SAND2011-3447C

Application of Research Reactors: Production of Isotopes

Lecture 6

7 June 2011

Dr. Geoffrey Forden

SAND# 2011-3447C

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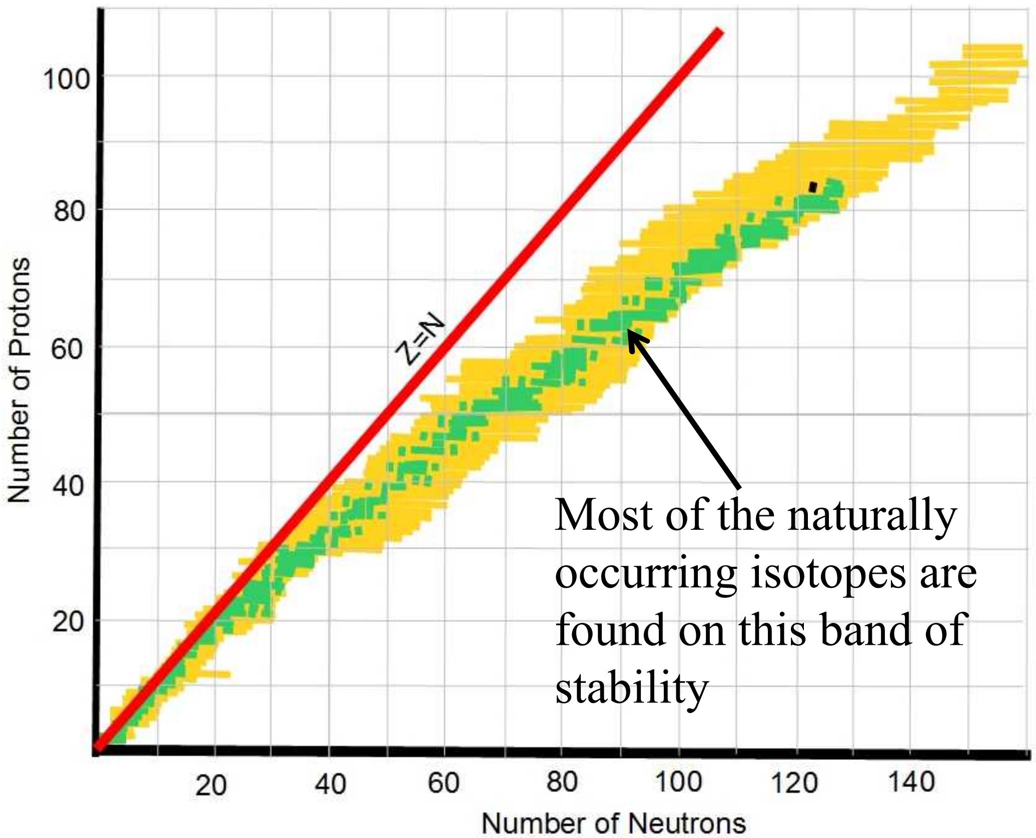
Review: What are Radioisotopes?



