Some Long Range Impacts of Research at the BGRR

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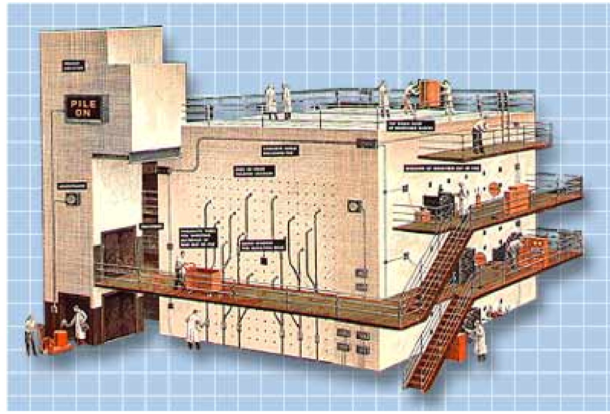
Brookhaven Graphite Research Reactor



- The first reactor to be devoted to basic research – 1950-1968
- Inside the graphite core neutrons generate fission of uranium which produces energy and more neutrons as well as many new nuclei
- Outside the core neutrons were used for scattering on materials for many purposes or for capture on nuclei to produce other nuclei
- Over 50 experiments could be done at one time

Some uses of neutrons

- **I want to focus on some applied uses, but will begin with some basic research experiments at the BGRR whose connection I hope will become clear**
- **Neutrons can be deflected by atoms in materials - they are complementary to x-rays in determining structure of materials and in particular magnetic properties because while the neutron has no charge it has magnetic properties – widely used today**
- **Because neutrons can modify materials through damage they can change character of materials, e.g. irradiation may change color, or resistance or other features**
- **Many radioisotopes were produced, either via fission or neutron capture, and studied or shipped to industries, hospitals and universities for either applied or research uses – more detail to follow, but first to some basic nuclear research that was key**

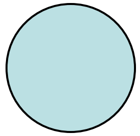
Measurement of Cross sections

- A major activity was the measurement of neutron capture cross sections of nuclei
  (often similar to the "cross sectional area" of a nucleus– π R^2)

  e.g. the BGRR pile was made of carbon

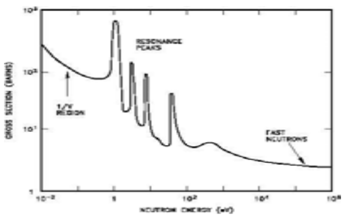
  n + C-12 → C-13 stable

  n + C-13 → C-14 unstable (major residual activity in pile)



The common units of cross section are .000000000000000000000001 cm^2 -- given the whimsical name "**barn**" as in as "big as a barn door"

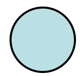
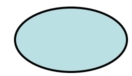
BNL produced the "barn book" – compilation of neutron cross sections for many nuclei and neutron energies



- There are some *big* surprises
  - Cadmium/Boron/others had an enormous cross sections so used for control rods to slow down reactor as needed
  - One isotope of Xenon has a huge cross section (1 million times larger than expected) so that as it built up in the fuel from fission it would prevent a reactor from operating
  - Of course some other isotopes had much smaller cross sections than expected

