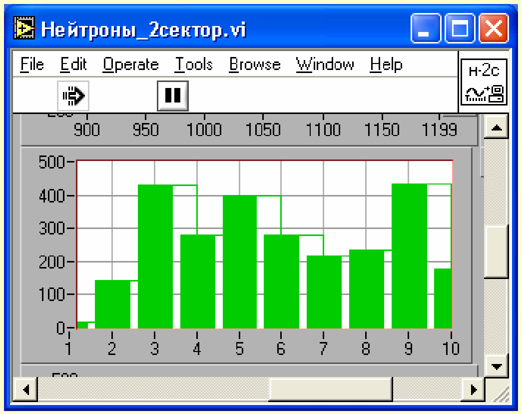
Longitudinal emittance at the
exit of DTL Tank 1of SNS Linac



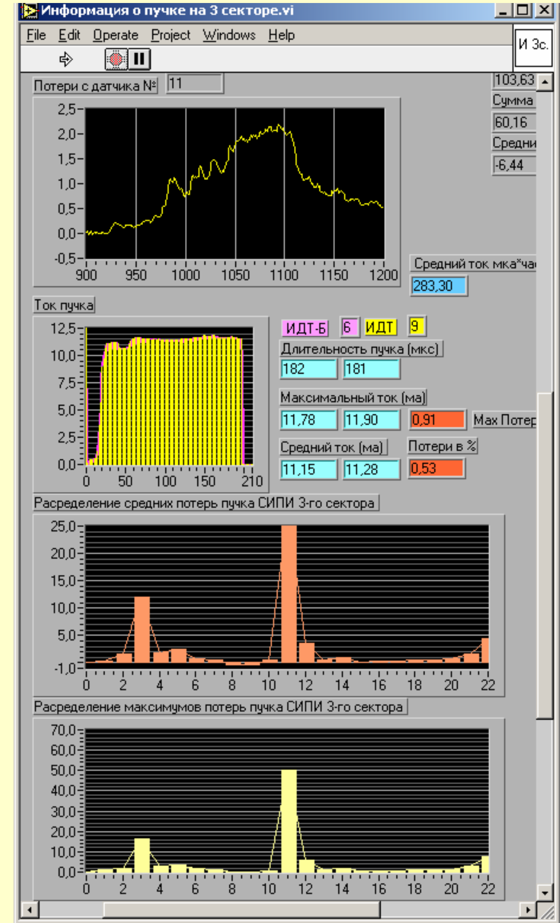
	1	2	3	4	5	6	7	8	9	10	11
Module Phase, deg	-110.0	-108.0	-106.0	-104.0	-102.0	-100.0	-98.00	-96.00	-94.00	-92.00	-90.00
Delta_Phi_1, deg	-5.69	-3.85	-3.85	0.57	2.20	3.68	5.61	7.19	8.57	10.04	11.40
Delta_Phi_2, deg	3.08	4.09	4.09	1.98	1.87	2.64	-0.07	0.07	0.21	-2.26	-2.35