Source: Geoff Forden, based on http://www.phy.ornl.gov/hribf/science/abc/

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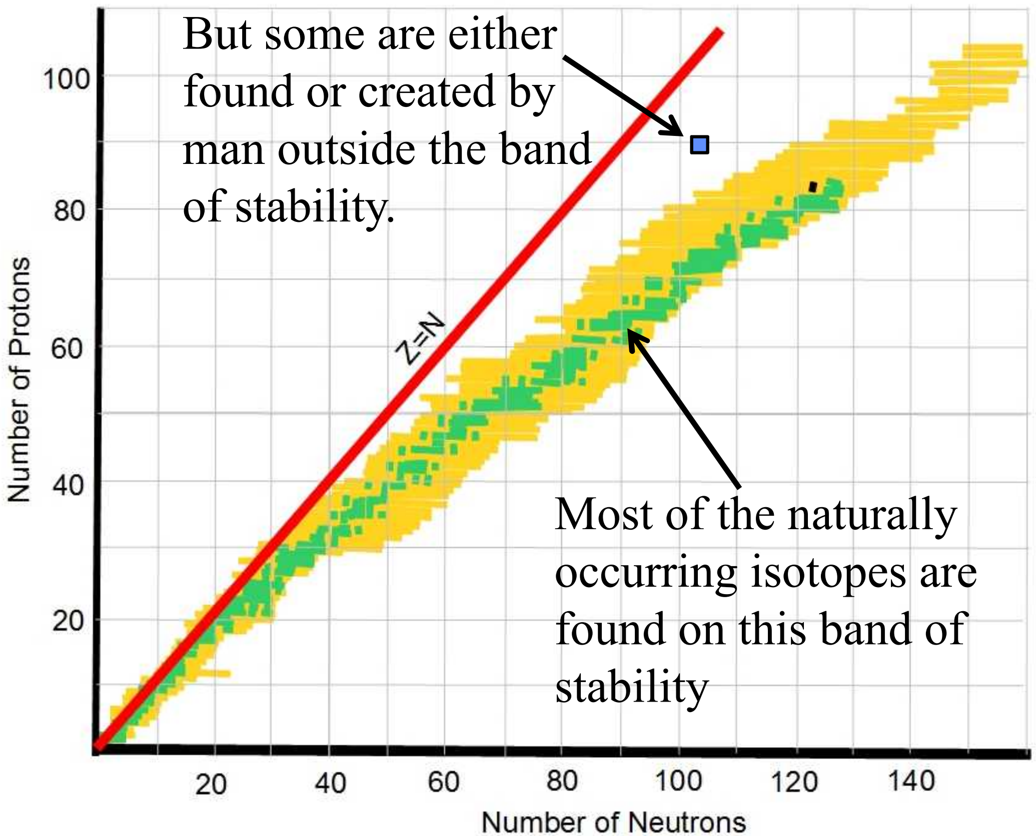
Review: What are Radioisotopes?



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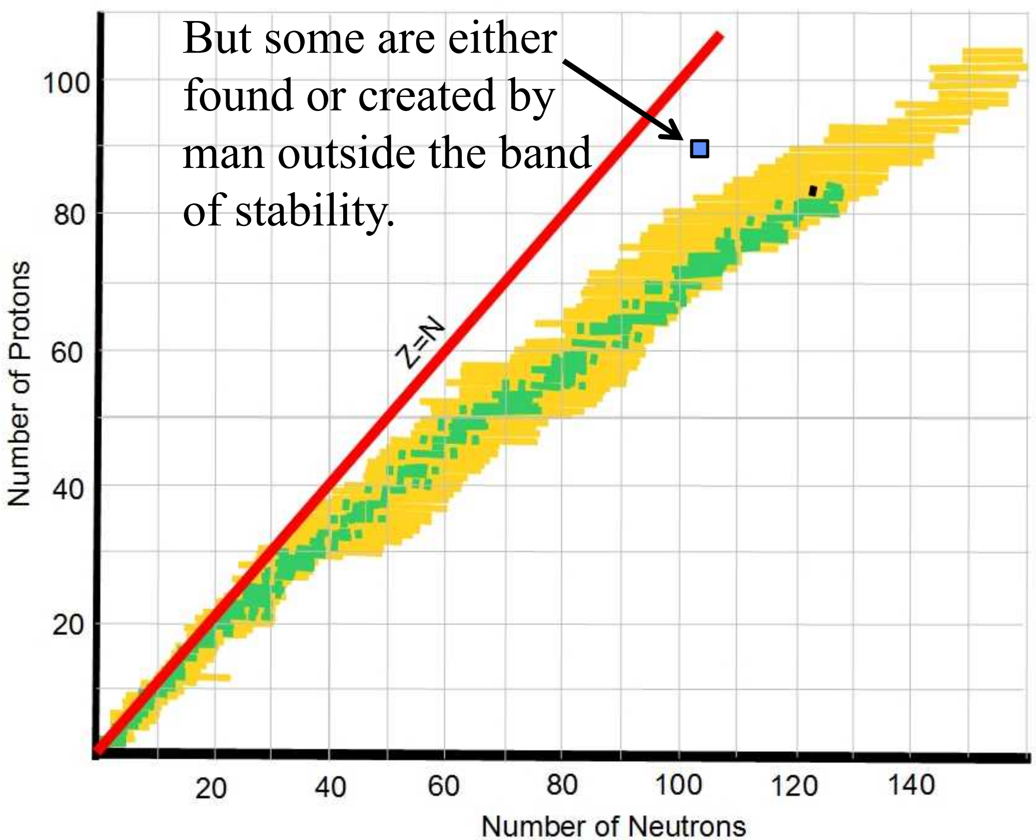
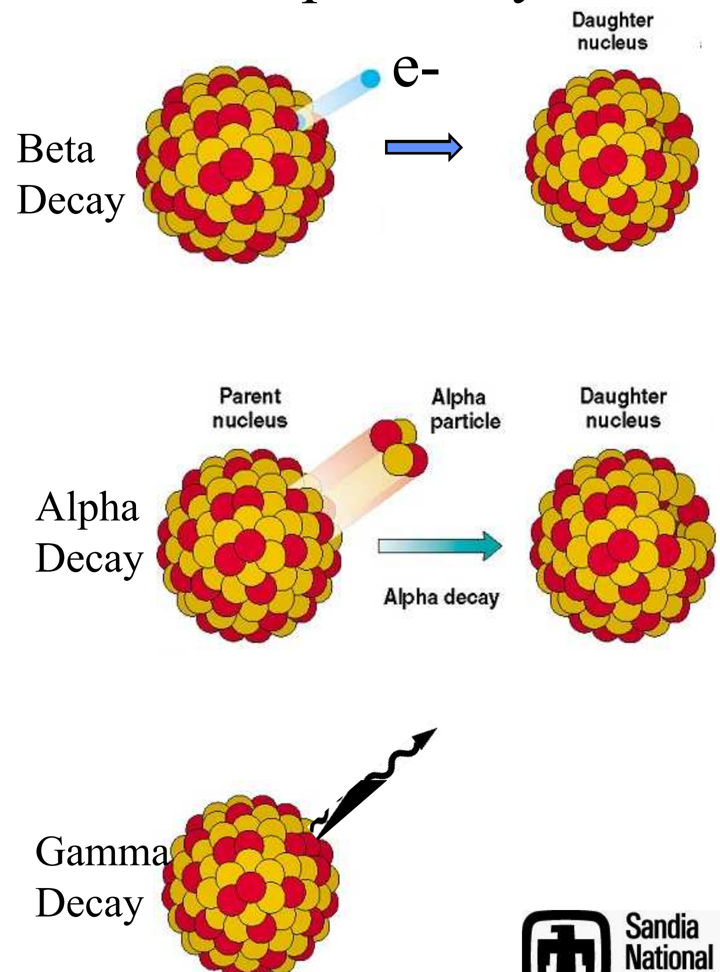
Review: What are Radioisotopes?