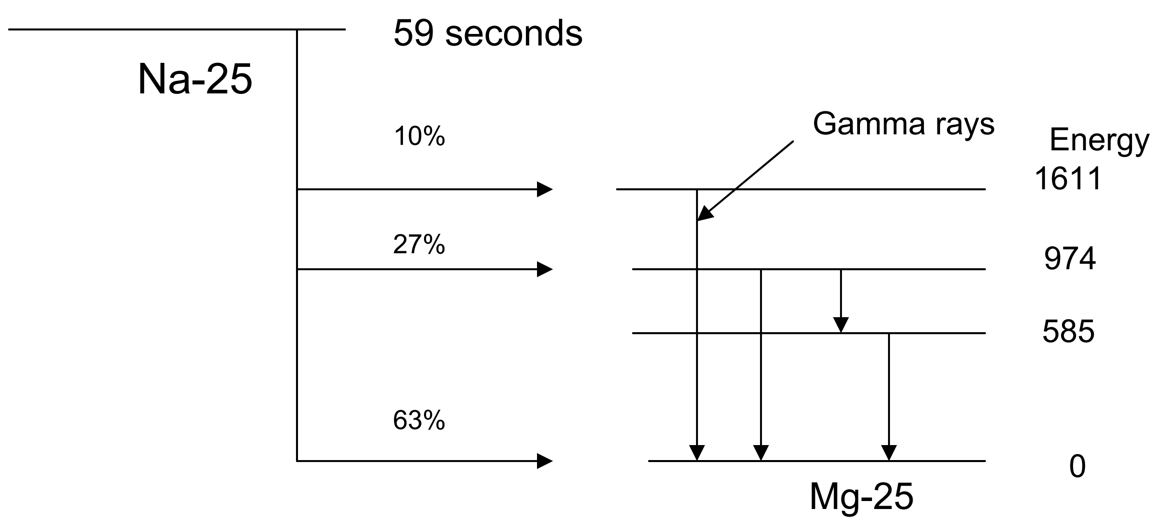
Decay Schemes of Nuclei

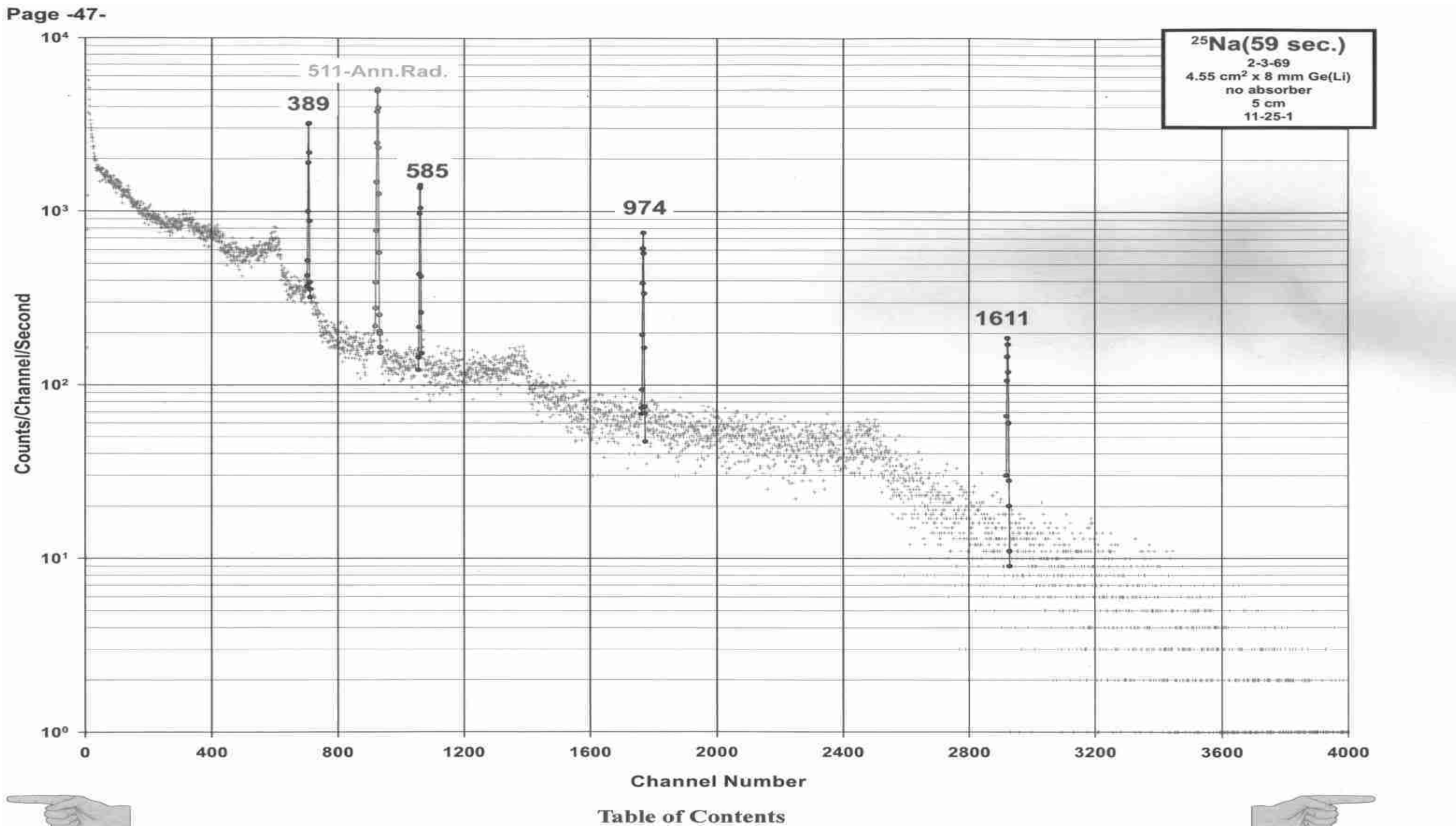
The original purpose of the studies of excited levels of nuclei and their decays was to understand what nuclei look like and what causes the levels to be where they are