ΔT-procedure at the SNS Linac

Beam Loss Measurements



Example of information on Beam Loss in INR LInac with neutron detectors



Example of information on Beam Loss in INR LInac

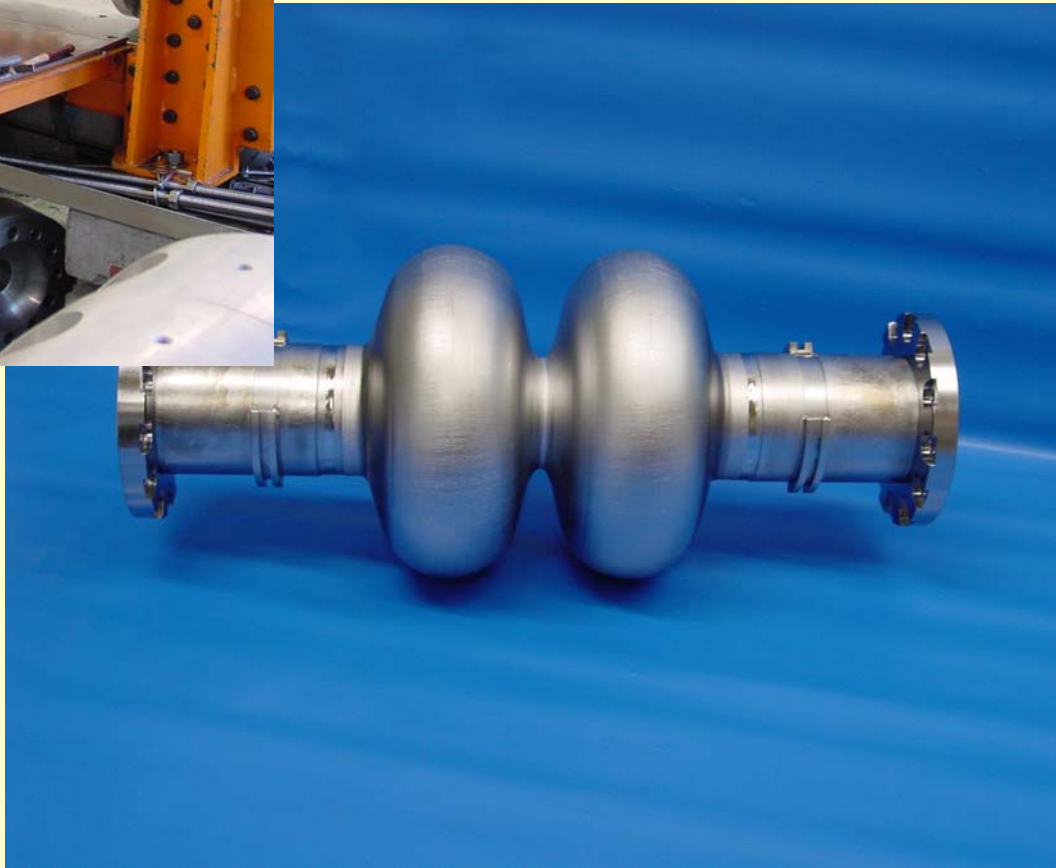
INR has developed and supplied for Beam Loss System of SNS Linac:

- Beam Loss Monitors (Neutrons) – 30 pc
- High Sensitivity Beam Loss Monitors (Neutrons) – 13 pc
- Small Beam Loss Monitors (Neutrons) – 5 pc
- Dual Beam Loss Monitors (Neutrons + Gamma) – 10 pc
- Collimated Beam Loss Monitors (Neutrons) – 3 pc

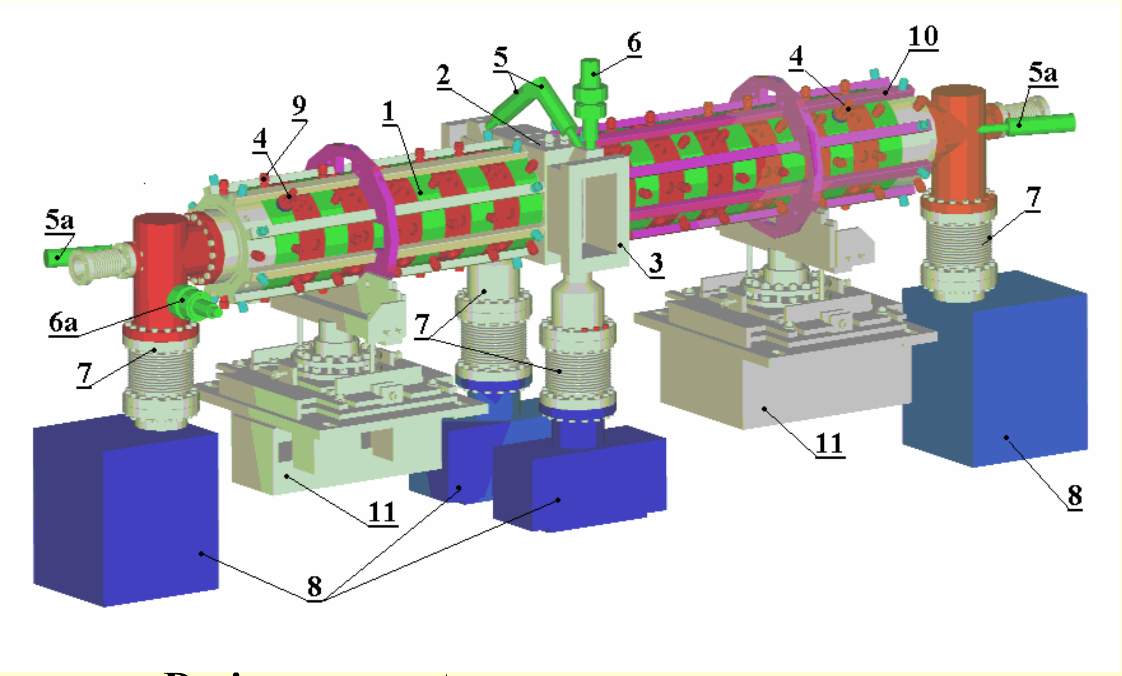
Beam Loss Monitor (Neutrons) for SNS Linac