Source: Geoff Forden, based on http://www.phy.ornl.gov/hribf/science/abc/

Example decays:



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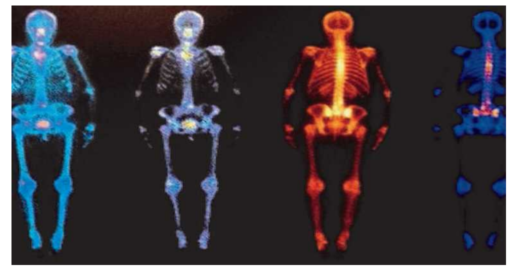
Uses of Radioisotopes:

- Medical
  - Imaging (diagnostic)
  - Cancer Treatment
- Industrial
  - Nuclear reactor start-up
  - Well Logging
  - Material/Structural Inspection
  - Elemental Composition Determination
  - Sterilization
- Research
  - From Basic to Applied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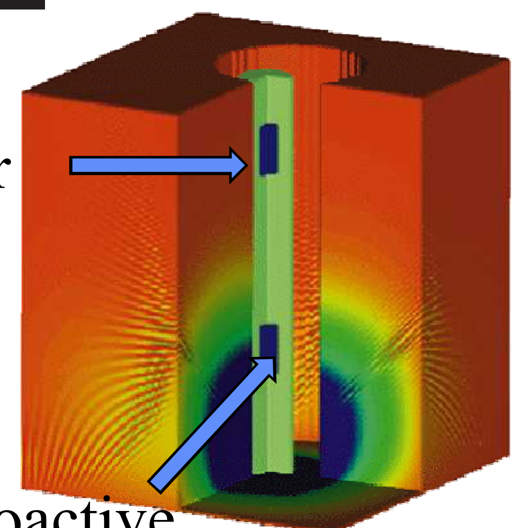

