Novel Medical LINACs for Challenging Environments

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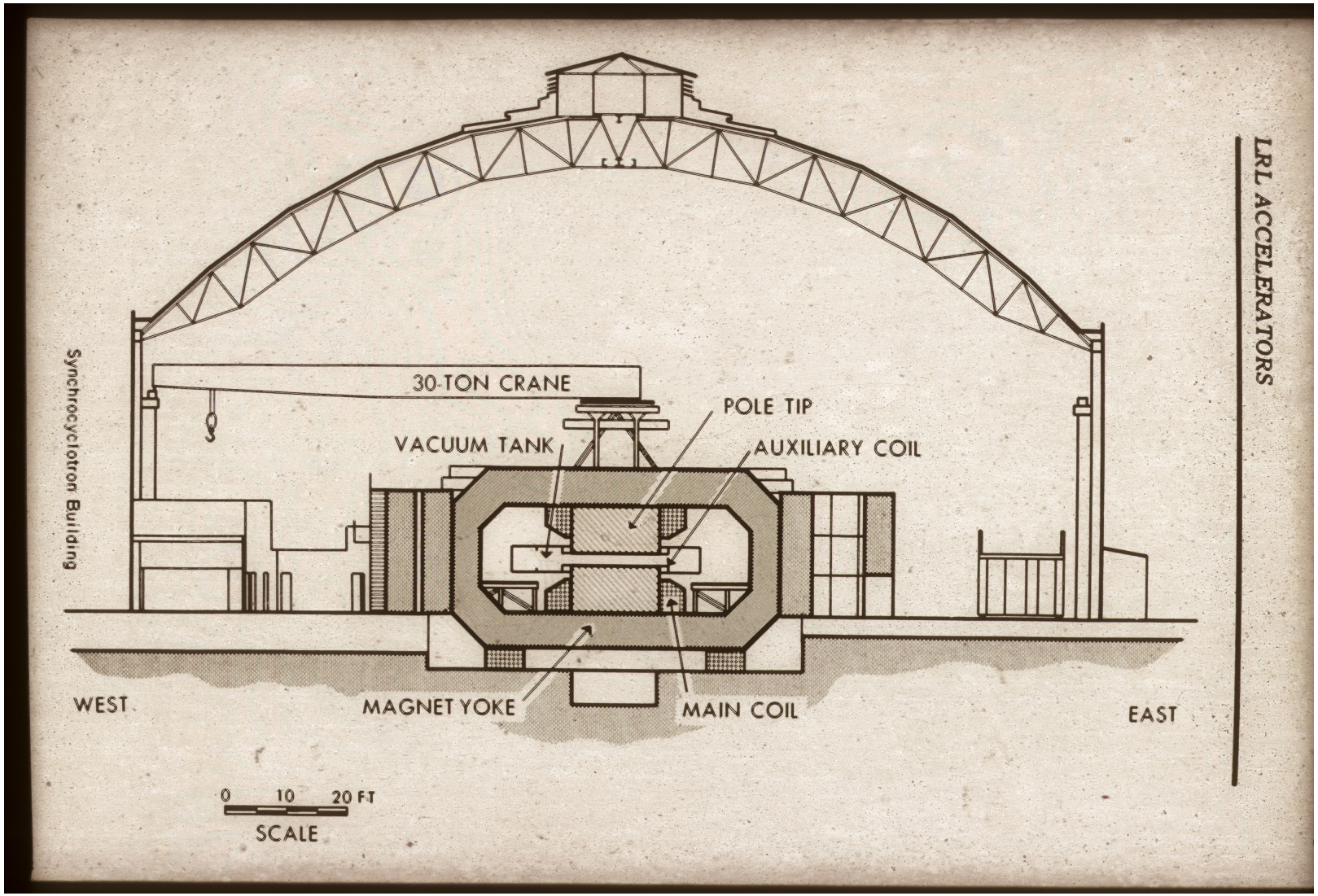
David Pistenmaa

This Presentation

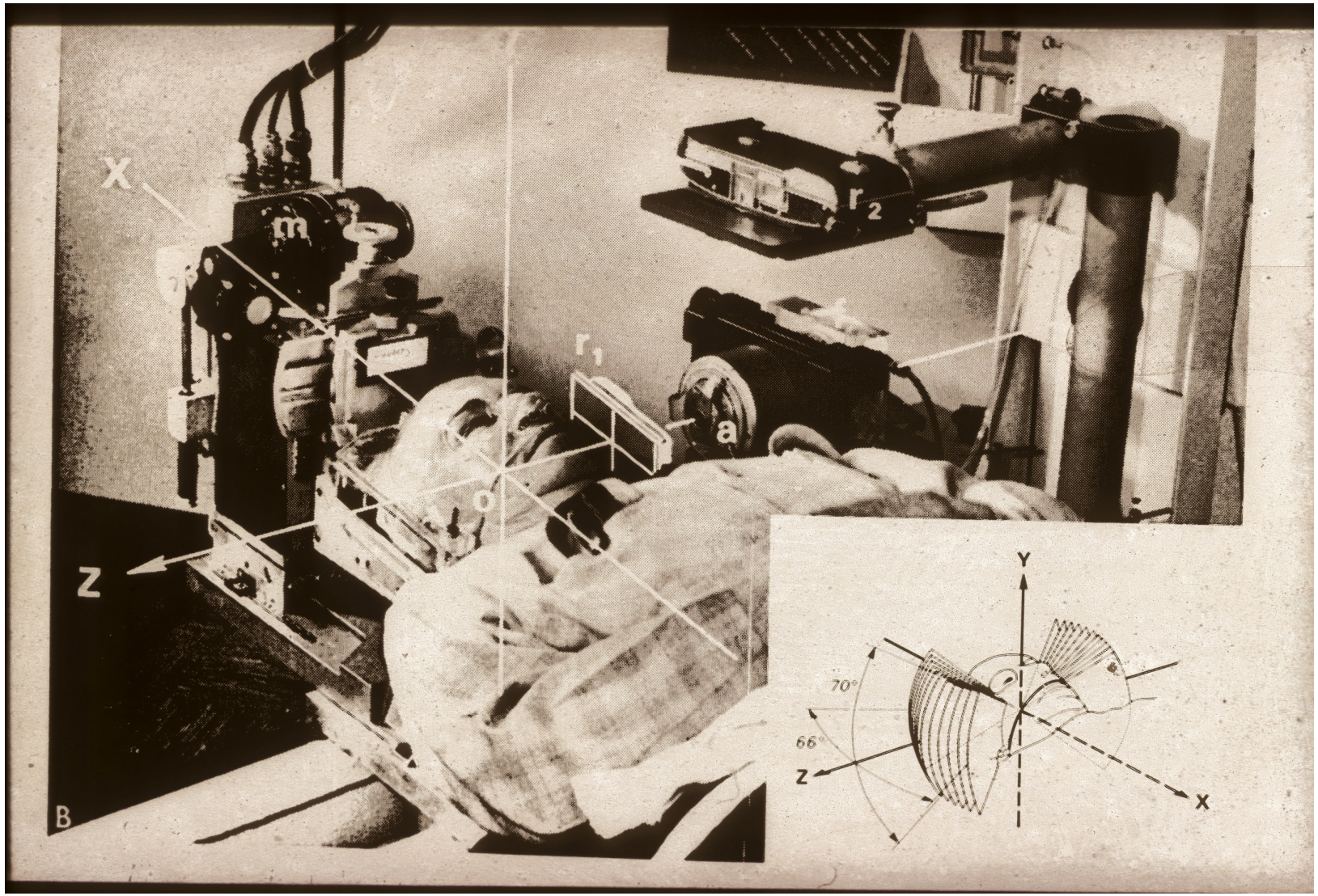
- The primary goal is to discuss an international collaboration to develop a linear accelerator and associated radiation therapy treatment system that will better serve patients and providers in low- and middle-income countries (LMICs) and be of interest to providers in upper-income countries (UICs) in order to generate funds to support the necessary educational programs.
- First, since this is a particle accelerator conference, I would like to take you on a brief tour of particle facilities I have had an opportunity to visit. Many of you may never have visited them.