SC Cavities Technology

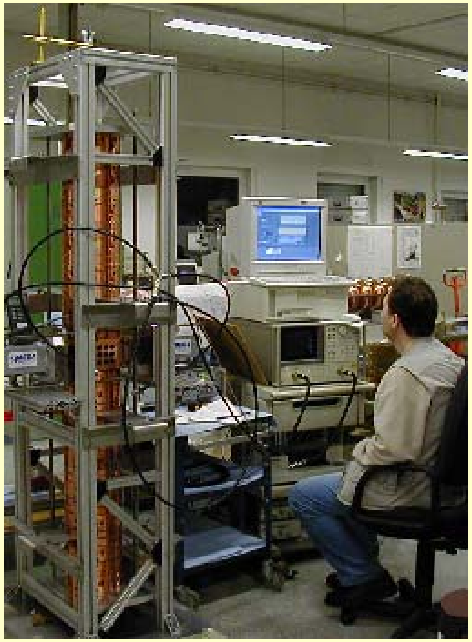
DESY - INR



The normal conducting booster cavity development for the Photo Injector Test Stand PITZ-2 stage, DESY, Zeuthen. The cavity is based on the Cut Disk Structure (CDS), proposed (1997) and developed in INR.



Booster cavity layout. 1 - regular cells, 2 - rf coupler, 3 - rf flanges, 5, 5a - photo multipliers, 6, 6a- vacuum gauges, 7 - pumping ports, 8 - ion pumps, 9 - internal cooling circuit, 10 - outer cooling circuit, 11 - support and adjustment.



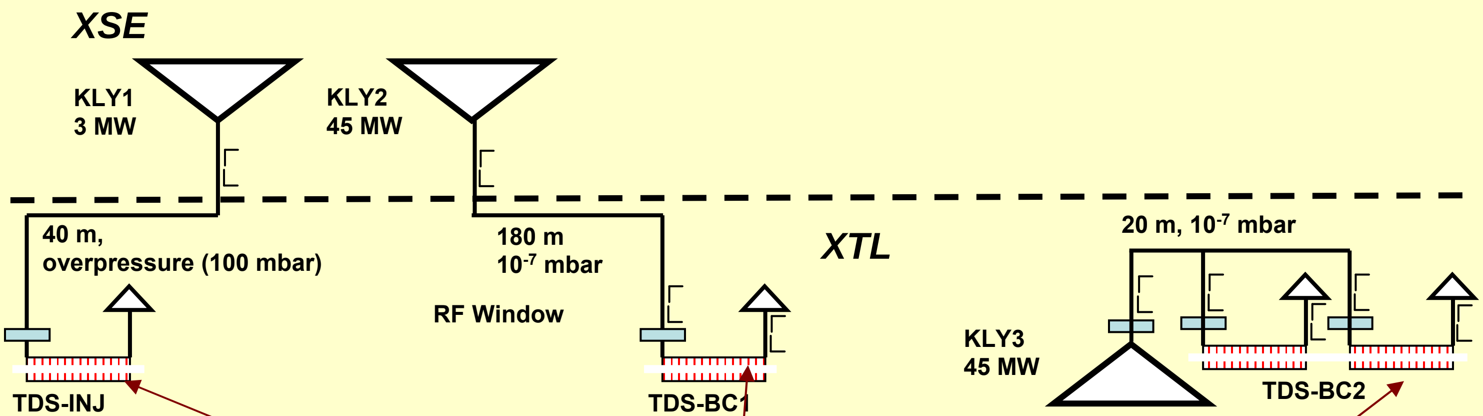
Design parameters

Operating frequency	**- 1300 MHz,**
RF pulse length	**- up to 900 μs,**
RF pulse input power	**- up to 8.6 MW,**
Repetition rate	**- up to 5Hz,**
Accelerating gradient	**-up to 14 MV/m**
Heat loading	**-up to 20 kW/m**
Energy gain	**- 22.8 MeV**