Source: https://computation.llnl.gov/casc/well_log/NWL.html

* Image source: SNL, https://ip.sandia.gov/files/files/u146/of1020_Medical_Isotope_Data_Sheet_SAND_2010-1108P.pdf

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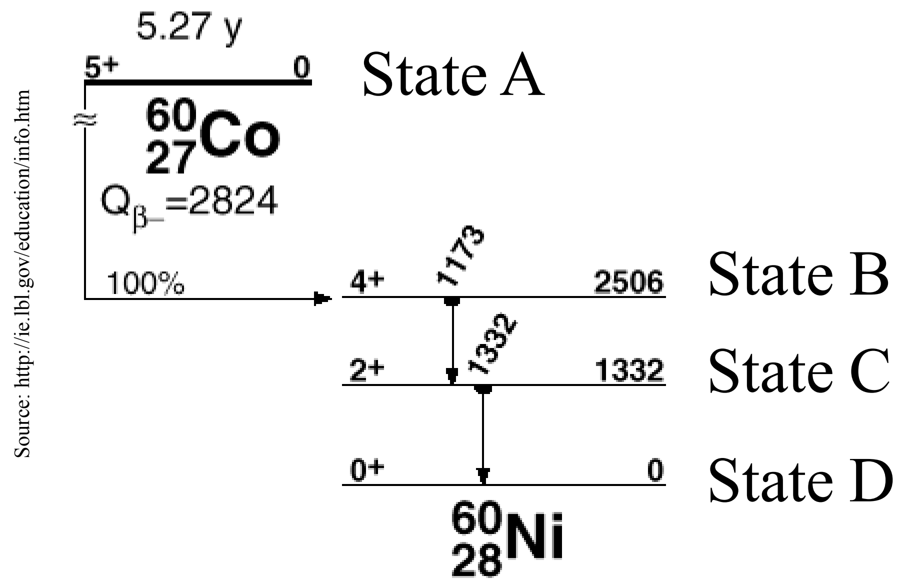
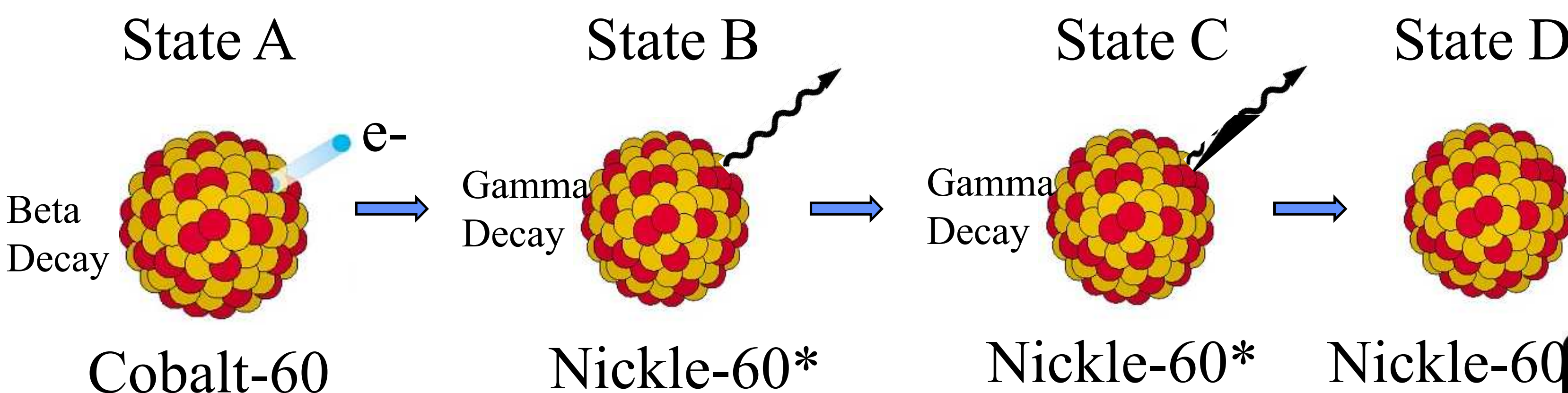
Examples of Isotope Uses: Cobalt 60 (^{60}Co)