 spherical  deformed

For example - the spherical one vibrates and the deformed one rotates

Much of the information that allows one to determine this behavior comes from studies of nuclei produced by neutron capture or fission that are not stable and decay to another nucleus –





Each nucleus has a unique decay scheme so can be identified

Many isotopes produced either from fission or neutron capture were studied in detail – decay schemes, half lives etc.

Basic Research to Applications

- The fact that neutrons can change properties of materials had an early use -- in the late 1950's one of first satellites to be sent into orbit (where radiation is a hazard) were irradiated at BGRR and first ones found all to fail so they were redesigned before launch

- Most radioactivity can be detected very sensitively so can find *very* small amounts of material –
  - e.g. very easy to measure 1 millicurie of activity which for a 1 hour half life nucleus translates into about .0000000001 grams of material

- This sensitivity has many applications – for some it is vital to know the particular element so the unique decay scheme is needed and detectors were continually improved to make this possible

- Of course how small amount of a specific nucleus you can measure also depends upon the cross section for neutron capture and its lifetime

Multi-grade Motor Oil

- In the early 1950’s the BGRR was used to aid the development of multi-grade motor oil that is used in cars today
- Single weight oil works at high temperatures or low temperatures, but not well at both. Metal parts in engines would wear quickly so oil had to be changed very frequently (1000 miles) – and of course engines would not hold up either
- Automobile and oil companies collaborated to change that
- BGRR was used to irradiate various parts with neutrons (piston rings, etc.) to make them somewhat radioactive
- Then the engine was run and the amount of radioactivity that was seen in the oil after use in various conditions – cold, hot, etc. – led to the development of multi-grade oils so that oil and engine parts last much longer today – and incidentally reduce pollution

Art and Archeology

- Another example of a technique started at the BGRR was measuring trace elements in a variety of art and archeological objects

- Irradiate a small sample of an object or a whole painting with a small number of neutrons and look at gamma rays to identify elements

  – Trace elements in clay are different from different parts of the world– “fingerprint” of pottery helps determine where it came

  – Different paint pigments have different compositions and trace elements. Metropolitan Museum of Art had a number of paintings checked with autoradiography at BNL for authenticity or --

  – In some cases found other paintings below the final one

Woman with a pearl necklace (Vermeer)

Note - the map on the wall, the instrument on the chair and the tiles on the floor are not in the final painting

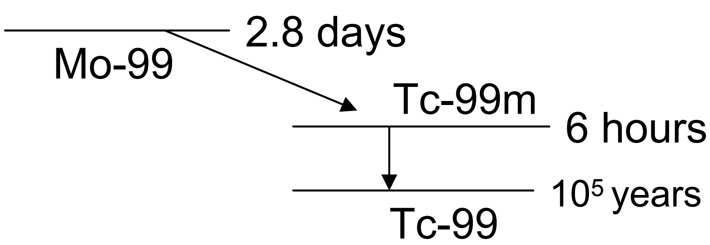
Some Medical Applications from the BGRR

- **Isotopes produced at the BGRR were shipped to hospitals and industries as well as universities**

- **Some early ones - I-131 for thyroid cancer, Y-90 for a variety of cancers**

- **Co-60 and Cs-137 are used for a variety of applications, including medical ones, and were produced at the BGRR and shipped all over the world**

- **And *then* an isotope produced in the fission of Uranium – mentioned in 1955**



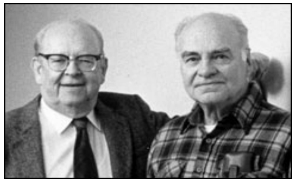
Note Tc-99m has a single gamma ray (140 keV)

In 1958 a note in the annual report “***Tc-99m is a potentially useful short-lived isotope***”

Tc-99m development

- **Potential medical benefit**
  - Short half life - only 6 hours
  - Single 140 keV gamma can escape the body but is easily shielded so detectors can focus on small area of body.

