Operation of Indus Synchrotron Radiation Sources and its management during COVID-19 period

R K Nathwani, R K Sahu and T A Puntambekar

Raja Ramanna Centre for Advanced Technology (RRCAT), Indore, India

Email: rakesh@rrcat.gov.in

12th Workshop on Accelerator Operations, 5th- 8th October, 2021, Barcelona, Spain
Organised by ALBA Synchrotron

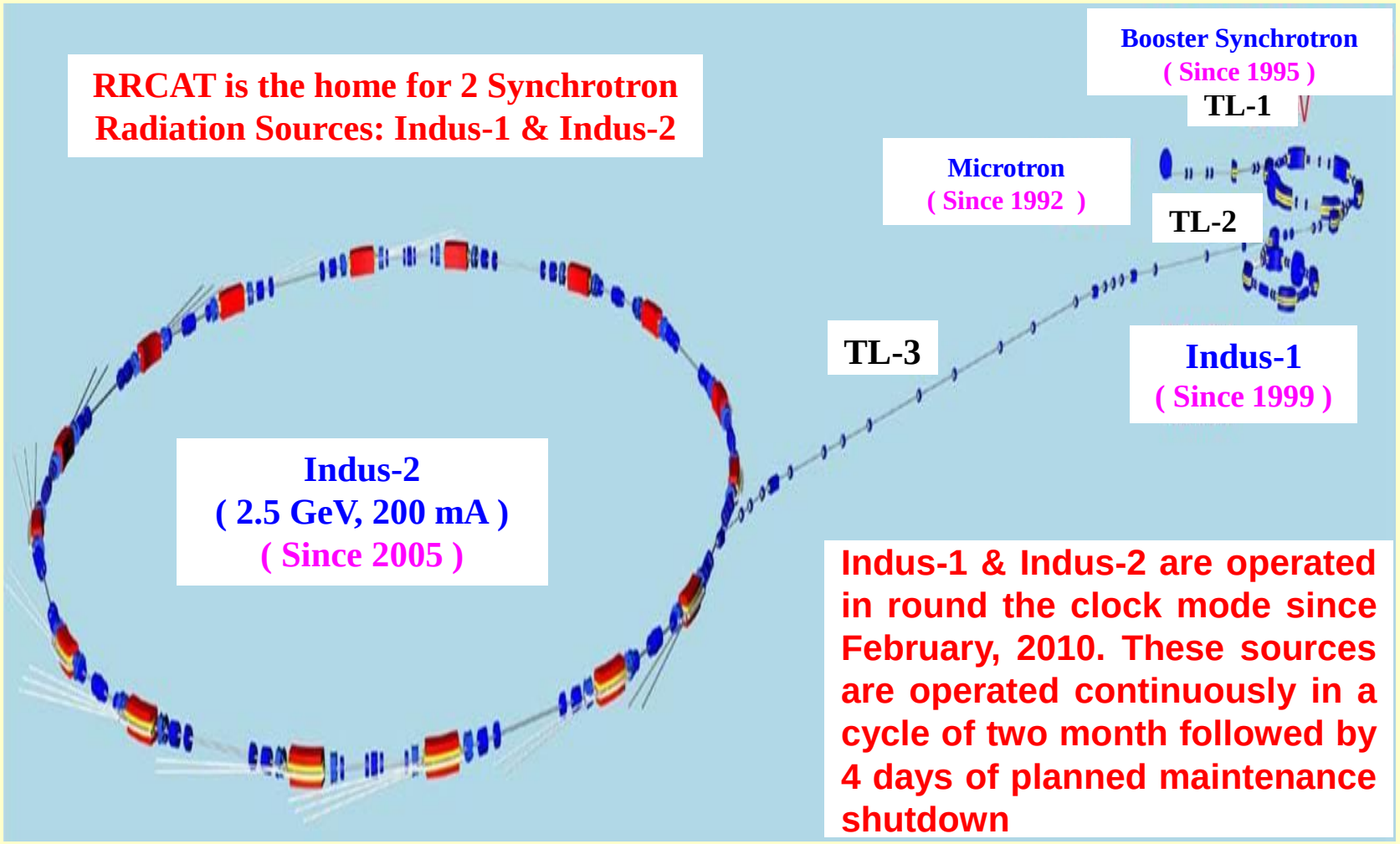
OUTLINE OF PRESENTATION

- Introduction to the Indus Synchrotron Radiation facility
- Operation of Indus-1 & Indus-2 Accelerators
- Operational Performance in recent years
- Utilisation
- Challenges faced in operation during 1st wave of Covid pandemic in India in 2020 and subsequently during 2nd wave in 2021
- Measures undertaken for preventing the spread of Covid-19 during machine operation
- Conclusion

INDUS ACCELERATORS AT RRCAT

- **RRCAT - A premier unit of the Department of Atomic Energy, Government of India, engaged in R&D in the front-line areas of Accelerators and Lasers science, technology, and applications**
- **RRCAT has indigenously designed, developed, and commissioned two synchrotron radiation sources: Indus-1 and Indus-2. These are the largest particle accelerators in India**
- **Indus-1 is a 450 MeV/125 mA electron storage ring with 7 beam lines**
- **Indus-2 is a 2.5 GeV/200 mA electron storage ring presently having 17 beam lines in operation**
- **Indus facility is being operated in round-the-clock mode as a national facility since 2010, for a large number of researchers from universities, academic institutions and national laboratories**
- **The facility is operated under licence from Atomic Energy Regulatory Board(AERB)**

Schematic View of Indus Accelerators



Indus Sub-systems

Accelerator Physics

Controls

Magnets

Beam diagnostics

Magnet P/Ss

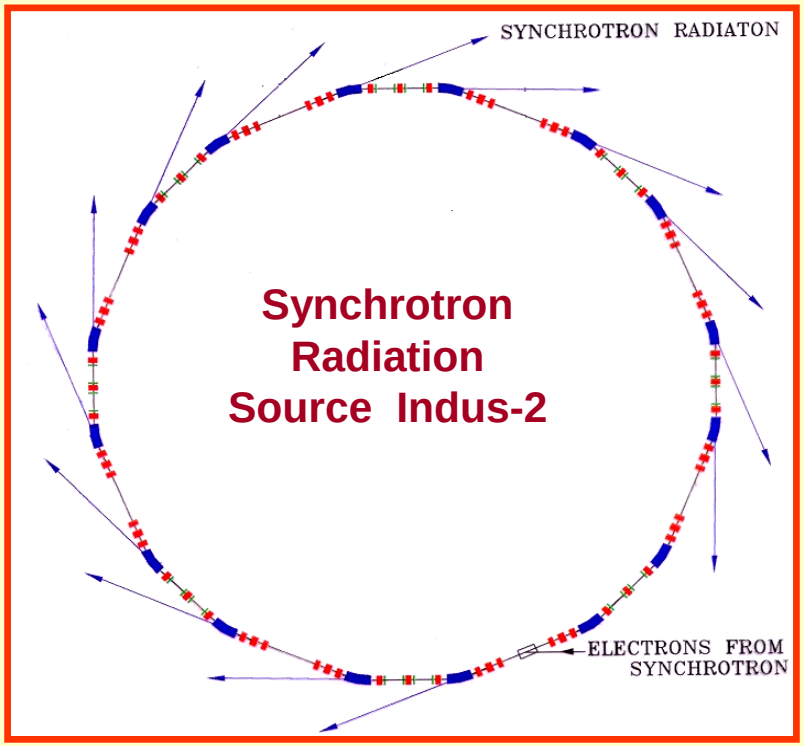
Ultra High Vacuum (UHV)