Mountain Pass in South Korea, 1954

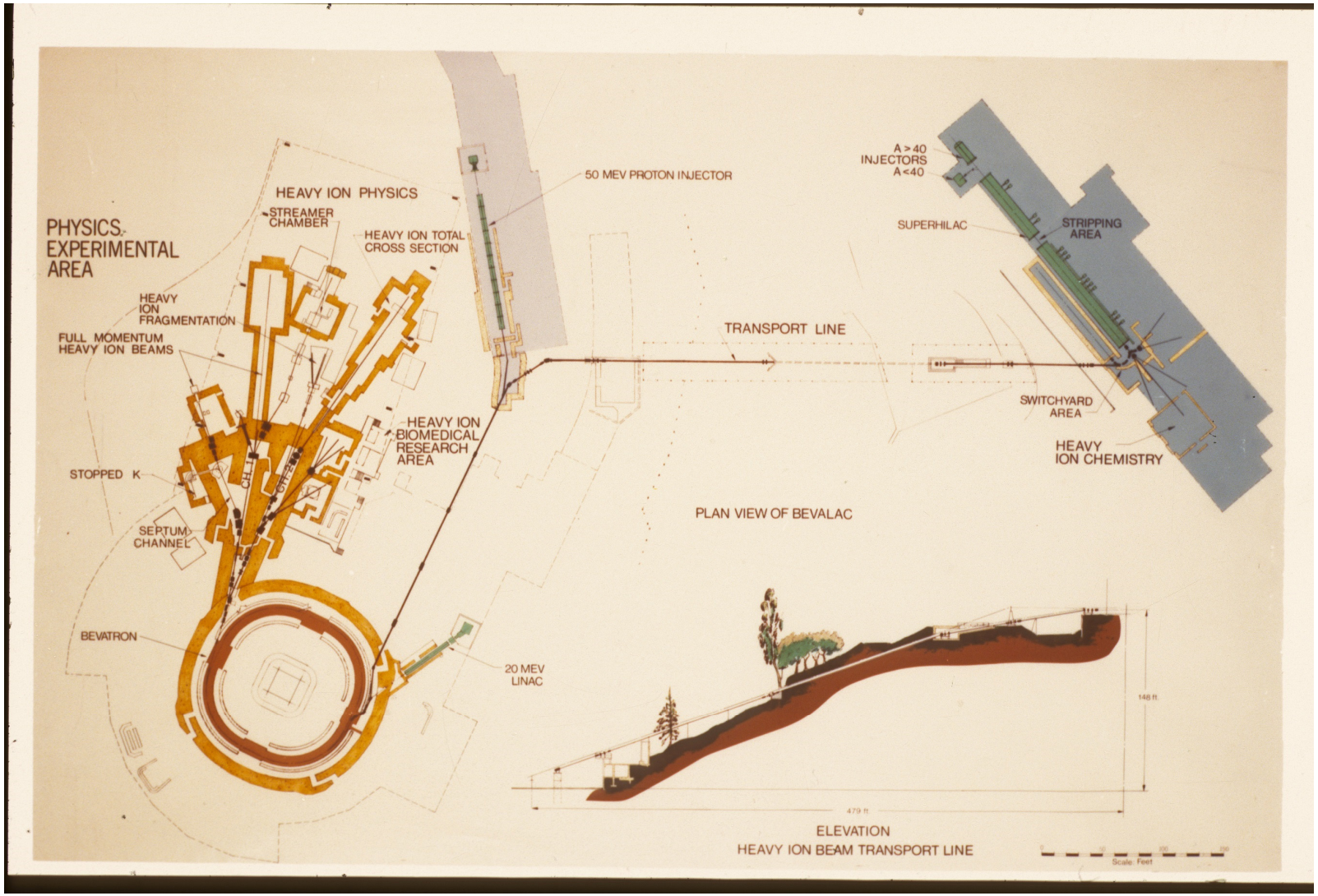
LBL 184”Syncrocyclotron



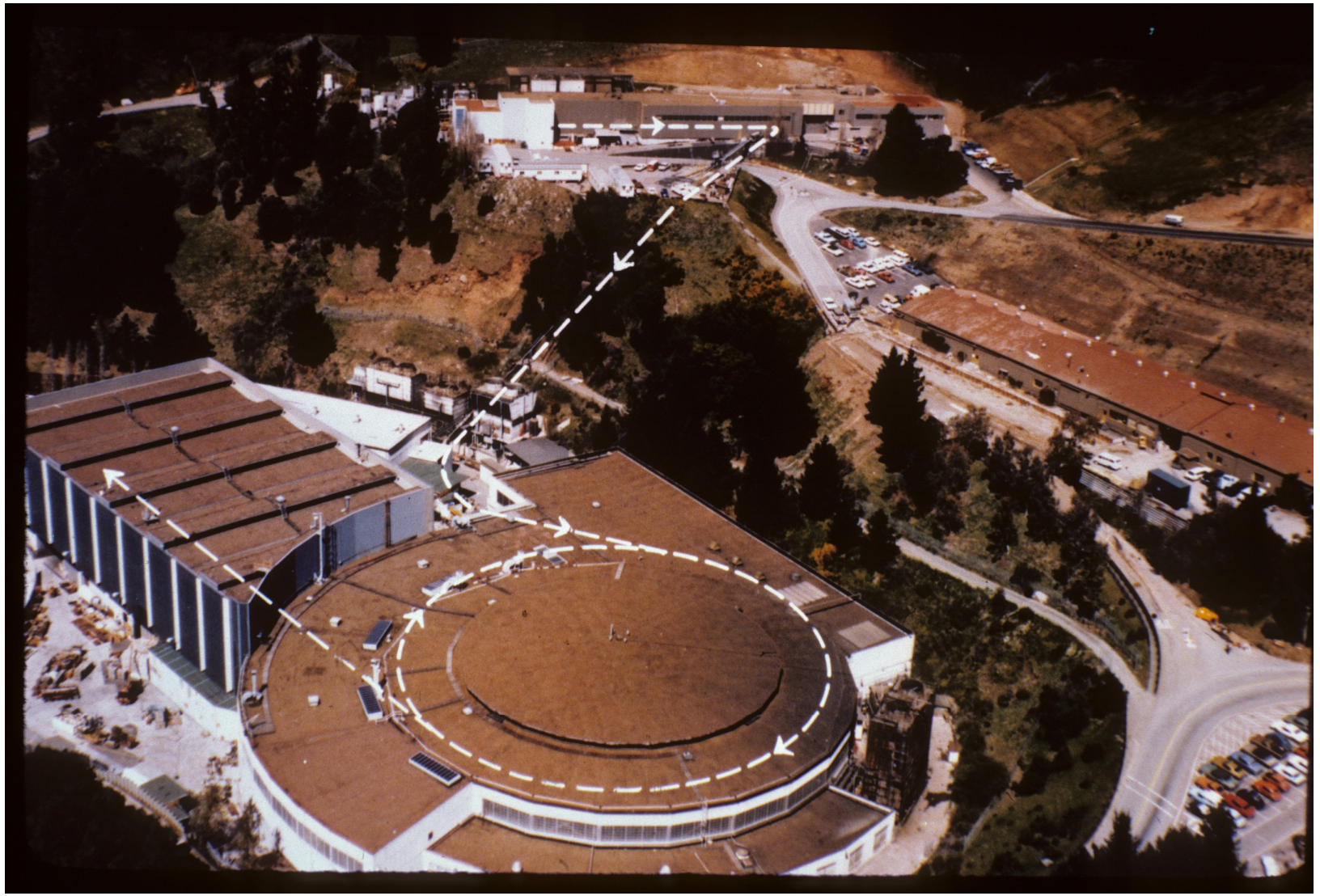
Helium Ion Irradiation of the Pituitary Gland