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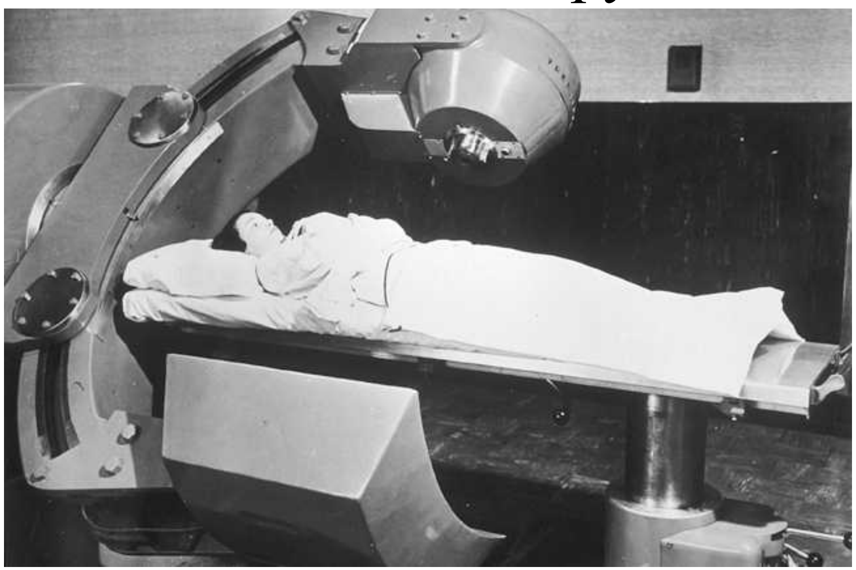
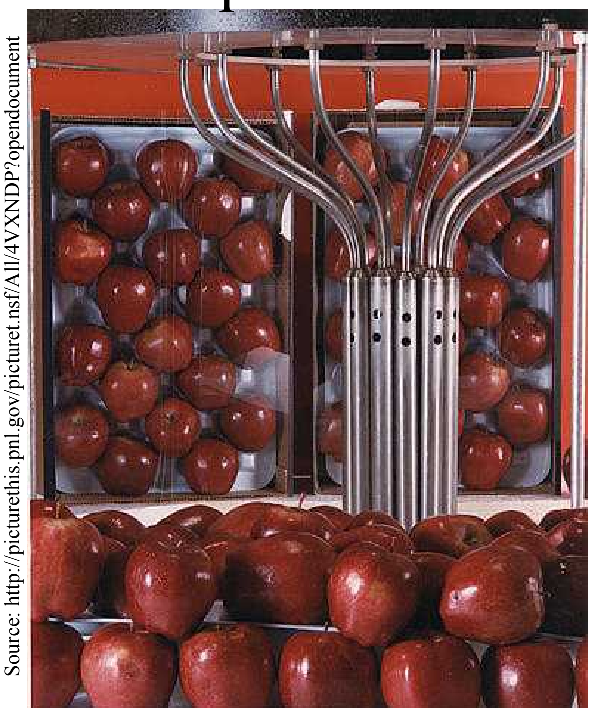
Examples of Isotope Uses: Cobalt 60 (^{60}Co)

Gamma Therapy

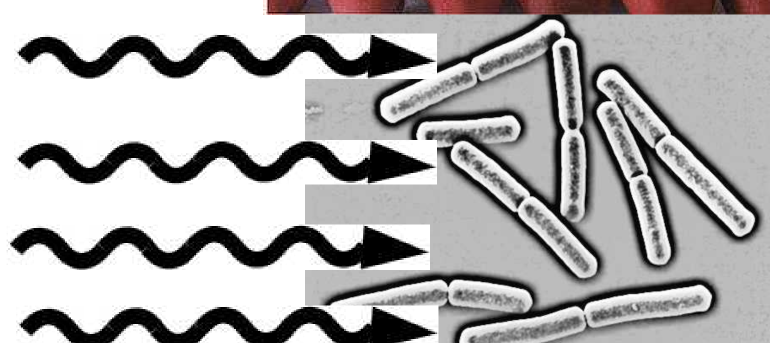


Source: http://visualsonline.cancer.gov/details.cfm?imageid=1819

Food preservation



Source: http://picturethis.pnl.gov/picturet.nsf/All/4VXNDP?opendocument



Source: http://www.nasa.gov/mission_pages/station/research/experiments/POEMS.html