RF System

LCW system

Survey & alignment

Compressed Air System



Radiation Safety & Heath Physics

Fire and Industrial Safety

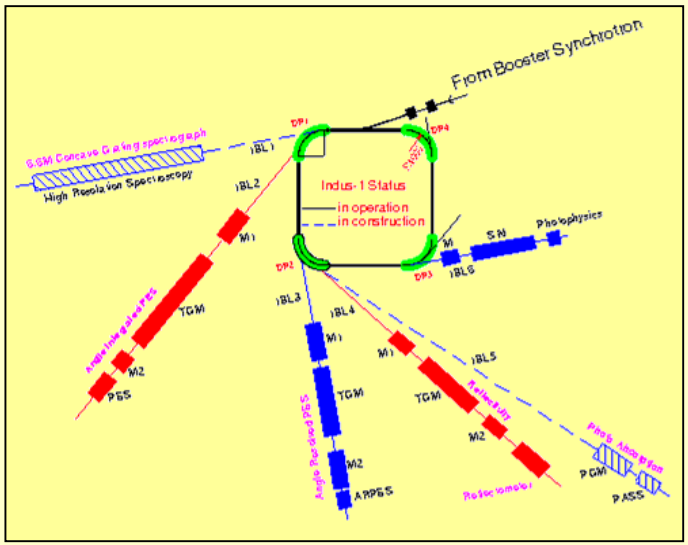
Most of the sub-systems have been developed indigenously

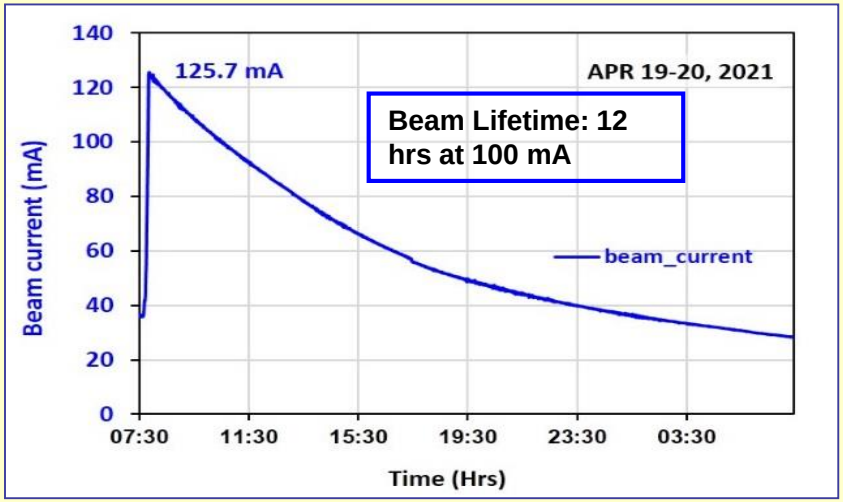
The Injector System

There is a common injector system for Indus-1 and Indus-2 comprising of a 20 MeV/30 mA microtron, a 20-550 MeV/10 mA booster synchrotron and beam transport lines TL-1 and TL-2 for delivering electron beam to Indus-1 and Indus-2 storage rings

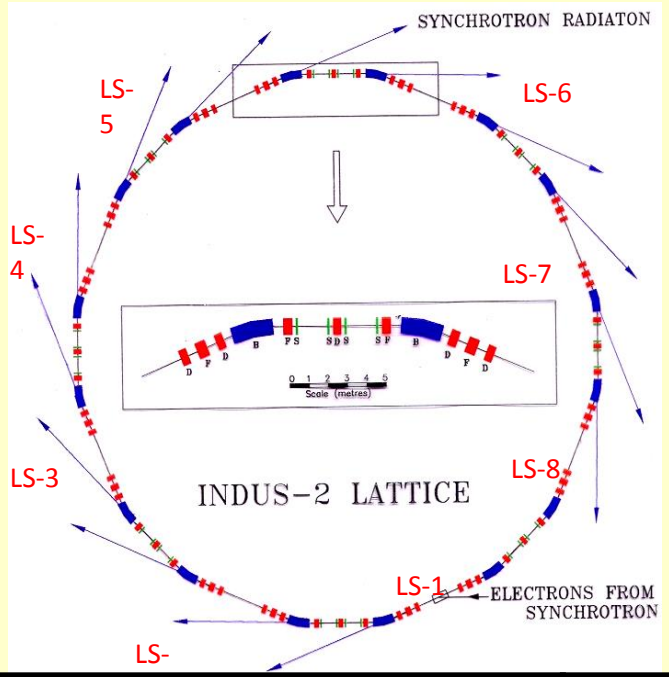
The Synchrotron Radiation Source Indus-1

Energy		450 MeV
Current		125 mA*
Critical wavelength(λ_c)		61.38 Å (BM)
Circumference		18.966 m
Superperiods		4
Tune		1.601, 1.467
Beam emittance	(ε_x)	1.90 x 10^{-7}m.rad
	(ε_y)	1.90 x 10^{-9}m.rad
		(1% coupling assumed)
Beam size (σ_x, σ_y)		0.66 mm, 0.36 mm
		(Centre of BM)
RF frequency		31.613 MHz
Harmonic number		2
No of Beamlines		7