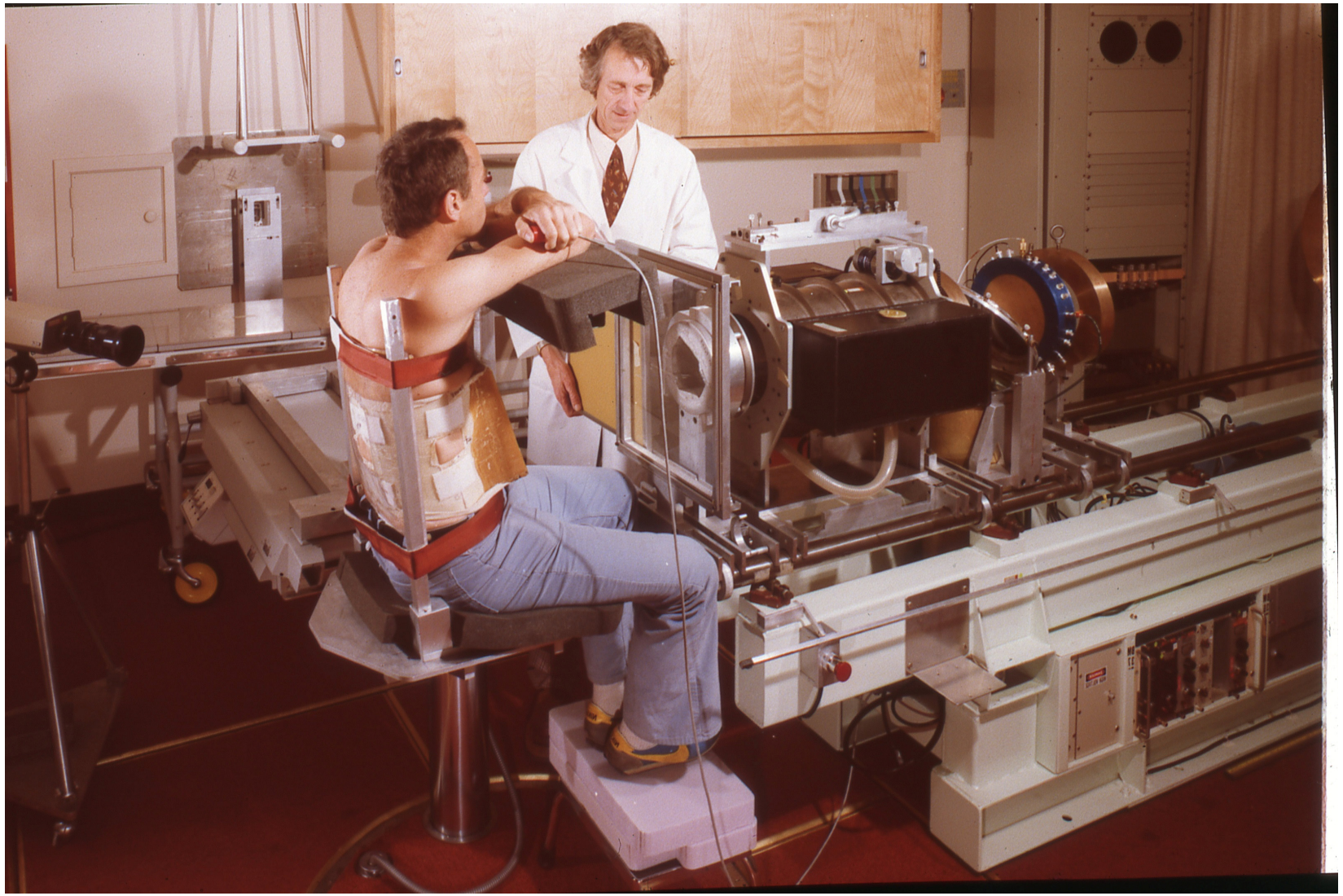
Heavy Ion Experiments at the HILAC



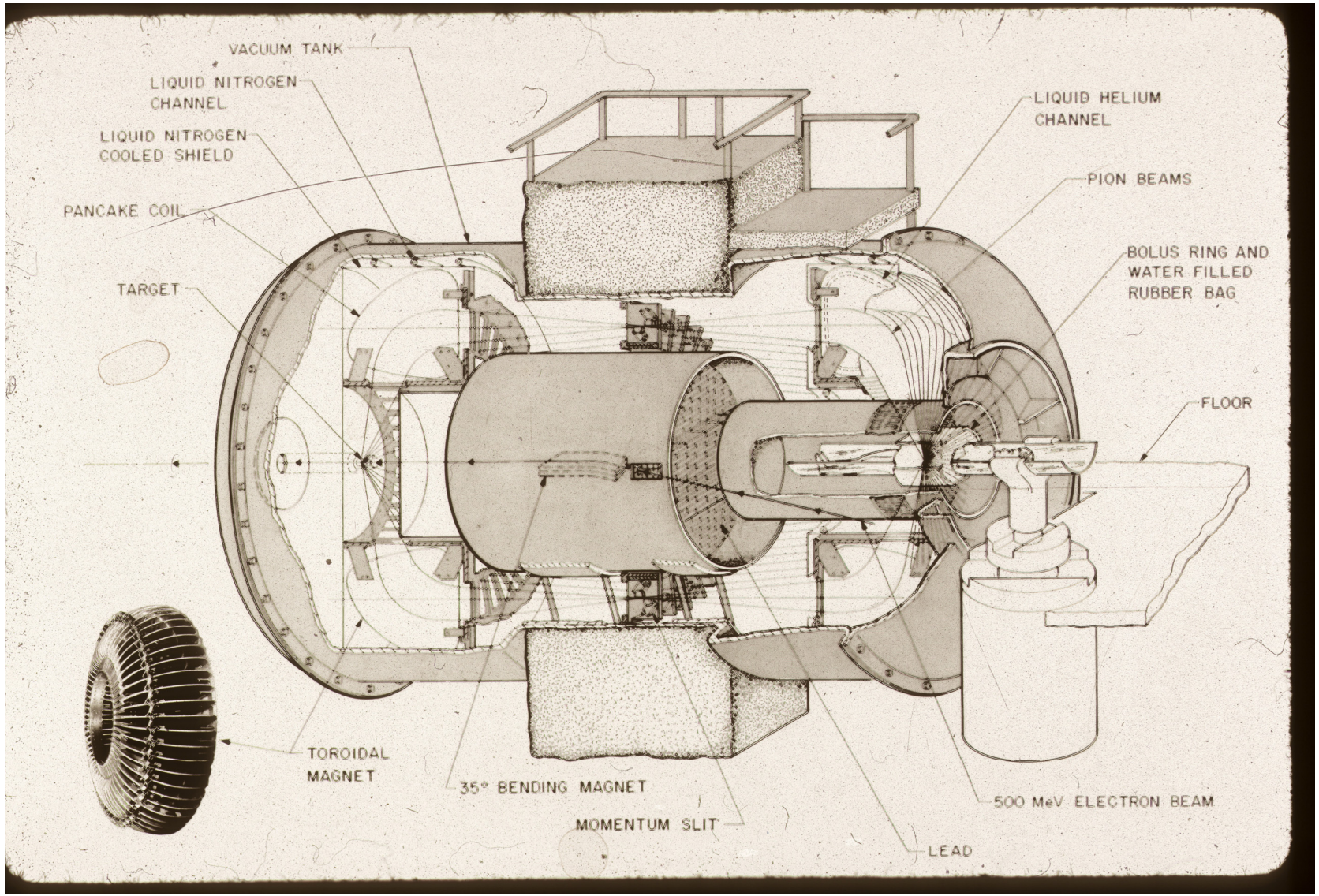
Heavy Ion Radiotherapy at the Bevatron



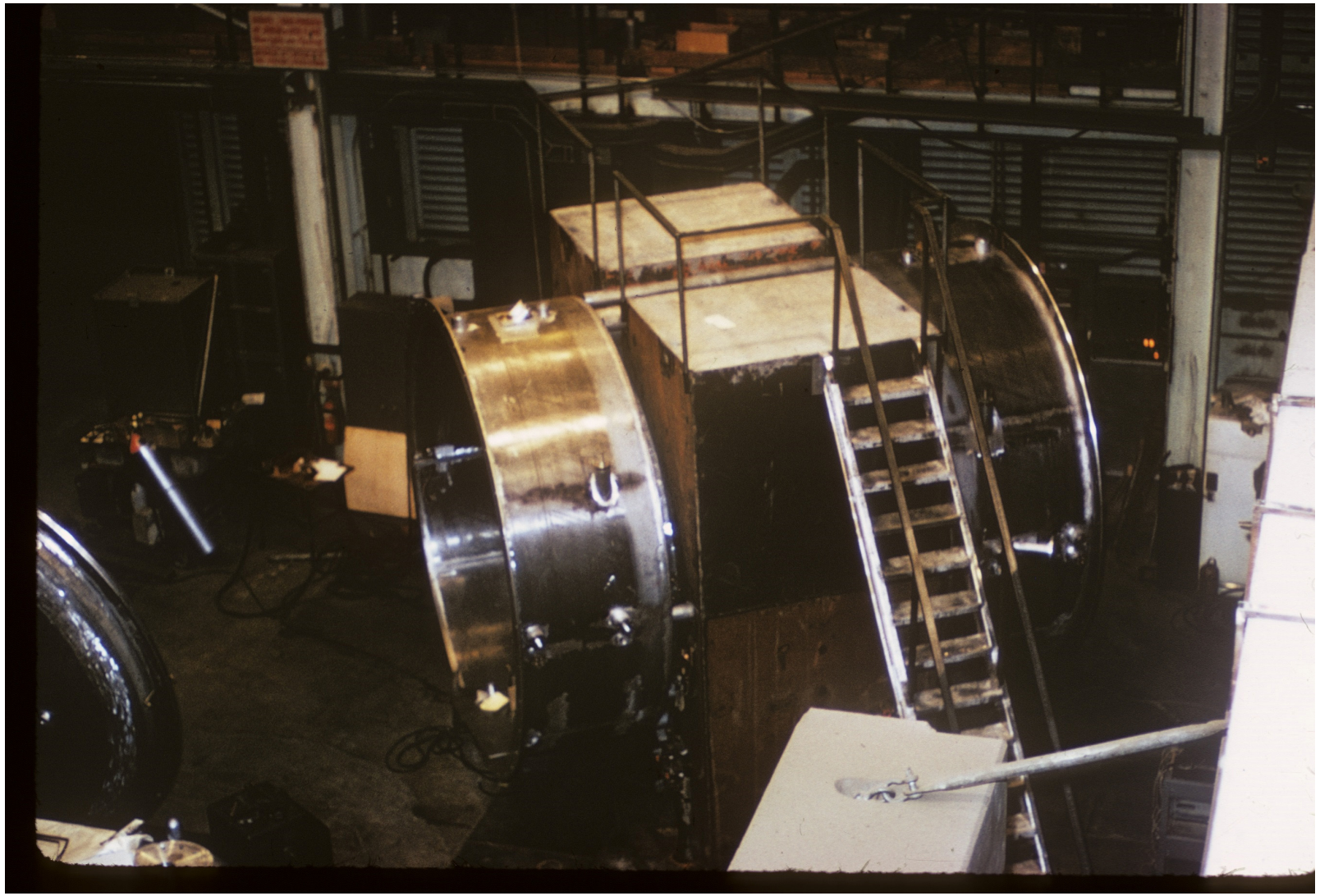
Clinical Set-up for Heavy Ion Irradiation