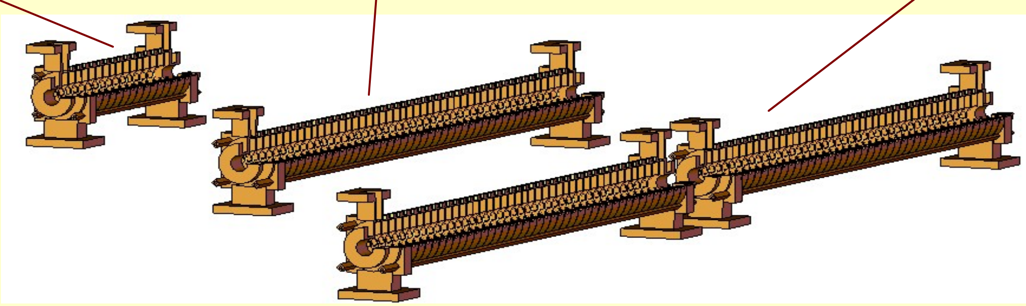
INR developed cavity is now under construction in DESY, Hamburg.

XFEL Special Beam Diagnostics

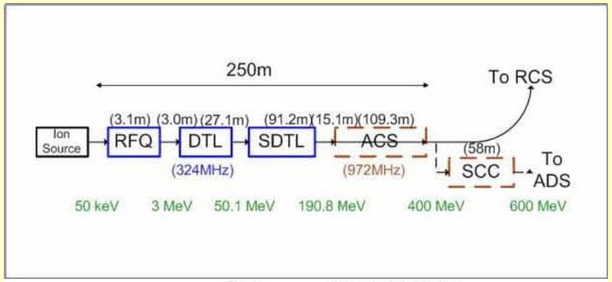
To achieve and maintain stable operation of the XFEL, three dedicated diagnostic sections **are foreseen for the characterization and stabilisation of the electron beam.** The diagnostic sections will be located in the injector and downstream of the two bunch compressor sections BC1 and BC2. **For the measurement of the longitudinal beam profile, the slice energy spread and the slice emittance,** transverse deflecting structures (TDS) will be installed in all three diagnostic sections.



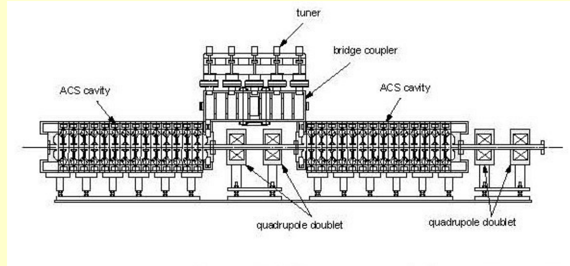
Location	Ud	t_fill, ns
Injector	1.7 MV	<120
BC1	14 MV	<320
BC2	27 MV	<320



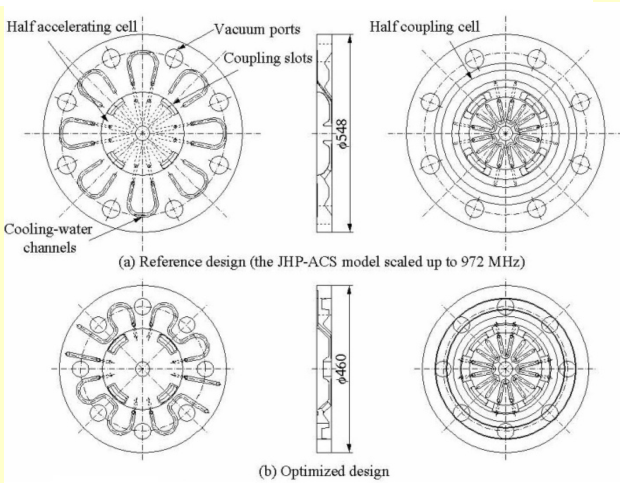
Collaboration with KEK in the development of the Annular Coupled Structure (ACS) for J-PARC linac.



Scheme of J-PARC Linac.