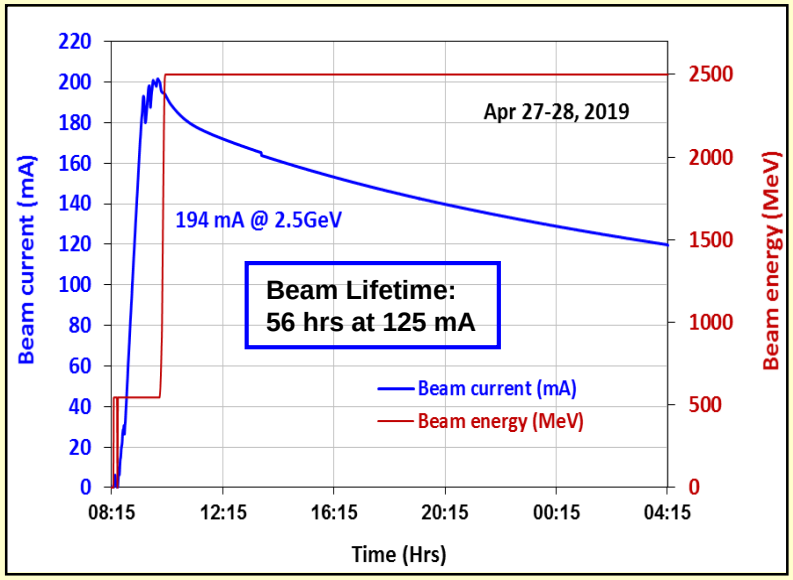




The Synchrotron Radiation Source Indus-2



Typical User mode operation of Indus-2

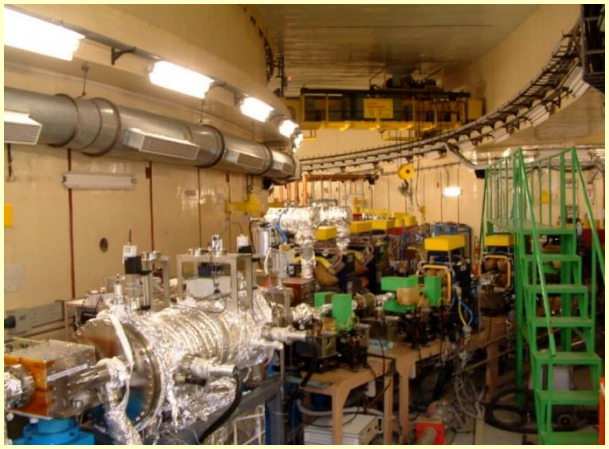


Parameter	Value	Parameter	Value
Beam Energy	2. 5 GeV	No of RF cavities	6
Maximum Current	200 mA	RF frequency	505.812 MHz
Circumference	172.4743m	Critical wavelength	2 Å
Tune point	9.3, 6.14	Energy loss per turn	623 keV
Insertion Devices installed	3 Undulators	No of beamlines in Operation	17

Few pictures of Indus-2 storage ring

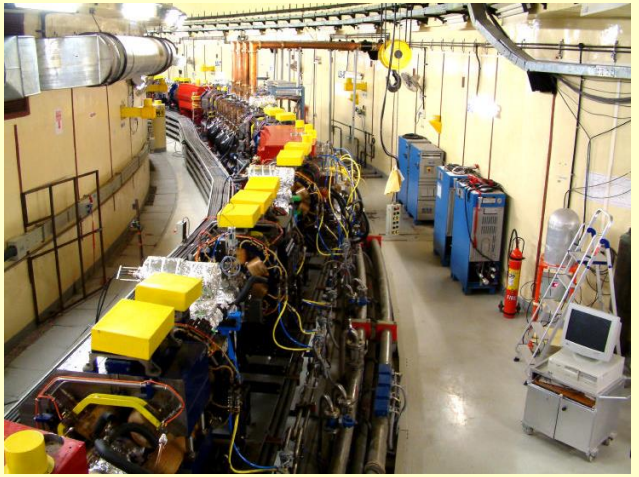
TL-3 joining Indus-2

Indus-2 Injection septum & kicker magnets



Undulator

Indus-2 tunnel



Indus-2 RF System (350 kW, 505.8 MHz)
SSPA 4X60 kW, 1X60 kW IOT, 1X50 kW Klystron)

RF Cavities

Equipment gallery and Beamlines

Indus control room

OPERATION OF INDUS ACCELERATORS

- **Indus machines are being operated in round-the-clock mode as a national facility since 2010**
- **Day to day operation, upgradations and maintenance activities are managed and monitored by the Indus Accelerators Coordination Committee (IACC)**
- **Staff deployed for operating these machines is pooled from various sub-system groups who have built these accelerators and are involved in carrying out R & D in Accelerator Technologies.**
- **A comprehensive training of ~ 8 months is provided to the staff on operation of the facility which comprises of lecture course, written examination, on-job training, checklist clearing, walk through tests on 13 different sub-systems leading to licensing/qualification of the operators**
- **Presently we have pool of 60 trained and qualified personnel for operating the facility. They work in shifts for few days in a month and continue R & D work for the remaining period.**
- **Operation crew during a shift comprises of 6 personnel, Shift In-charge, Beam Physicist, Health Physicist and three System Supervisors**
- **Maintenance is carried out by the Sub-system groups**

OPERATION OF INDUS ACCELERATORS …

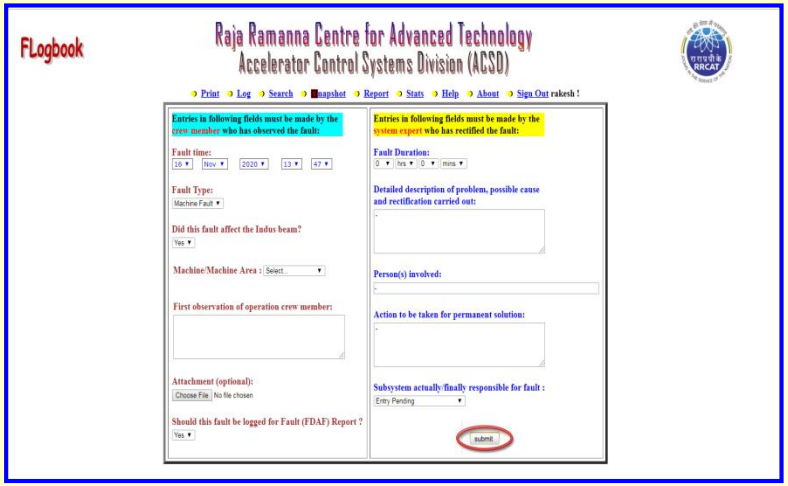
- The Indus Server contains real time data & information regarding the operation of Indus facility and the performance of its sub-systems. It also stores the historical data of various sub-systems.

- Day to day operation of Indus facility is managed online through web based modules on Indus Server. Some of theses are
  - Daily work-plan and standing Instructions
  - E-logbook
  - Fault-logbook
  - Beamline booking manager
  - Machine Experiments manager