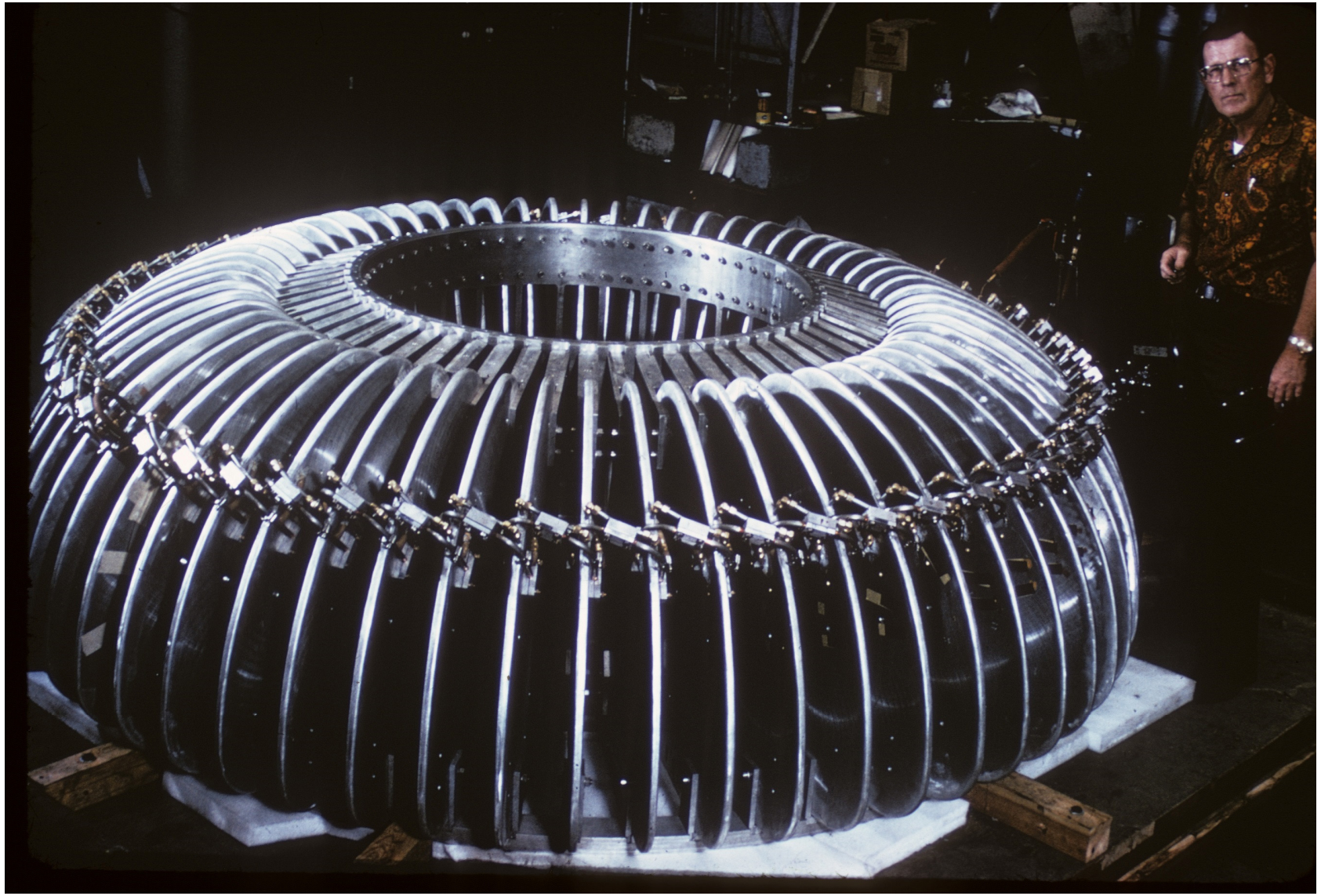
Stanford Pi-meson Irradiation System



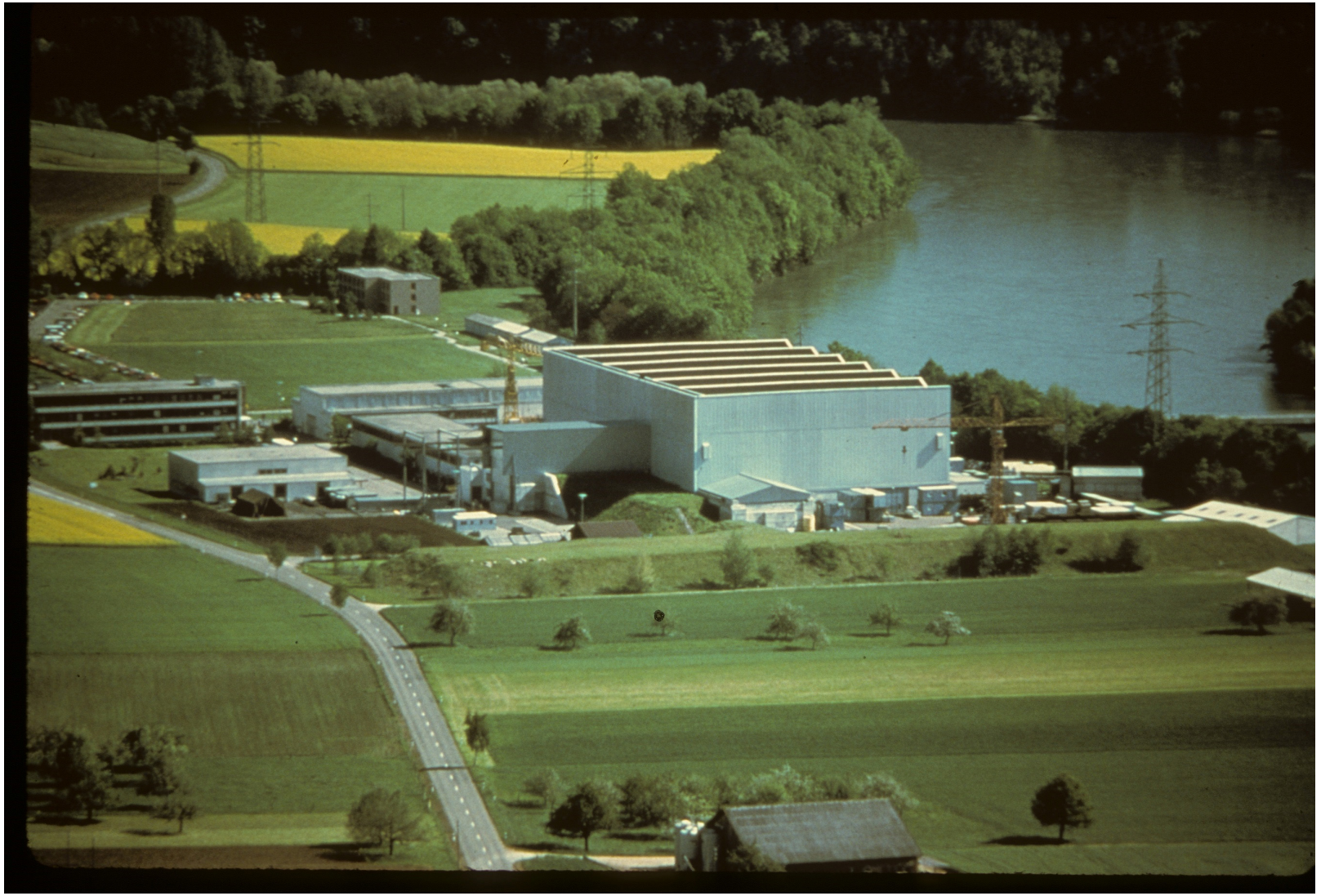
Partially Constructed Pi-meson Generator



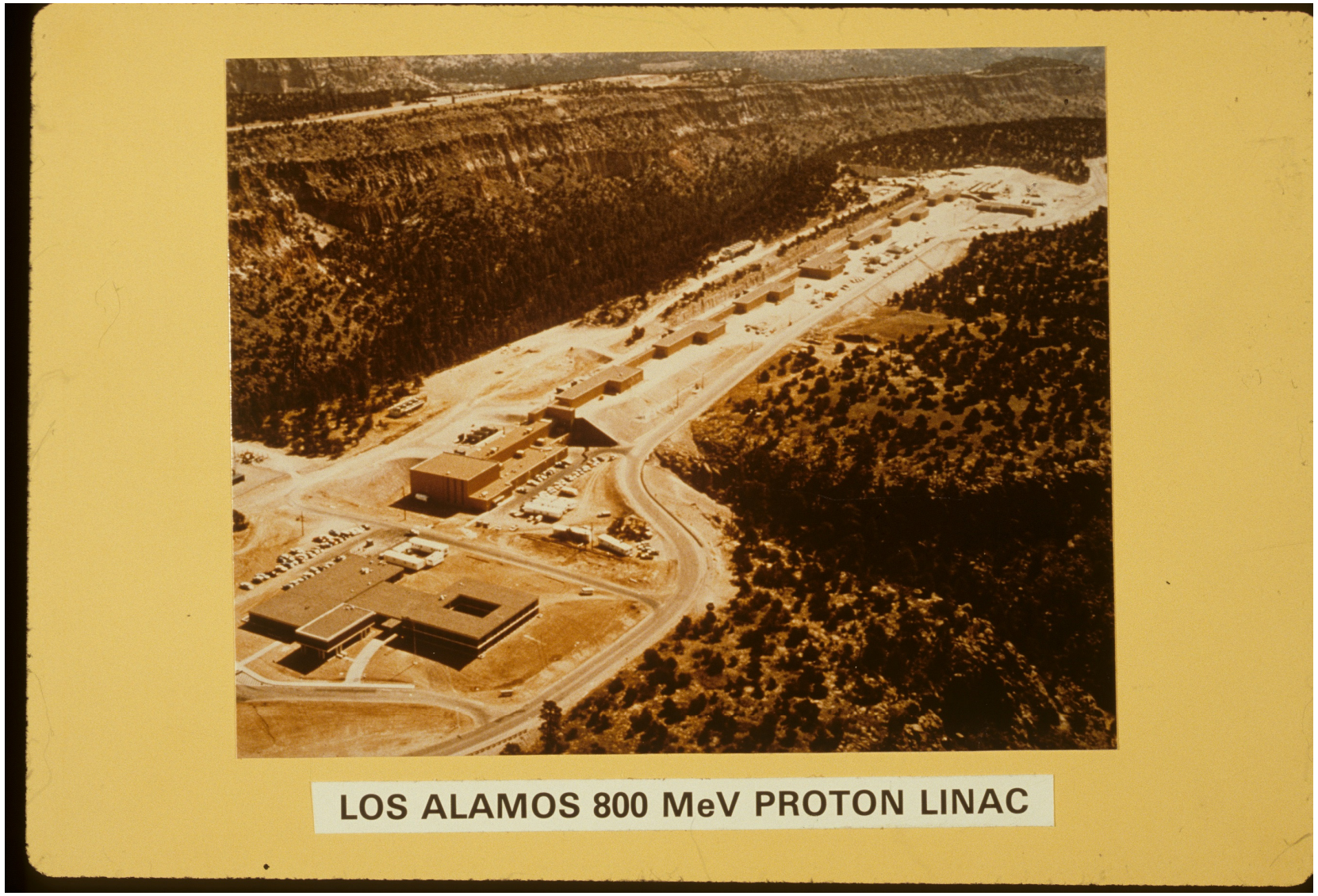
60-channel Superconducting Magnet



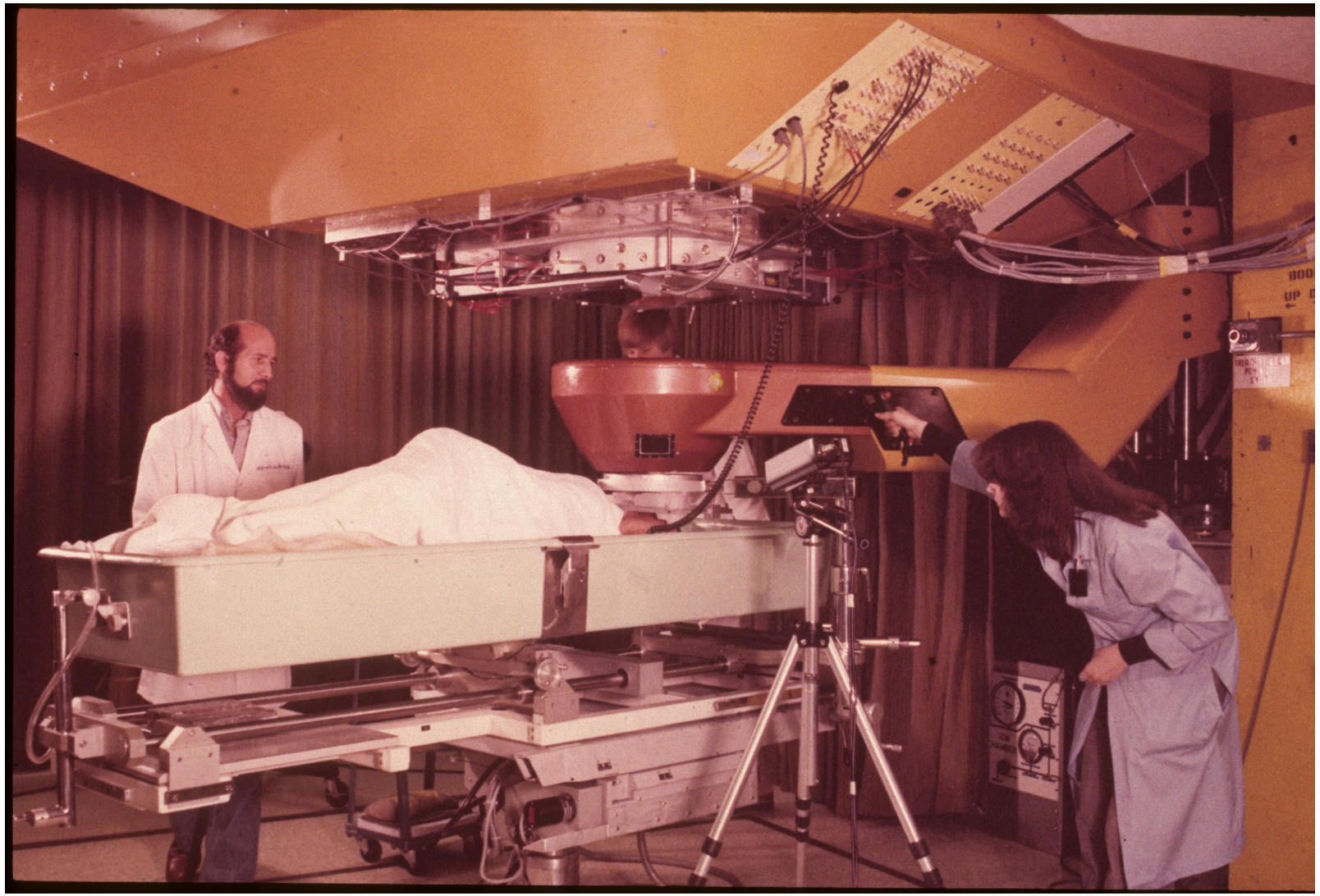
Paul Scherrer Institute, Villigen, Switzerland