W. Tucker, P. Richards



- **How to make it useful ?**
  - Needs to be very pure (no other activities)
  - In order to get it to a hospital from a reactor requires some innovation since the half life is so short.
  - Mo-99 has a half life of 2.8 days so is much easier to ship and store
  - Need to create a simple way a hospital can "milk" Tc-99m from Mo-99
  - That technique (known as a Tc-99m generator) was devised at BNL during the BGRR days by the two individuals pictured above
  - Need to attach it to a chemical that will go to appropriate location

BNL played a major role in all aspects of the development

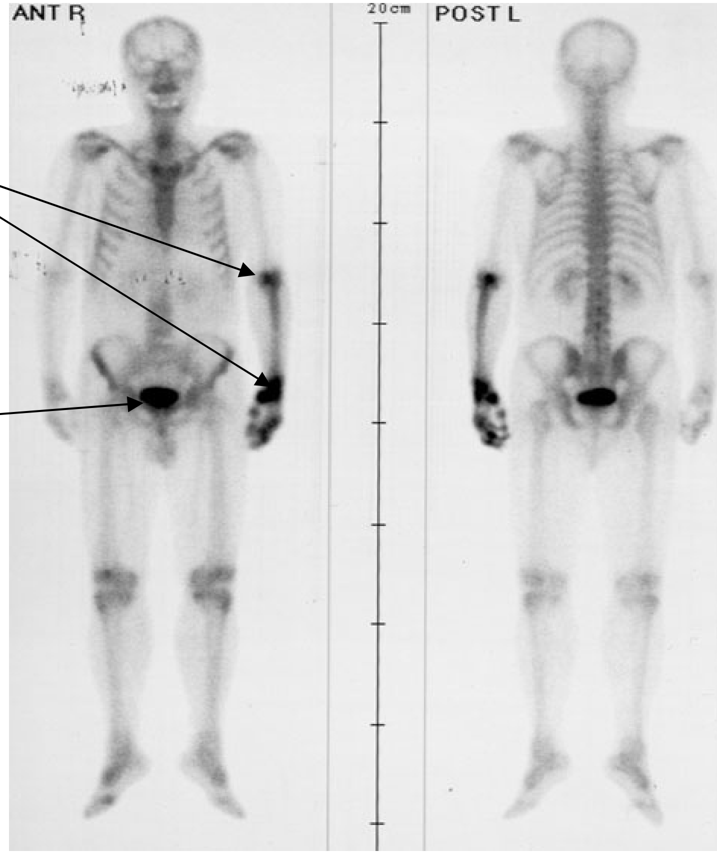
Tc-99m development

- From 1959 – 1961 continue to work on making the extraction more pure and develop chemicals to attach Tc to
- Began to ship Mo-99 and the Tc-99m generator which increased in years 1961-66
    - 1, 20, 27, 116, 597, 661
- During this period BNL continued to work on attaching Tc to various chemicals that would focus on specific parts of the body
- In 1967 the AEC decided should not compete with industry so moved production to industry and the shipments stop

Tc-99m is now used *millions* of time a year (about 13 million times in US alone) - Used as diagnostic tool for heart scans, bone scans etc. –

the *most used* medical radionuclide in the world today

Location of cancer metastases to bone



Today there is a crisis as the reactors (nearly all foreign) that were the prime producers of Mo-99 are shut down and the medical community and Congress are very concerned – So much so that there is a bill introduced to restart US production

Summary

- Basic research at the BGRR, such as measuring cross sections and studying the structure of nuclei or materials, didn’t always turn into practical applications and one doesn’t initially know which ones will or won’t

- And for those that did turn out to be useful couldn’t predict when. For example, there were many steps and years of work among several different disciplines that brought Tc-99m to prominence

- I hope that these few examples from the BGRR show basic research can and has had enormous benefits to society in a wide variety of areas – often in unexpected ways

An amazing feat

- The helicity of the neutrino – which way does the spin point – along the direction of motion or against it ?
- It is one of the classic and most clever experiments in physics and it relied upon an isotope produced in the BGRR – and in fact the *only* one that could work
- Why is this amazing ?
  - The neutrino has no charge, travels at about the speed of light and doesn't interact with matter much (can travel through the earth many times without interacting)
  - And yet we know it has a "left handed" helicity – spin is opposite to the motion