Managing Indus operation through web based applications on Indus Server

Today's Work Plan & Standing Instructions 13-Nov-2020

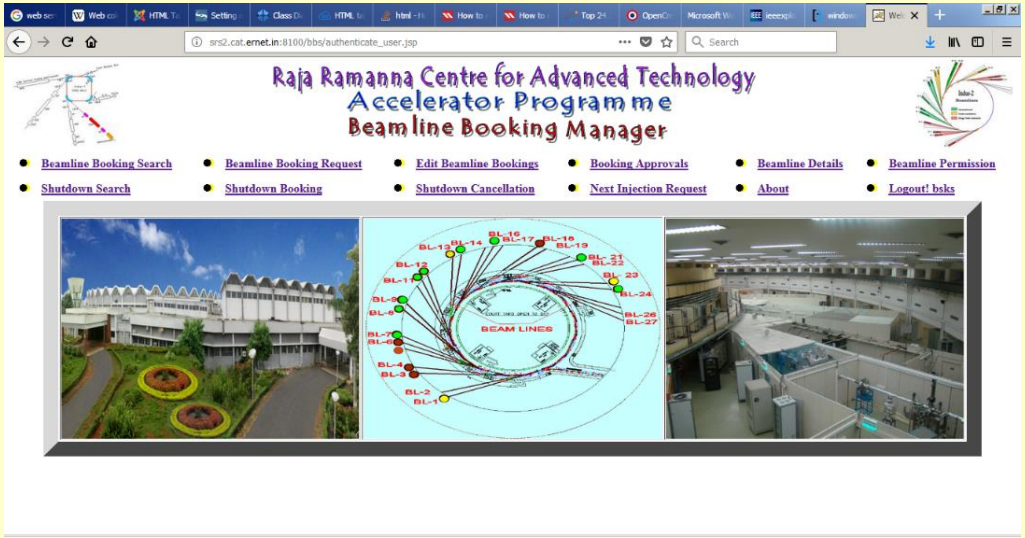
- 06:00 hrs : Fill Indus-1 & provide beam to users
- Indus-2 :
- I & II shifts : Experiments for bunch length reduction (low alpha) by APS (Sh Abdurrahim)
- After completion of above experiment, magnet connections to be restored by APSD, all changes made in subsystem shall be restore back to normal user mode and trial beam filling shall be done.
- Indus-2 Requirements:
- Entry in Indus-2 ring shall not be allowed without work-permit.
- The split ACs in AHU no 5 & 6 of Indus-1 should be kept OFF



- **Sample work plan**
- **Format for logging of faults**

Beamline Booking Manager

Module for booking beam time and planned shutdowns in the machine



Today's Beamline Bookings 2018-08-10

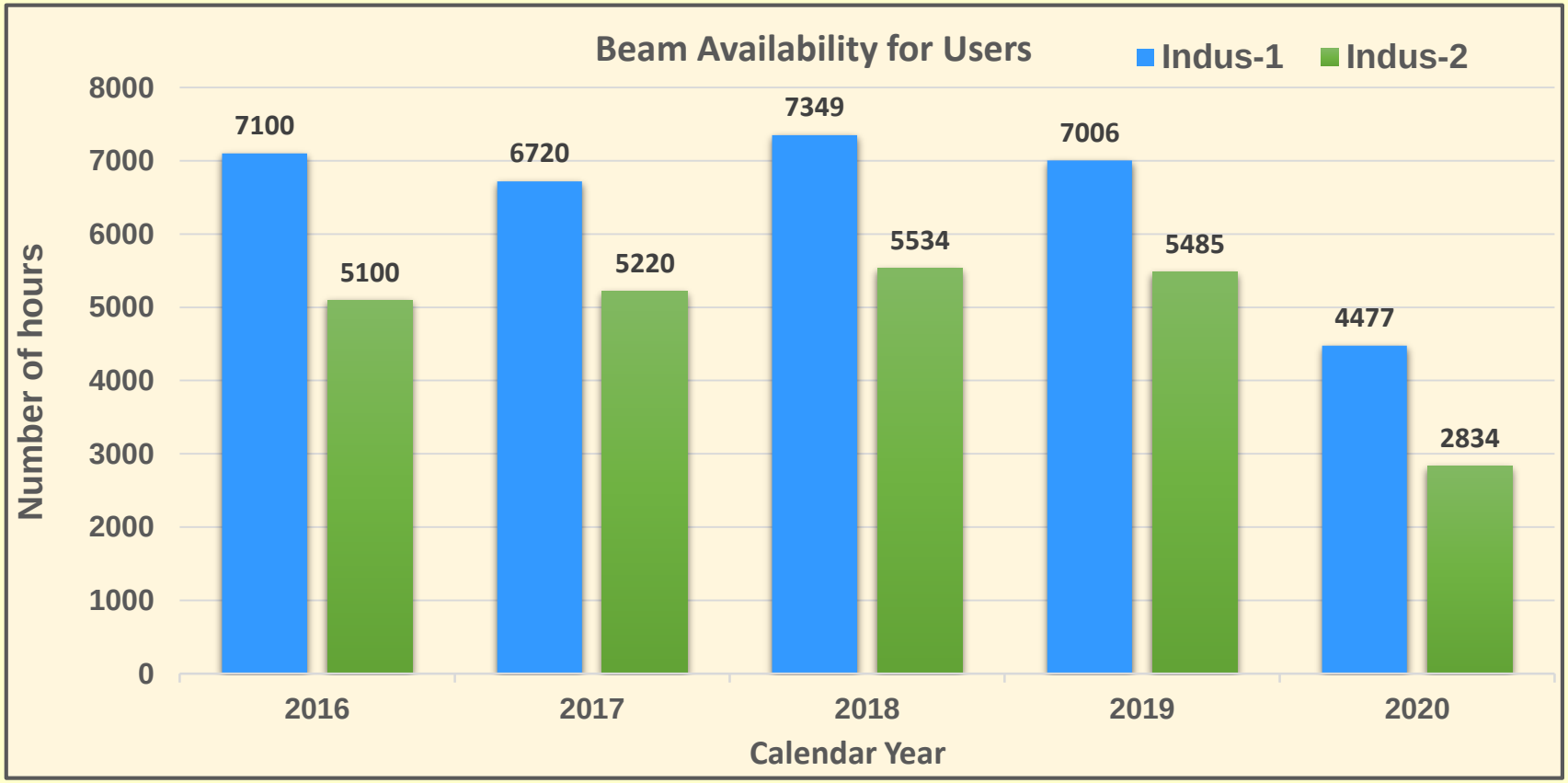
Sr. No.	Storage Ring	Beamline	Beam Current (mA)	TimeSlot	Username	Affiliation	Approval
1	Indus-1	BL1	60	1000-1900	Kiran Kumar Gorai	RRCAT	Yes
2	Indus-1	BL2	100	0900-1800	sourabh Mukharji	UGC-DAE-CSR, Indore	Yes
3	Indus-1	BL3	120	1000-2000	Mr. Sahadeb Ghosh	HBNI RRCAT	Yes
4	Indus-1	BL4	100	0900-1800	Rajkumar Gupta	RRCAT	Yes
5	Indus-1	BL7	100	0900-1800	rksharma	RRCAT	Yes
6	Indus-2	BL1	100	0900-1800	mukul gupta	UGC-DAE CSR, indore	Yes
7	Indus-2	BL11	200	0900-1800	Lakshmana Rao	NIITR	Yes

Beamline booking status for a day as seen on large format displays in control room

Safety systems installed in Indus complex and safe operation practices

- Radiation Safety Systems, Radiation monitors
- Fire alarm system, Smoke Exhaust system
- Access control gates, CCTV surveillance system
- Machine Safety Interlock System to ensure safety of the machine
- Fire fighting team equipped with fire tender and latest fire fighting equipment on round-the-clock basis.
- Work permit system is followed for maintenance and upgradation work in sub-systems
- Periodic surveillance of Interlocks and Safety systems is carried out.