Pi-Meson Treatment Facility at Los Alamos



Pi-meson Treatment Room at Los Alamos



Ill-fated Superconducting Super-Collider

Proton Therapy Corporation

- 1999 – Tenet Corporation set aside $250M for three proton therapy centers in the US
- Initial planning: ordered three cyclotrons and nine gantries from IBA in Belgium. Fabrication was well underway
- NO payment schedule had been set by HCFA so financial model was suspect
- Tenet – allegedly – withdrew funds to cover earthquake damage to its facilities in California

CERN


Welcome
LHCb
ATLAS
CERN Meyrin
CERN Prévessin
SPS
SUISSE
FRANCE
CMS
ALICE
LHC 27 km
to
CERN
Accelerating Science and Innovation

STFC Daresbury Laboratory, Manchester, UK

My assigned presentation

- Explain why as many as 12,600 medical linear accelerators will be needed in low- and middle-income countries (LMICs) by 2035.
- Show how we are developing a radiation therapy treatment (RTT) system for what we call the challenging environments found in most LMICs.
- Show how a less expensive but excellent RTT system can help to reduce the risk of terrorism using radioactive materials (cobalt-60)

Approach/outline

- There is a cancer problem in low- and middle-income countries (LMICs) that will get worse in the years to come.
- There is a major role for radiation therapy (RT) in addressing this problem. Over one-half of patients with cancer can benefit from RT when it is available.
- There is an enormous shortfall of RT equipment and of clinical and technical staff in LMICs.
- Will discuss one collaborative effort to address this shortfall in RT equipment and staff in LMICs.
- Will mention the project's relationship to an effort to ameliorate security issues related to cobalt-60 machines

Needs by 2035 in LMIC

The global increase from 15 million cases of cancer in 2015 to 25 million in 2035 (65-70% in LMICs) will require an additional:

- 12,600 megavoltage treatment machines
- 30,000 radiation oncologists
- 22,000 medical physicists
- 80,000 radiation technologists

Massive challenge needs sustainable solutions for both near-term and long-term which cover LINACs, trained personnel and infrastructure.

Reality in numbers……

- No radiotherapy (RT) in 36 countries worldwide
- No or almost no radiotherapy in 28 of 59 countries in Africa
- HIC (high income countries) have over 60% of all radiotherapy machines but only 16% of the world's population
- Low- and middle-income income countries have less than 10% of radiotherapy machines but have over 50% of the world's population
- Around 70% of patients with cancer do not have access to radiation therapy globally

Atun et al, Lancet Oncology. 2015

Radiotherapy in Cancer Care

In high income countries

120,000
are served by a single radiotherapy machine

In middle income countries

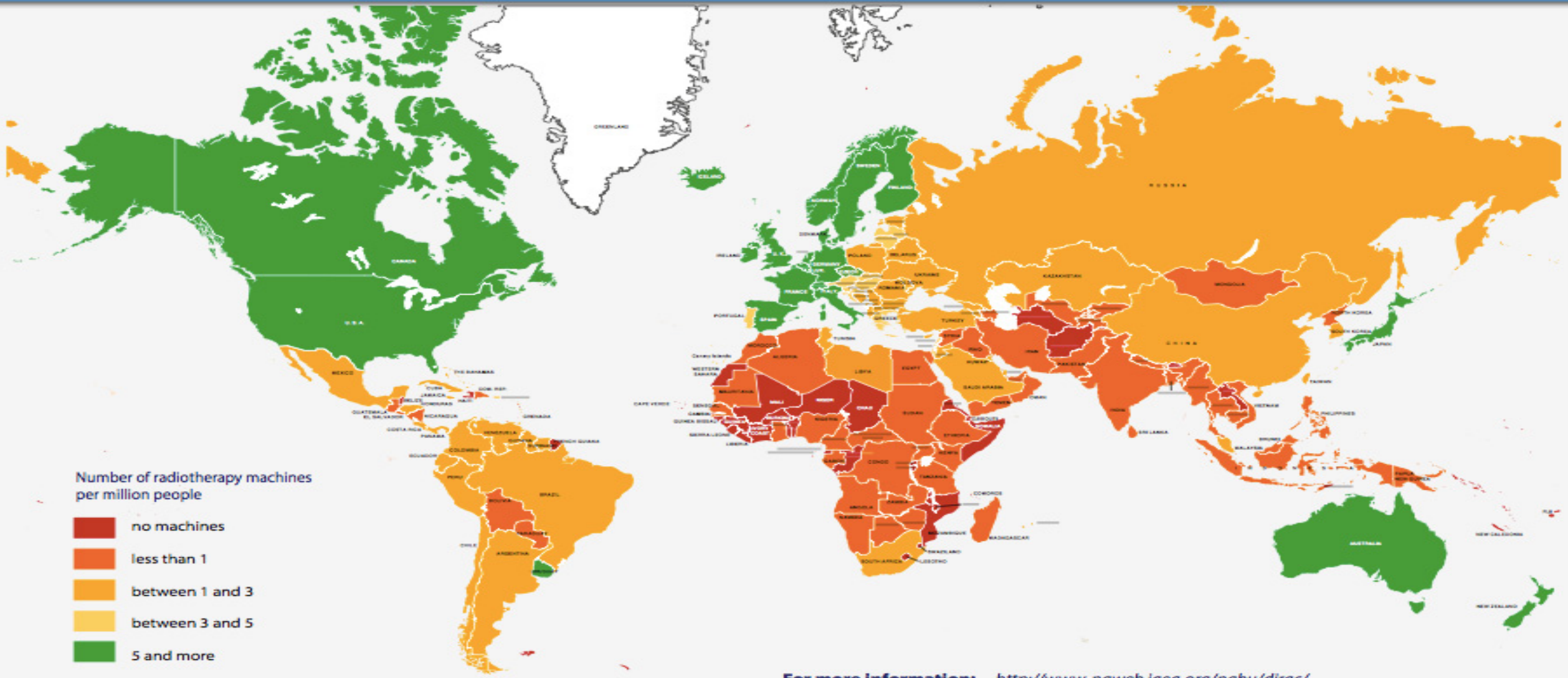
1 million
are served by a single radiotherapy machine

In low income countries

5 million
are served by a single radiotherapy machine

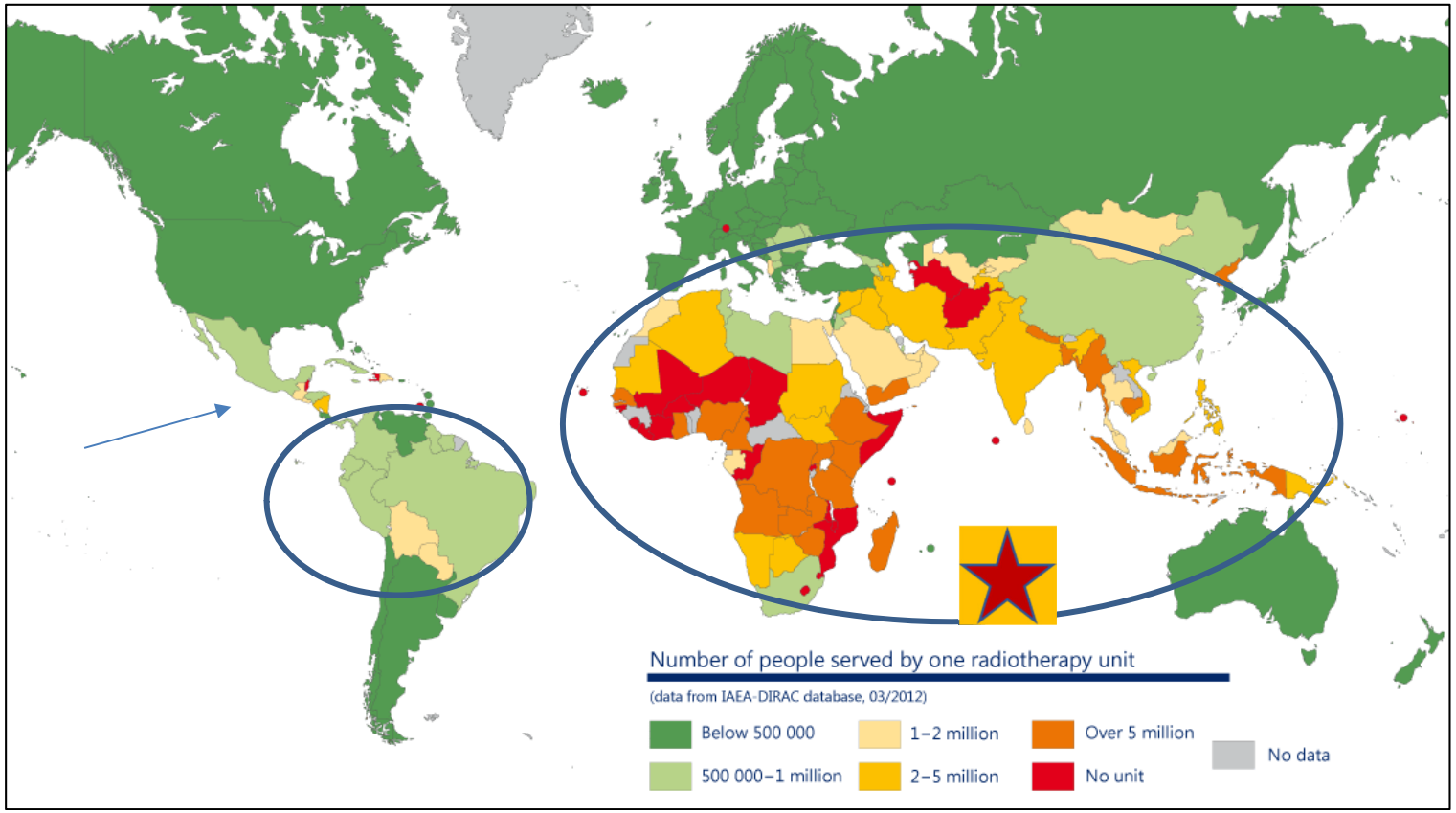
Availability of **RADIATION THERAPY**

Number of Radiotherapy Machines per Million People 2012



25 MILLION CASES PREDICTED IN 2035, 65–70% WILL OCCUR IN LOW-AND MIDDLE- INCOME COUNTRIES

Why might global oncology be considered low priority by some: shortage of RT per IAEA



https://cancer.iaea.org/agart.asp

7 Issues to address

1. There are other diseases we need to take care of before cancer.
2. Infectious diseases are a threat to us, so lets deal with that.
3. It's too expensive and poor places can't afford it.
4. Did you look at that shortage!! That's a disaster but its just too hard and too big to fix.
5. The infrastructure is awful for healthcare and for technology.
6. It doesn't earn revenue so its bad for my career.
7. Etc

How We Are Addressing the Shortage of LINACs in LMICs

- “We” refers to an international collaboration:
  - International Cancer Expert Corps (ICEC)
  - CERN
  - UK Sciences and Technology Financing Council (STFC)

- Just a few comments to introduce ICEC

ICEC Mission and History

ICEC Mission

Improve the outcomes of cancer care to the underserved in low and middle-income countries (LMICs) and those in challenging environments, as well as to indigenous populations in geographically underserved regions in upper-income countries (UICs).