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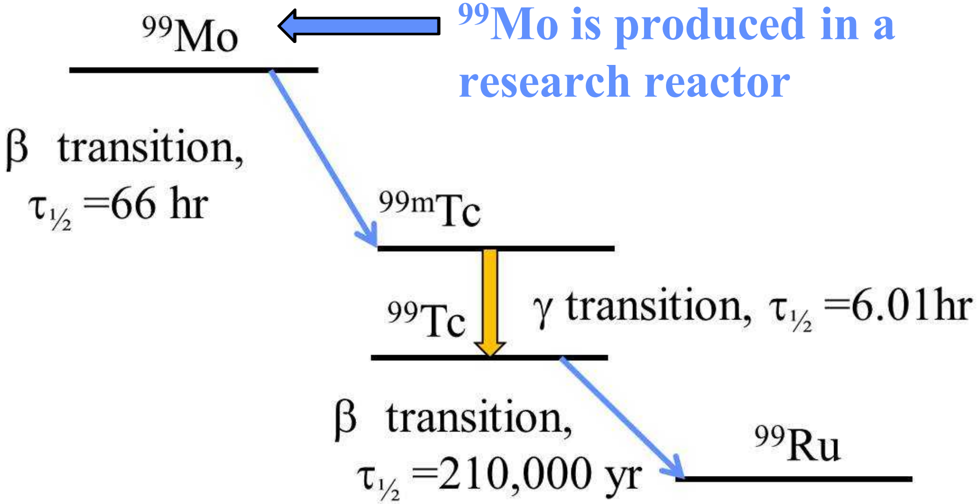
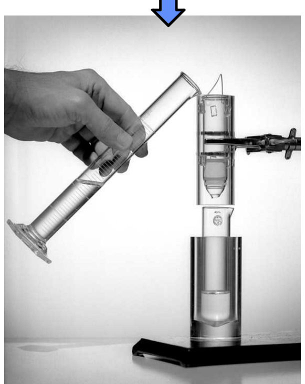
Examples of Isotope Uses: Molybdenum-99

Source: G. Forden based on information from http://www.phy.ornl.gov/hribf/science/abc



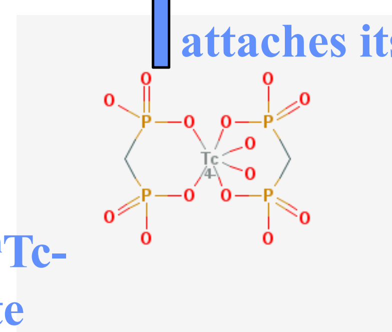
^{99}Mo is produced in a research reactor

^{99m}Tc is separated from the ^{99}Mo every 6 hours



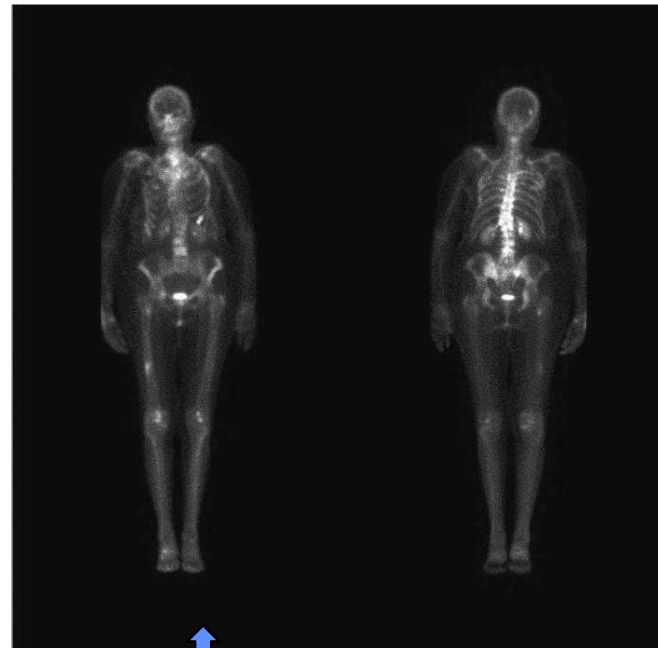
Source: http://www.bnl.gov/bnlweb/pubaf/pr/1998/bnlpr101698.html

^{99m}Tc is chemically combined to form ^{99m}Tc-Methyl diphosphonate



^{99m}TcMDP preferentially attaches itself to bone cancer.