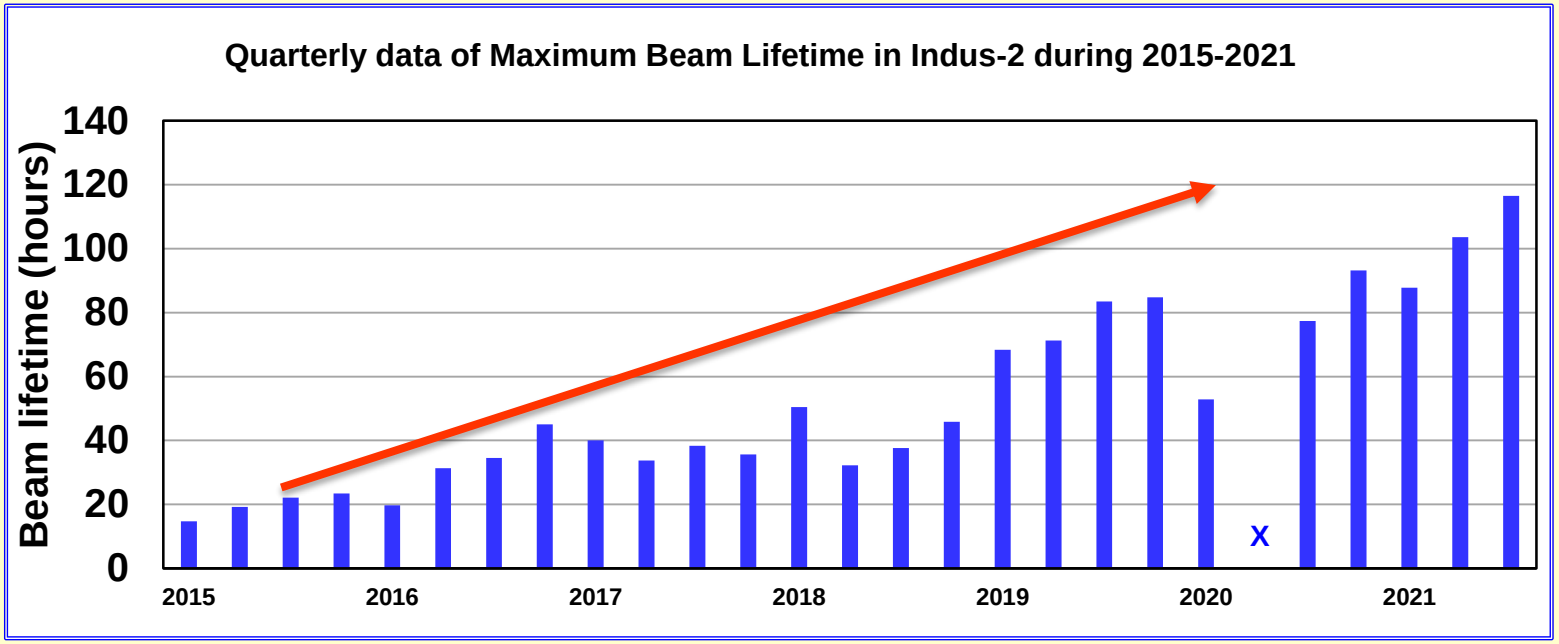
Operational Performance of Indus Accelerators in recent years



Average beam availability during 2016 to 2019
Indus-1 : ~ 21 hrs/day
Indus-2 : ~ 16 hrs/day

In 2020, operation was affected due to lockdown and pandemic. Average beam availability was ~ 17 hrs/day in Indus-1 and ~ 11 hrs/day in Indus-2

Improvement in Beam Lifetime of Indus-2



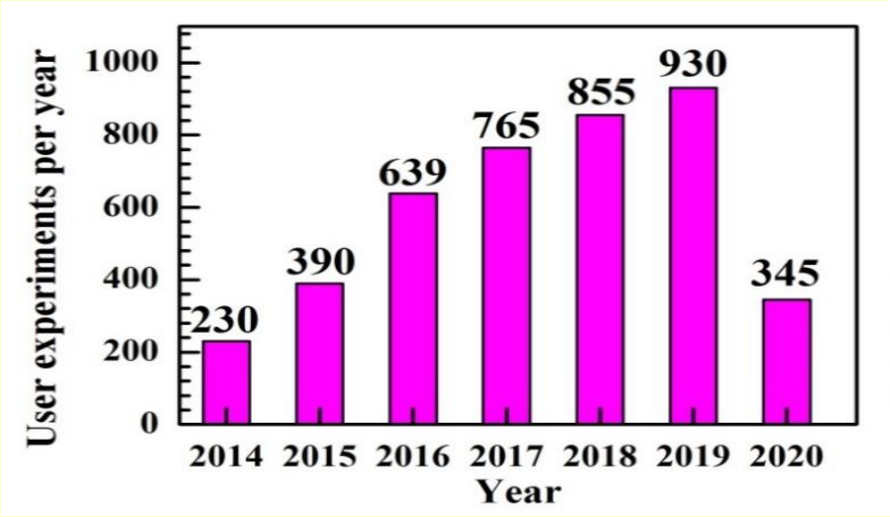
Lifetime at 100 mA of stored current at 2.5 GeV

(X: No operation during 2nd quarter of 2020 due to lockdown)

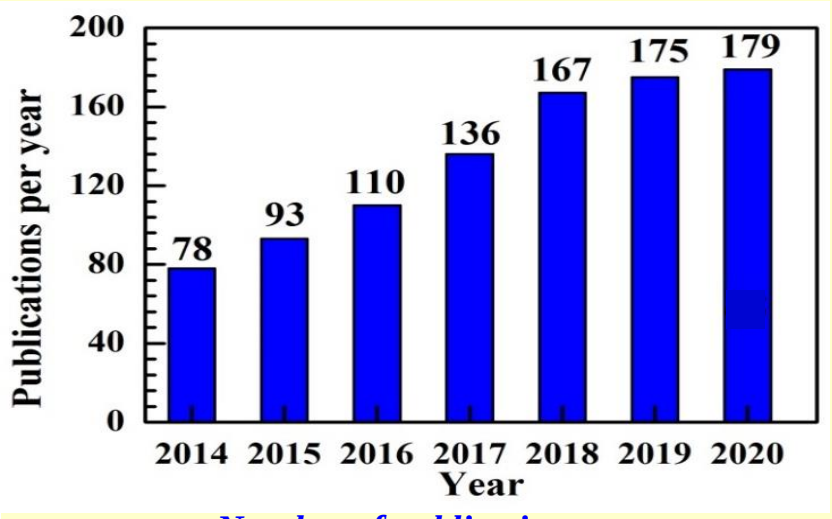
The beam lifetime in Indus-2 has improved consistently since 2015. The maximum beam lifetime in 2015 at 100 mA current was ~ 27 hrs which improved four times to more than 100 hrs in 2021. This is attributed to good dynamic vacuum level in the ring, periodic maintenance carried out in vacuum system and performance enhancement measures undertaken.