- **Formed in 2013 as an NGO 501(c)3** registered in the U.S. as a response to the WHO report on cancer outcomes.
- **Builds on a 20 plus year history** of mentoring partnership work to improve cancer outcomes in underserved communities in the U.S. and internationally.
- **Uses a network of global and multi-sectoral partnerships** to build the human capacity and capability to establish sustainable cancer programs that function at international quality standards.

ICEC Expert Corps

A broad spectrum of expertise for a complex systems solution

Medical

- Radiation oncologists
- Medical oncologists
- Pediatric oncologists
- Surgical oncologists
- Oncology Nurses
- Pathologists
- Radiologists
- Surgeons - general
- Surgical subspecialists
- Pharmacologists
- Psychologists
- Public health

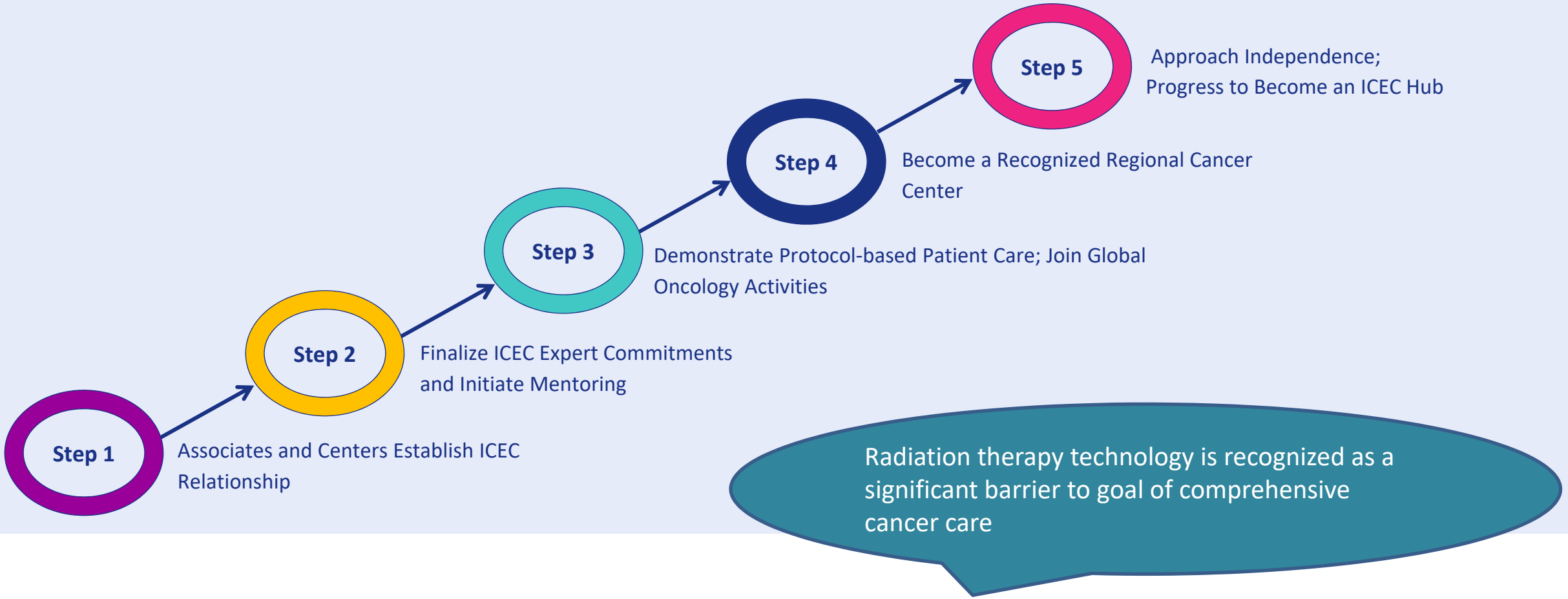
Science, non-MD

- Prevention and screening
- Epidemiologists
- Medical physicists
- Technologists
- Basic & translational scientists
- Treatment guidelines
- Statisticians
- Social scientists
- Regulatory Affairs specialists
- Pharmacists

Support

- Educational tools
- Finance
- Clinic administration
- Service technicians
- International policy
- Patient advocacy
- Economists
- Social workers
- Communications
- Cancer survivors
- Information tech (IT)
- Data-management
- Legal

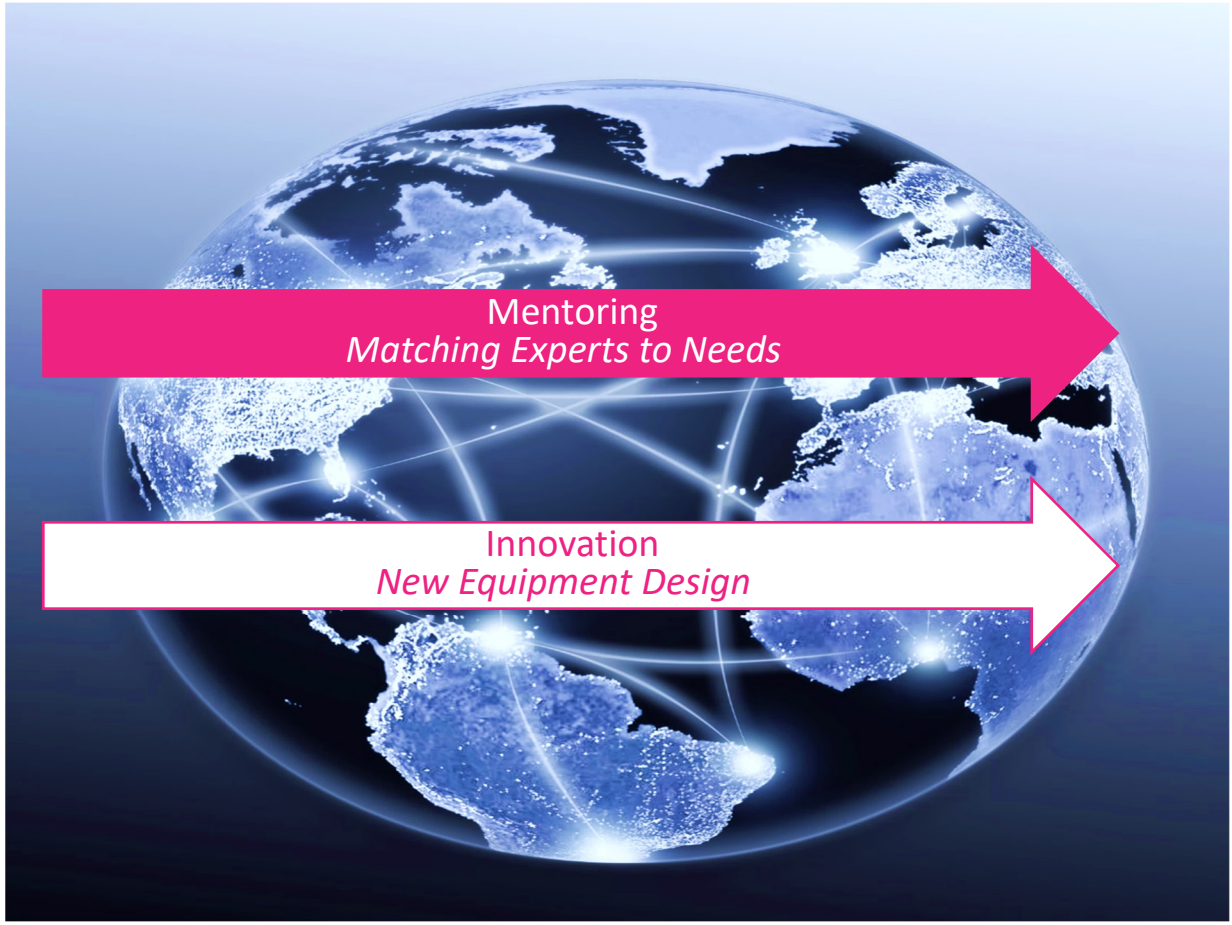
ICEC 5 Step Progression Plan



It Takes a System to Improve Cancer Care

International Cancer Expert Corps (ICEC)

ICEC envisions a world
in which everyone has access to interventions to prevent and treat cancer and its symptoms using high-quality best practices available for the local circumstances.



How We Are Addressing the Shortage of LINACs in LMICs

- The shortage of LINACs was discussed at an international meeting in Europe in 2015 by Manjit Dosanjh (CERN), Norman Coleman (ICEC) and Ugo Amaldi (CERN)
- Ugo suggested that CERN might be able to provide technical expertise to address this problem
- ICEC sponsored and CERN hosted the first workshop at CERN in November 2016

BBC News, 8 April 2016

Uganda's radiotherapy machine for cancer treatment breaks

8 April 2016 | Africa

Share

The radiotherapy machine, which is now broken beyond repair, was donated in 1995

Uganda's only radiotherapy machine used for treating cancer is broken beyond repair, the country's main cancer unit says.