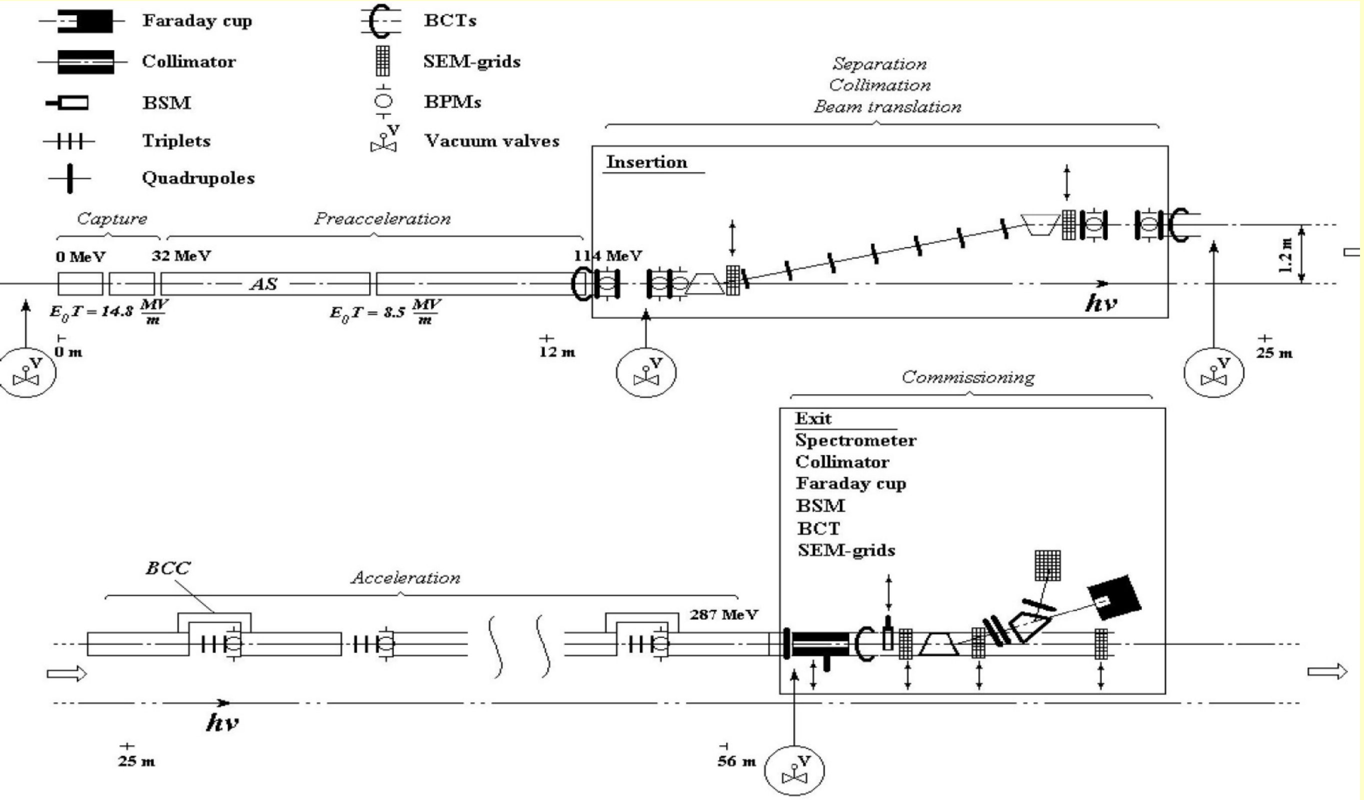
Layout of a ACS module.



ACS intermediate cell configurations.

Operating frequency - 972 MHz
Heat loading - up to 80 kW/m
Vendor - Mitsubishi Heavy Industries
First module commissioned to full RF power 2006 spring.