Indus Beam Utilisation

In line with improvement in machine performance, the utilization of synchrotron radiation at Indus beamlines has also increased steadily over the years. Users from over 150 universities, research institutes national laboratories and few companies from pharmaceutical industry have used the SR beam for carrying out experiments. Seven beamlines in Indus-1 and 17 beamlines in Indus-2 are operational at present



Number of experiments per year



Number of publications per year

Select list of users of Indus-1 and Indus-2

Universities

- Vikram University, Ujjain
- Goa University
- Mumbai University
- Univ. of Allahabad
- Univ. of Pune
- Ravishankar Univ. , Raipur
- Nagpur University
- DAVV, Indore
- RGTU, Bhopal
- Andhra University
- Panjab University, Chandigarh
- MS University, Baroda
- Jiwaji University, Gwalior
- Punjabi University, Patiala
- Aurangabad University
- MANIT, Bhopal

Research / Educational Institutes

- IIT, Mumbai
- IIT, Kanpur
- CEERI, Pilani
- DAE-UGC-IUC, Indore
- IISc, Bangalore
- VJTI, Mumbai
- JNCASR, Bangalore
- ISM, Dhanbad
- SVERI, Pandharpur
- ISRO Satellite Centre, Bangalore
- BHU, Varanasi
- NCL, Pune
- TIFR, Mumbai
- BARC, Mumbai
- IGCAR, Kalpakkam

Industry

Many companies from pharmaceutical industry have also carried out experiments at Indus-2 beamlines

Managing Indus facility during first wave of COVID-19 pandemic in India

- Indus machines had to be shutdown in March, 2020 in wake of nationwide lockdown declared by Government of India to prevent outbreak of COVID-19. The lockdown was enforced strictly and only the essential services were allowed
- Lockdown lasted for more than 2 months. During lockdown measures were taken to ensure the safety of Indus systems and Indus complex
- All essential and emergency systems e.g. UHV system of the machine and beamlines, AHUs, fire alarm system, emergency power and CCTV system were kept ON during this period
- All these systems were routinely monitored for their healthiness through periodic visits by essential services staff
- Healthiness of the coolant system was maintained by circulating Low Conductivity water (LCW) to all the loads of Indus-1 and Indus-2 at low pressure
- The Indus Accelerator Coordination Committee (IACC) members were in communication through the available communication means during the period of lockdown

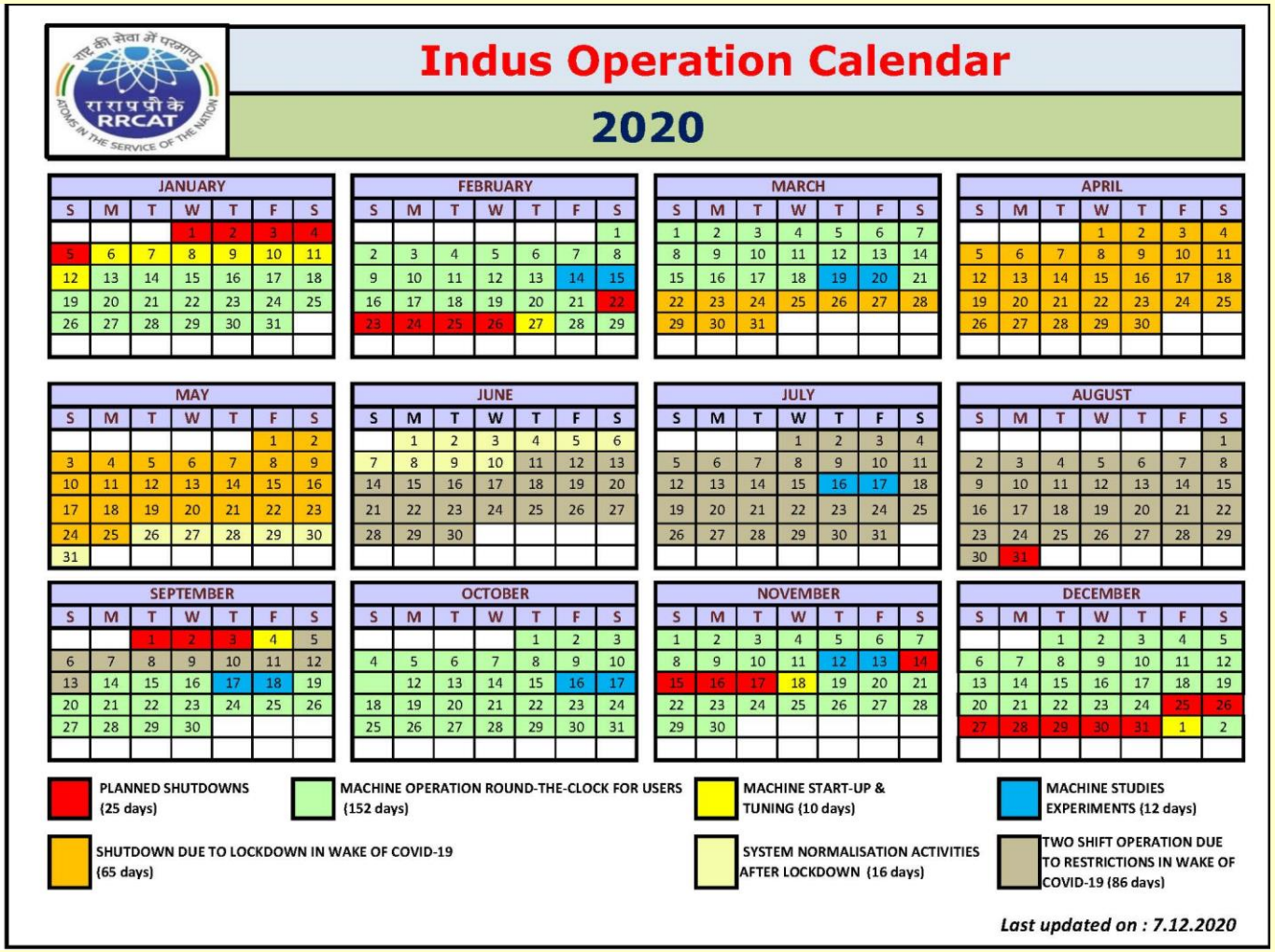
Startup of Indus facility after 1st lockdown

- The lockdown ended in the beginning of June, 2020 with government allowing opening of the center with reduced manpower , restrictions and following the guidelines for preventing the spread of COVID-19
- Normalisation of Indus facility was initiated in phased manner starting with testing and restoration of sub-systems.
- A detailed plan for startup of Indus facility was prepared
- All radiation safety as well as machine safety interlocks of Indus-1 & Indus-2 were tested thoroughly by the local safety committee.
- An Standard Operating Procedure (SOP) was formulated for management of control room and other facilities related to shift operation in order to prevent the spread of COVID among operation and maintenance staff.
- In 2nd week of June, the operation of Indus facility was started in phased manner in 2 shifts mode (06:15 to 21:30 hours). Within few days, regular operating current was attained in both the machines and users started using the beam

Startup of Indus facility after 1st lockdown ….