This leaves thousands unable to get potentially life-saving treatment.

http://www.bbc.com/news/world-africa-36047346

Medical LINACs for Challenging Environments

- Design Characteristics of a Novel Linear Accelerator for Challenging Environments, November 2016, CERN
- Bridging the Gap Workshop, October 2017, CERN
  - Understanding the problem firsthand from LMIC participants
  - Oncologists, medical physicists, accelerator physicists, ancillary staff

•Botswana, Ghana,
•Kenya, Nigeria,
•Tanzania, Zambia,
•Zimbabwe, Nepal,
•Jordan, AFRICSIS

- Burying the Complexity Workshop, March 2018, Manchester
- Accelerating the Future Workshop, March 2019, Gaborone

CERN

International Cancer Expert Corps
Partnering to transform global cancer care

Science & Technology Facilities Council | UK Research and Innovation

Challenges in Providing RT in LMICs Reported by ODA Representatives at the Workshops

- Procurement: current LINACS are technologically complex and expensive ($2-4M)
- Service contracts offered by vendors are very expensive
- Machines are sensitive to frequently unreliable electricity and to other infrastructure issues (water, heat, humidity, dust, etc.)
- Equipment/component failure is all too common (MLCs top the list)
- Lengthy downtimes occur when equipment fails due to lack of spare parts and personnel to execute repairs
- Significant shortage of competent staff (physicists, physicians, therapists, nurses)
- Facilities are often geographically isolated (for technical support and for patients to access care due to lack of transportation)
- Public opinion: “Your cancer will kill you so why get treatment”

Survey of Failures of LINAC Components

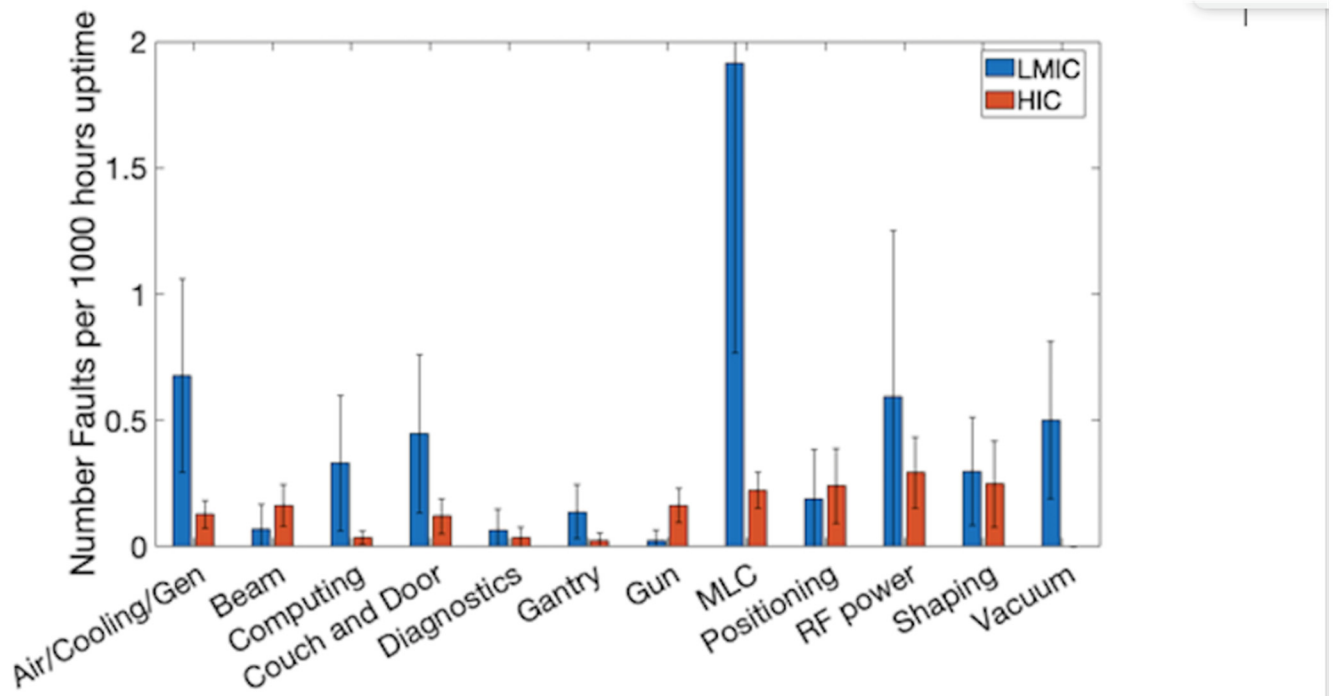
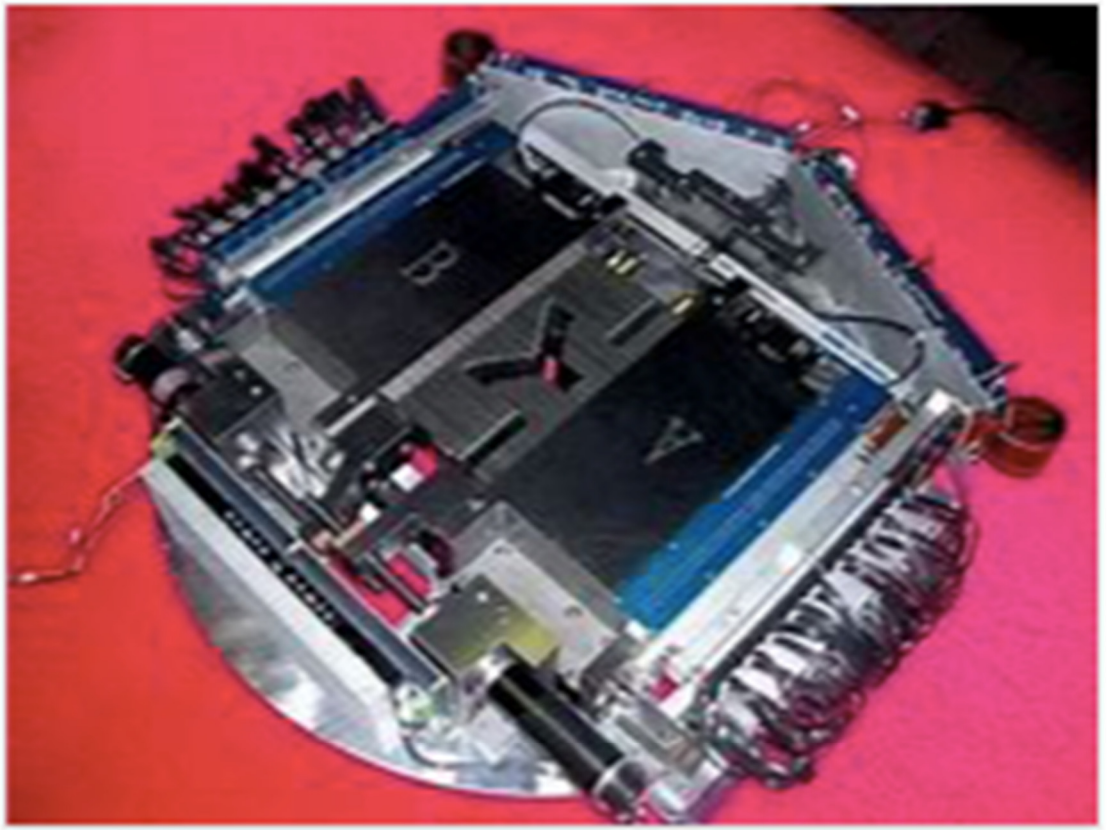


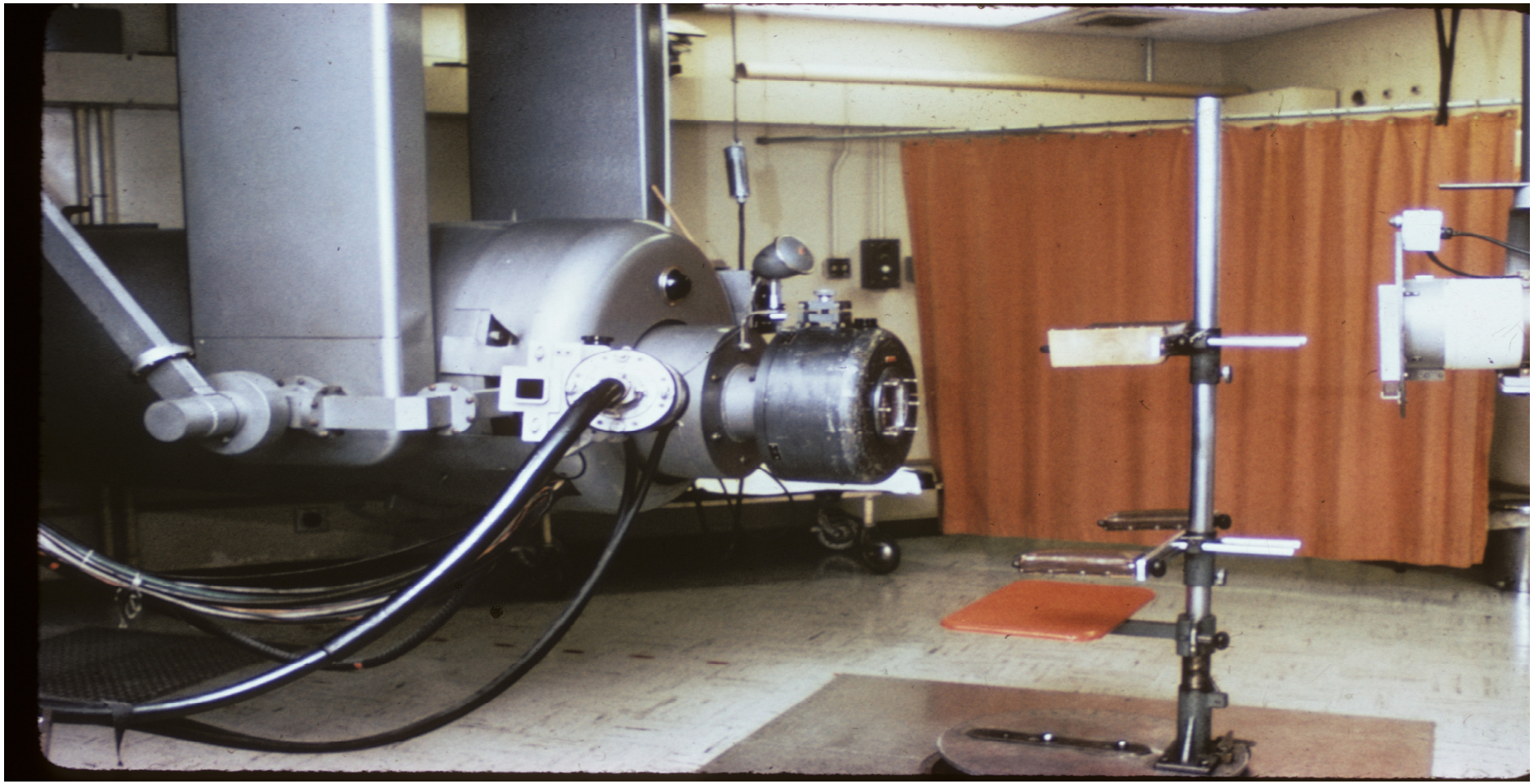
Figure 1: The number of C faults that occur in each environment per 1000 hours of LINAC uptime. The LMIC data is calculated by taking the mean number of faults per 1000 hours uptime of the 6 Nigeria LINACs and 2 Botswana LINACs and the HIC is the mean of the 6 UK LINACs. The error bars represent the standard deviation to give an indication of the spread.