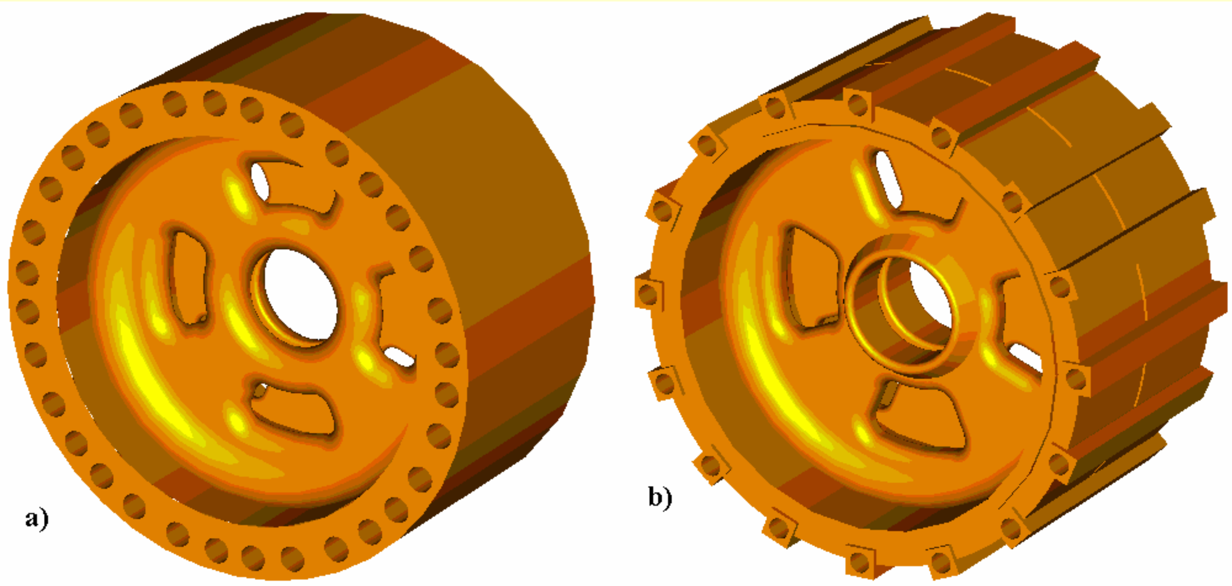
Proposed PPA scheme for the ILC



PPA scheme:
- capture-
- pre-acceleration-
- beam cleaning
- acceleration.

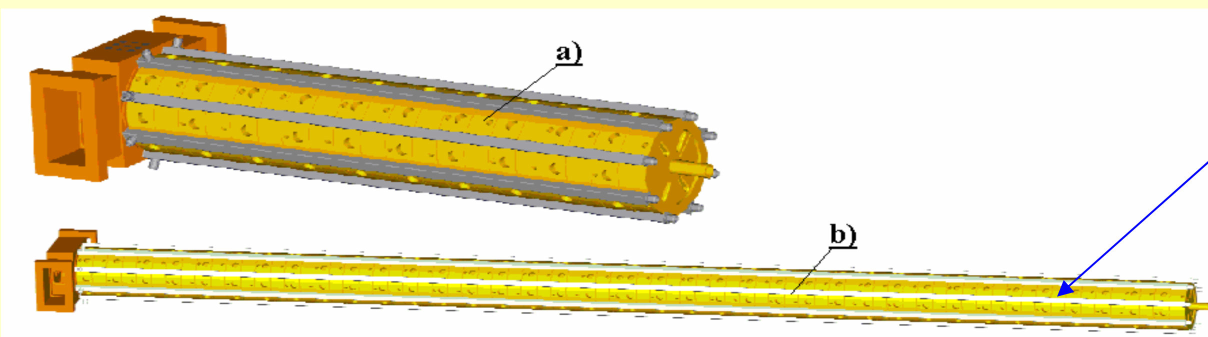
The critical part of the Normal Conducting Positron Pre-Accelerator (PPA) in ILC Positron Source are capture sections, which should operate with an accelerating gradient of up to 15 MV/m in combination with long RF pulses (~ 1ms).

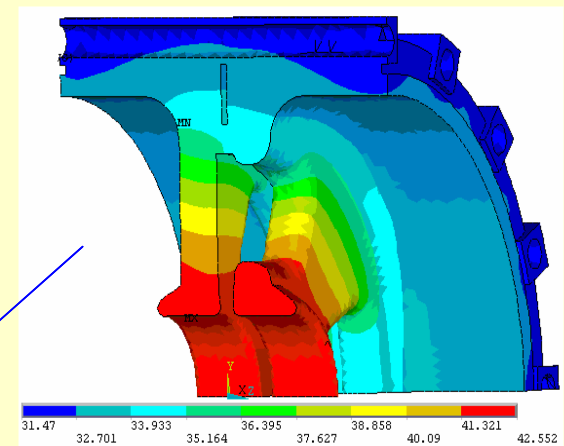
CDS for ILC PPA



Frequency	1300 MHz	1300 MHz
Max. surf. field	40.0 MV/m	40 MV/m
Accel. gradient	<19.0 MV/m	~8.5 MV/m
Aperture diameter	47 mm	46 mm
Ze	36.6 MO/m	40.4 MO/m
Group velocity	0.044c	0.054c
Power dissip.	42 kW/m	8.5 kW/m

CDS4W options for high (a) and moderate (b) accelerating gradients in the PPA accelerating system.





Conclusion

INR Proton Linac is operating ~ 2000 hours per year.

Protons energy is till 209 MeV (klystrons!), average current is till 150 μA.

The Linac applications are as follows:

- Neutron complex (nano/condensed matter etc),
- Isotopes production,
- Beam therapy (construction of the complex is near completion).

INR team is actively participating in many international particle accelerator collaborations.

Thanks to all Accelerator Complex and Experimental Area Divisions people.

Thanks for Your attention!