- Round-the-clock operation of the facility was resumed from second week of September
- In September/October COVID cases began to increase, however majority of Indus staff remained unaffected from the virus
- Till September, 2020 the startup of the facility and operation was carried with constraint of working with reduced manpower in compliance with the guidelines issued by district administration from time to time for preventing the spread of COVID-19.
- In view of travel restrictions due to COVID-19, usage of SR beam at Indus beamlines was mostly limited to in-house users. External users were asked to send the samples by courier/post. After performing experiment, the data was mailed to the users.

Operation Calendar 2020 (changed due to COVID conditions)



The operation calendar for the entire year is displayed on RRCAT website and on Indus server. External users follow this calendar for booking experiments on Indus beamlines.

SOP for Operation and Maintenance Staff

- **Follow COVID appropriate behavior: Wearing mask, Frequent sanitizing of hands and maintaining social distancing while working in control room**
- **Daily thermal screening of the staff/visitors entering the campus**
- **Use face shields while working in close proximity**
- **Only four persons permitted at a time in the control room ensuring appropriate distancing**
- **Regular sanitization of control room, wash rooms, shift vehicle and common areas**
- **Sanitization of Chairs, Computer key boards, mouse and instruments during shift changeover**
- **The first aid center at Indus complex is quipped with thermal scanner and pulse oximeter for monitoring the health of the staff**

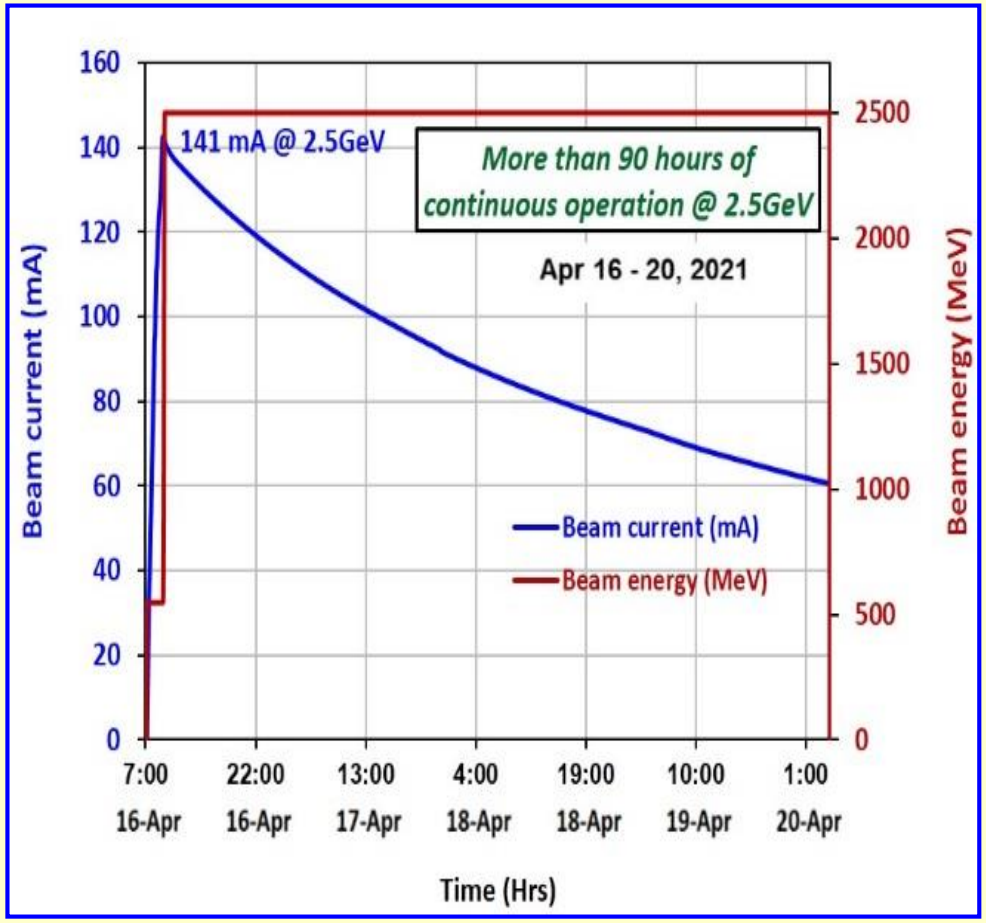
Challenges during second wave of COVID-19

- By mid of March, 2021 the number of COVID-19 cases began to increase again and 2nd wave started in India. The 2nd wave was more severe and devastating across India
- Large number of operation/maintenance staff as well as their family members, near and dear ones were affected by the deadly virus
- In this tough situation, the operation of the Indus facility was maintained. Large pool of trained manpower helped us in continuing the operation. Though the strength of staff in 2nd and 3rd shifts had to be reduced to 2 in each shift in place of 5
- Considering the severity of situation, the government declared 2nd lockdown in 3rd week of April and the Indus facility was shutdown again
- Similar to last year this year too the essential and Safety systems were kept running during lockdown. Regular visits were made to the complex to ensure the healthiness and safety of the facility
- After 2nd lockdown, the facility was normalized easily with the experience of previous year. The startup plan and procedures followed after lockdown in 2020 helped in smooth startup of the facility. Normal operation in 3 shifts was restored by 3rd week of June, 2021

Milestones achieved in operation during the pandemic period

- **Beam lifetime of more than 100 hours at 100 mA in Indus-2: On 17th April, 2021 a beam lifetime of 104 hrs and 20 minutes was recorded at beam current of 100 mA @ 2.5 GeV. This increase in beam lifetime may be attributed to further improvement in vacuum and re-optimisation of user orbit**

- **More than 90 hours of continuous beam operation in Indus-2 at 2.5 GeV**



Measures undertaken for preventing the spread of Covid-19 during machine operation

- Ventilation of the Indus Complex has been improved by installing exhaust fans in occupied areas and experimental hall
- The Air Handling Units of the occupied areas have been modified to operate in once through mode thereby stopping re-circulation of air
- UV based air purification devices have been installed in control room and wash rooms
- Meetings of the Indus Accelerators Coordination Committee and other meetings are held online through video conferencing mode (E-Sabha)
- SOP for following COVID appropriate behavior has been implemented for control room and maintenance staff. Only one system group was allowed to work at a time in Indus-2 ring

Measures undertaken for preventing the spread of Covid-19 during machine operation ….

- A cabinet for sanitizing logbooks, keys, small instruments and other things using UV has been provided for control room staff
- Alcohol based sanitizer dispensers have been kept at various places in the complex.
- Regular sanitization of control room, wash rooms and common areas is carried out.
- Vaccination camps were organised within RRCAT campus. Staff was motivated to get vaccinated. Priority given to operation staff in vaccination.
- Guidelines for COVID-19 safe work environment at RRCAT workplace were formulated for staff of the center and visitors

Measures for preventing the spread of Covid-19

Contactless Sanitizer dispenser

UV based upper room air purifier unit

Box for sanitizing items

UV based air disinfection lamps

Conclusion

- The Indus Accelerators are being operated successfully in round-the-clock mode as a national facility
- During last one and half years the COVID pandemic posed challenges in operation which were handled to the best possible extent
- After two lockdowns during the pandemic, the operation of the machines was resumed safely and within reasonable time
- Several measures taken up to prevent the spread of virus will continue for long time to come and have now become the ‘new normal’ for the facility

ACKNOWLEDGEMENTS

The work presented in this paper is the collective work of all the Staff of different Sub-System groups of RRCAT involved in developing, running, maintaining and upgrading and the Indus facility.
The authors sincerely acknowledge the efforts of each one of them

The authors are also grateful to the organizers of this workshop for accepting our paper and giving us opportunity to present the operational status of Indus Synchrotron Radiation Sources in front of International community.