Source: http://www.ncbi.nlm.nih.gov/books/NBK13505/figure/A8818/?report=objectonly



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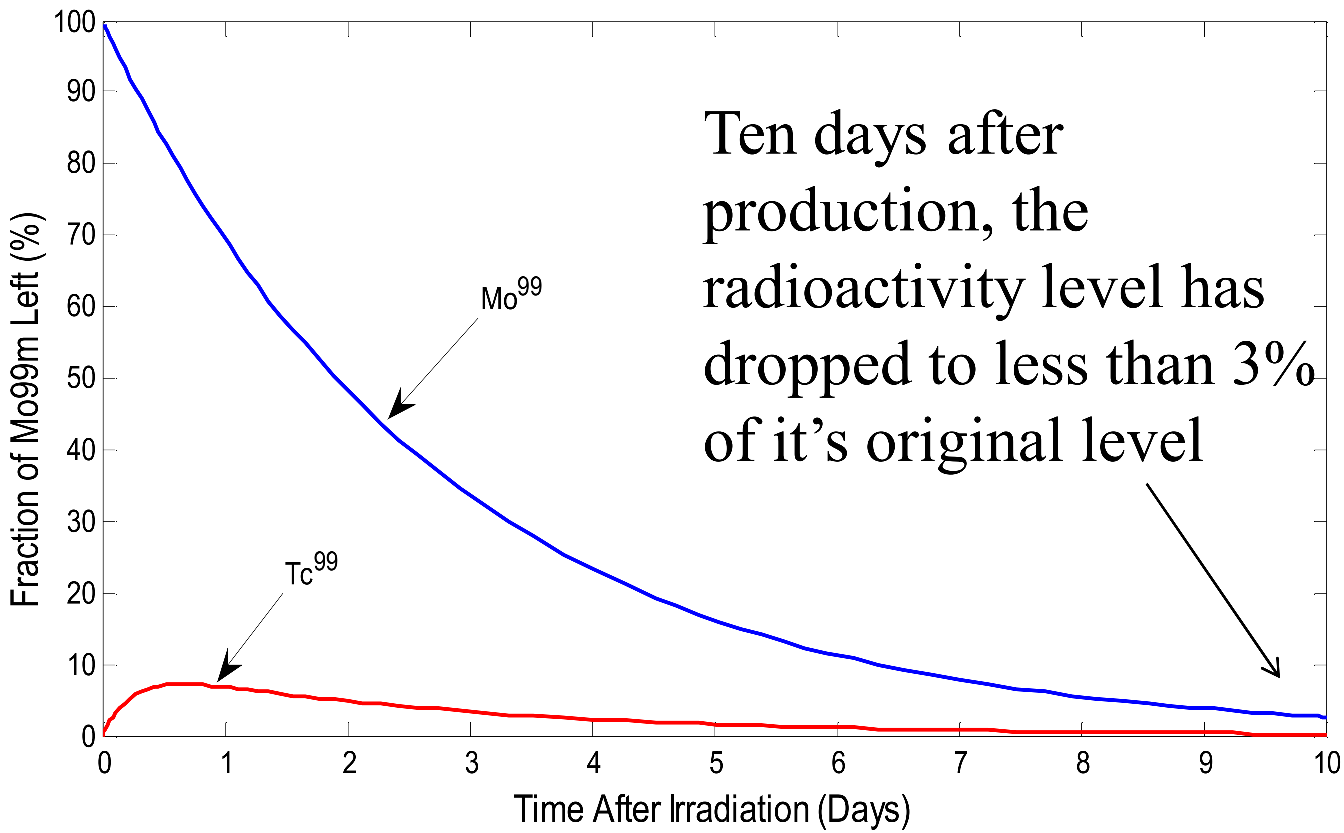
Some of these radioisotopes are very short lived:

Molbdenum-99 is a very common medical isotope—but it has a lifetime of less than 3 days



Source: G. Forden based on information from http://www.bnl.gov/bnlweb/pubaf/pr/1998/bnlpr101698.html