MLCs

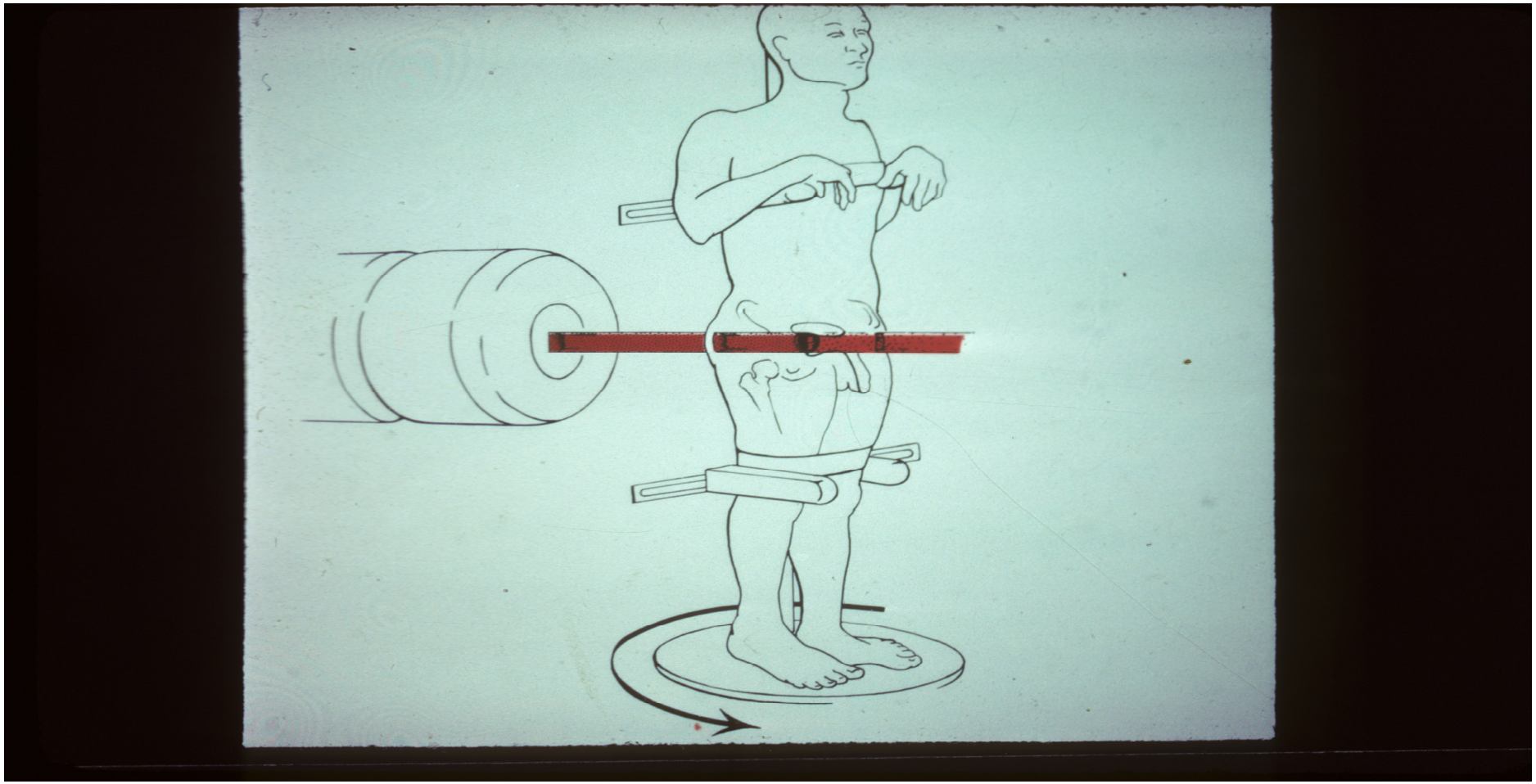

Multileaf Collimator
M.Sc Radiation Physics
KIDWAI MEMORIAL INSTITUTE OF ONCOLOGY



First Linac in Western Hemisphere



Schematic of prostate cancer treatment



Varian Truebeam Linear Accelerator

Varian Halcyon RT System

General Steps to Overcome the Challenges in Providing RT for Patients in LMICs

- Initial cost of LINACs – make less complex (fewer moving parts), reduce the number of high technology difficult to replace components,
- Reduce size of machine thereby reducing internal and external shielding and the cost of the facility
- Cost of technical service – lower servicing costs, increase reliability (robustness) of components, maximize modular design of the RT system and train staff to make most repairs
- Infrastructure issues – build robust radiation therapy treatment systems that are not as sensitive to electricity fluctuations and other infrastructure problems, provide secondary power supply
- Lengthy downtime with failure of components – increase operating life of components, regional spare parts storage consortiums
- Lack of competent staff – design a smart machine that requires fewer highly-trained staff to treat patients, remote treatment planning and QA, develop regional training programs, ICEC mentoring model
- Geographic isolation – remote fault diagnosis and repair, use LINAC simulation model to predict component failure, preemptive shipment of replacement components
- Access to care for patients – demonstrate that radiation therapy for patients with cancer is economically advantageous to encourage commitment of resources by local, regional and national governments

RTT System Design Considerations

- Agreed on 6 MeV electrons so no bending magnet needed
- More efficient electron gun
- More efficient RF generator (klystron)
- C-band waveguide
- Sealed vacuum for waveguide
- Passive self-correcting diagnostics for beam instrumentation
- Eliminate focusing coils/magnets to reduce cooling requirements
- Overall machine remote fault diagnostics and repair
- Better x-ray beam-shaping (software ilo lots of multileaf collimators {MLCs})
- Integrated diagnostic imaging system (to assess tumor's biological properties)
- Automated treatment planning (locally and remote) and QA

Projects Funded by STFC after Workshop at Daresbury

- Study of Accelerator Technology Options - Peter McIntosh and Alan Wheelhouse
- Robust Permanent Magnet Beam Delivery Systems for Medical Radiotherapy Linacs – Suzie Sheehy and Ivan Konoplev
- RF Power Systems and Optimized RF Structures for Electron Beam Acceleration – Ivan Konoplev and Suzie Sheehy
- Linear Accelerator Simulations for Stable and Sustainable Operation of Developing Country Radiotherapy Linear Accelerators -Stewart Boogert and Marco Carlone
- Cloud-based Electronic Infrastructure in Support of Linac-based Radiotherapy in Challenging Environments - Ajay Aggarwal and Jatinder Palta
- Defining (and Exploring?) the Gaps in the Re-engineering for the Next Generation of Medical Linear Accelerators

US Department of Energy (DOE)-National Cancer Institute (NCI) WORKSHOPS

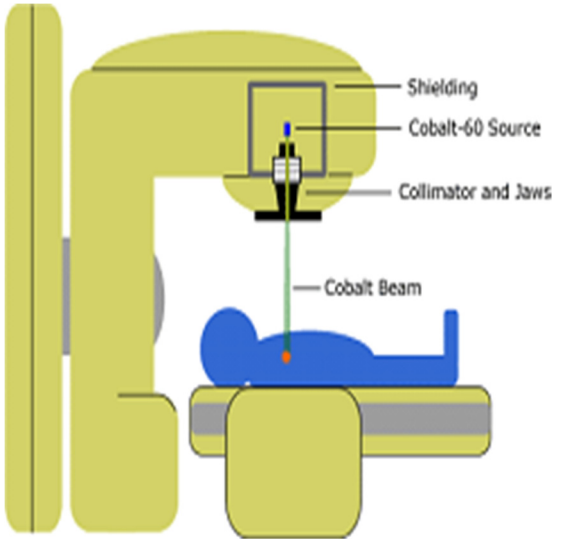
- Workshop on Ion Beam Therapy, Bethesda, MD, January 9-11, 2013

- Workshop on Basic Research Needs of Compact Accelerators for Security and Medicine, Tysons Corner, VA, May 6 – 8, 2019

- Collaboration of ICEC with DOE National Nuclear Security Administration (NNSA) - ongoing

Cobalt 60 Replacement: Cancer Treatment

- **Teletherapy machines that employ Co-60 sources can treat cancer**
- **In high-income states, teletherapy machines have been replaced with Linear Accelerators (LINACs)**
  - More Secure and Better Treatment
- **LINAC use less widespread in lower-income states because of higher costs, complexity and need for stable power sources, etc***
  - 1/2 of new cancer cases in developing countries, expected to be 2/3 by 2030
  - Sustainable Development Goal 3.3: Reduce premature mortality from NCDs (including cancer) by one-third by 2030
  - Use of LINACS varies directly with GDP/capita (Widespread use HMIC, medium LMIC, less LMIC)



Addressing Technology Access

Problem: Cobalt-60 and security risks - Linear Accelerator cost and complexity

- Because of their lower cost and lesser complexity to operate, cobalt-60 machines (cost of $750K) rather than linear accelerators (cost >$3M) are favored by most LMICs for radiotherapy
- Cobalt-60 machines pose a threat as they have an active radiation source that could be used to create “dirty bombs.” Many government agencies are committed to the safe replacement of cobalt-60 machines with LINACs.
- Cost and complexity of current linear accelerators serve as significant barriers for access to treatment in LMICs.
- Removal of cobalt-60 machines without a replacement creates an “access to care” problem

Solution: Identify a cost effective, full-function, less complex to operate linear accelerator machines (suitable for the LMIC environment) to replace current co-60 machines to increase treatment capacity and to reduce the security risk.

Proposed:
Cancer Care/Risk Reduction Initiative

- Develop New Appropriate LINACS for developing countries–the “I Phone” of LINACS- - affordable, easy to use, suitable for challenging environments but sophisticated (UK STFC/CERN/ICEC initiative)
- Appropriate servicing for existing LINACs in LMICs
- Related education, training, and sustainable mentoring for medical professionals to build capacity and capability
- Maximum Safety and Security
- Concerted plan for IAEA, to decommission, repatriate, and store/reprocess safely and securely all existing cobalt and other spent/disused sources in LIMIC cancer centers
- **Assist any participating country to acquire 1st LINAC or a LINAC for each Co-60 machine decommissioned and use it safely and securely**
- Helps meet UN Sustainable Development Goal 3.3: Reduce premature mortality from NCD by one-third by 2030

Current Status and Plans for the Future

- 2019 – Continue design and testing of LINAC prototype components; pursue funding for prototype fabrication and testing at Daresbury Laboratory
- 2020 – 2023 – develop prototype LINAC at Daresbury; design and test remainder of RTT system; integrate prototype into RTT system; explore partnering for manufacturing and distribution of RTT system in LMICs and UICs
- 2024 – 2025 – with commercial partner, initiate manufacturing and marketing of RTT system; implement plan for education, training and mentoring of personnel in LMICs

Can We Do This?

- This is a unique opportunity for the private and public sectors and LMICs with expertise in science, medicine, healthcare delivery, health policy and financing, health disparities, nuclear safety, and the environment to come together and develop a **global** solution to a complex healthcare access problem.
- The solution can be leveraged to offer **high value** radiation therapy technology to improve access and affordability in UICs.

END of Presentation

- Thank you for the opportunity to be with you