Thank You

Operational Beamlines on Indus–2 (bending magnet)

- Soft X-Ray absorption (BL-1)
  (100 eV to 1.2 keV)
- X-ray Imaging (BL-3)
  (5 keV to 30 keV)
- Soft x-ray reflectivity (BL-4)
  (120 eV to 1.2 keV)
- X-ray lithography (BL-7)
  (4 keV to 20 keV)
- Dispersive EXAFS (BL-8)
  (5 keV to 20 keV)
- Scanning EXAFS (BL-9)
  (5 keV to 25 keV)
- Extreme conditions XRD (BL-11)
  (5 keV to 35 keV)
- Angle dispersive XRD (BL-12)
  (5keV to 20 keV)
- Hard X-Ray PES (BL-14)
  (2keV to 15 keV)
- X-ray fluorescence micro (BL-16)
  (4 keV to 20 keV)
- Protein crystallography (BL-21)
  (5 keV to 20 keV)

Operational Beamlines on Indus–2 (bending magnet)

- **Beamline for Engg. Applications (BL-02) (5 keV to 25 keV)**
- **Grazing incidence x-ray scattering (BL-13) (4 keV to 25 keV)**
- **Small and wide angle x-ray scattering (BL-18) (5 keV to 20 keV)**

Besides the above there are two beamlines are for beam diagnostics.

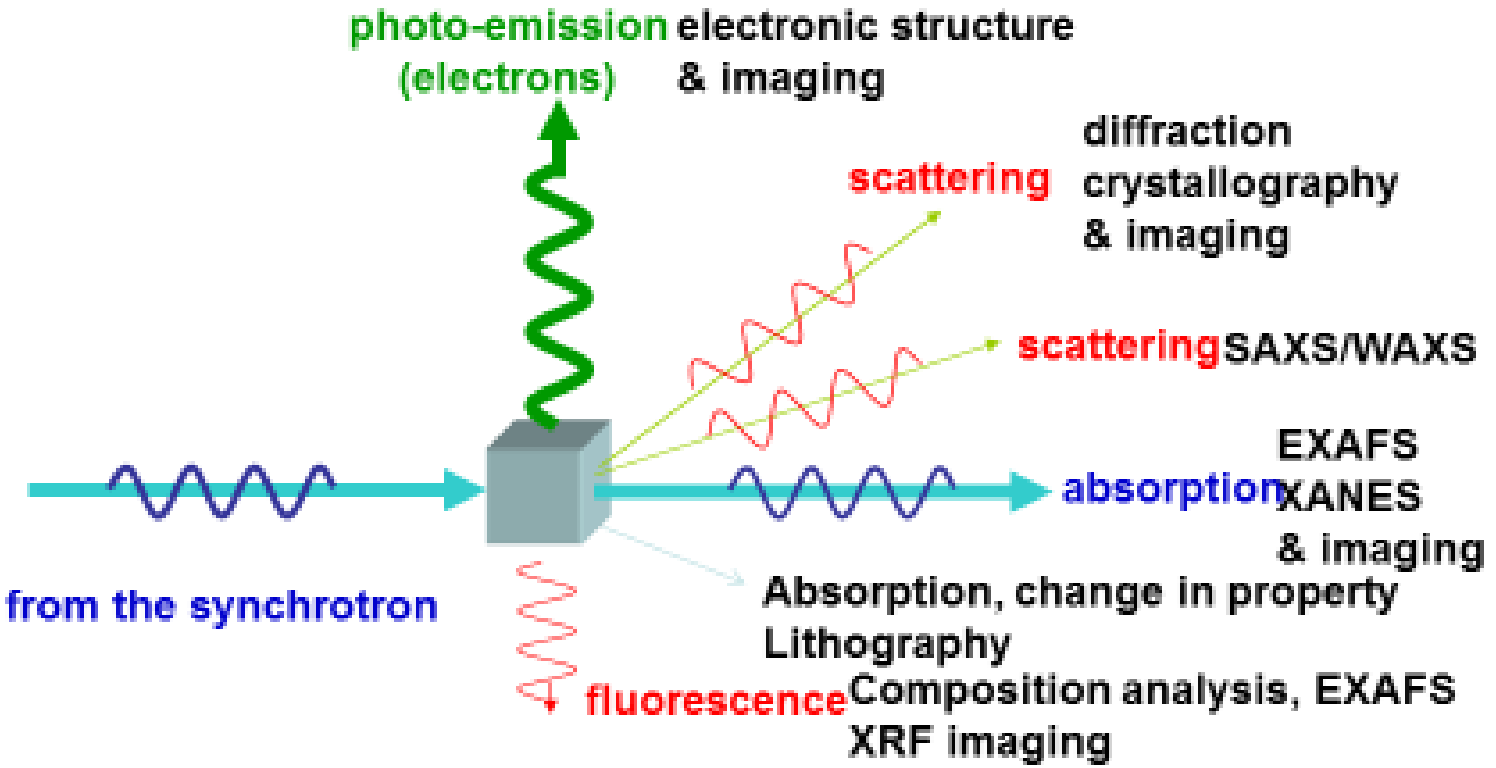
Insertion device based beamlines

Sr. No.	Beamline	Insertion Device	Energy range
BL-5	Atomic Molecular & Optical Sciences (AMOS)	Planar undulator (U1)	5-250 eV
BL-10	Angle Resolved Photo Electron Spectroscopy (ARPES)	Planar undulator (U2)	30-1000 eV
BL-15	Extreme Conditions X-ray Diffraction	Superconducting wavelength shifter (SWLS)	5 - 80 keV
BL-20	X-ray Magnetic Circular Dichroism (XMCD)	Helical undulator (U3)	300 - 1000 eV
BL-25	Protein Crystallography	Multipole wiggler (MPW)	5 - 20 keV

Beamlines on Indus-1

- **Soft X-Ray reflectivity beamline (40 – 1000 Å)**
- **Angle Integrated photoelectron spectroscopy beamline (60 – 1600 Å)**
- **Angle resolved photoelectron spectroscopy beamline (40 – 1000 Å)**
- **Photophysics beamline (500 - 2500 Å)**
- **High Resolution Vacuum Ultra Violet spectroscopy beamline (1300 - 3000 Å)**
- **Infrared spectroscopy beamline (600 cm^{-1} – 8000 cm^{-1})**
- **Photo absorption spectroscopy studies beam line (100 eV to 800 eV)**

All the processes at glance



Beamline: The setup that collects, collimates monochromatizes and focuses the SR beam on the sample

Different experiments require different beamlines.