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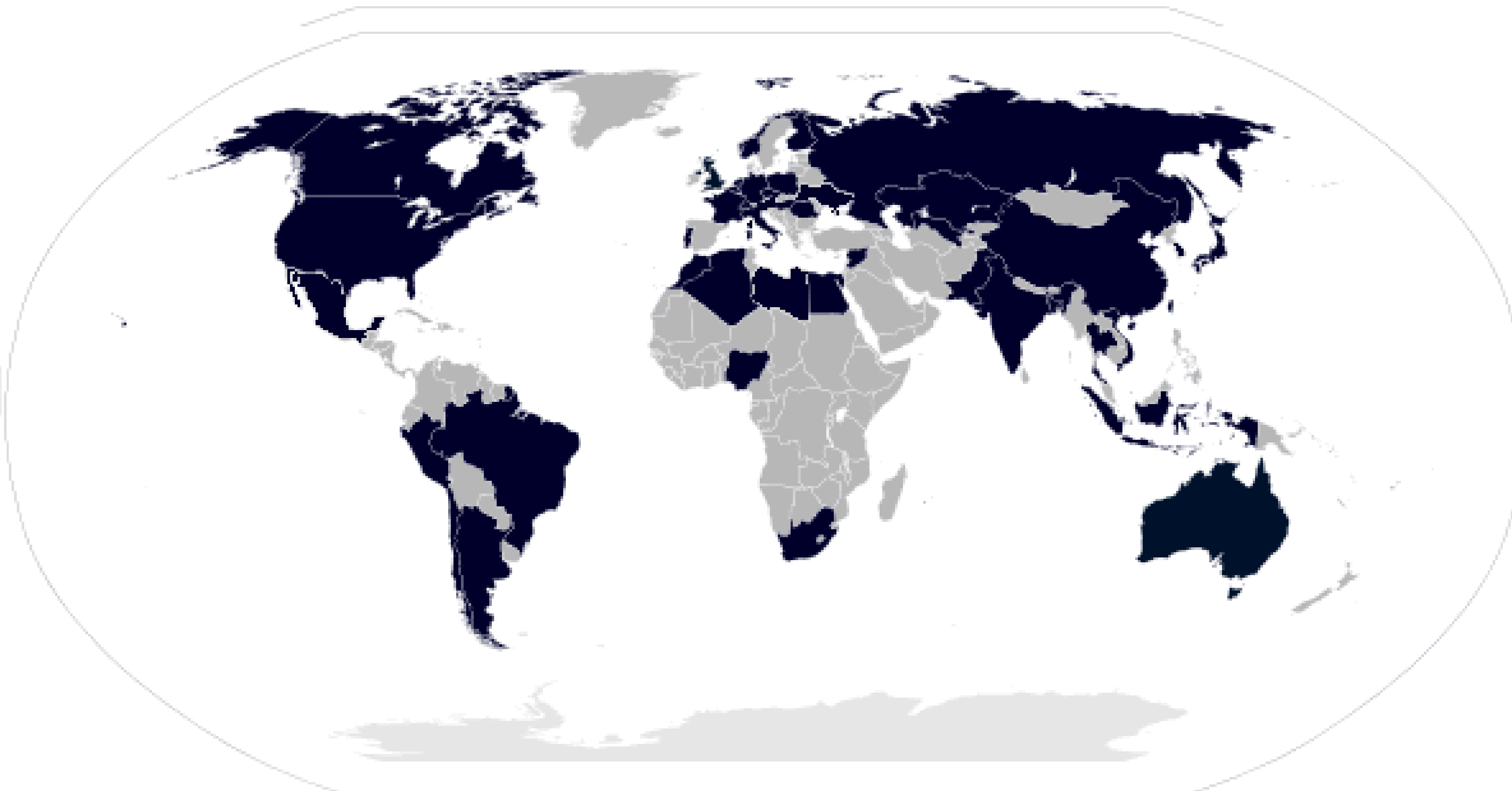
This is one of the reasons why more and more countries are starting to produce their own radioisotopes:

44 Nations have isotope production facilities using 84 reactors



Source: IAEA, http://www-naweb.iaea.org/napc/physics/research_reactors/database/rr%20data%20base/datasets/utilization/isotope_prod.html

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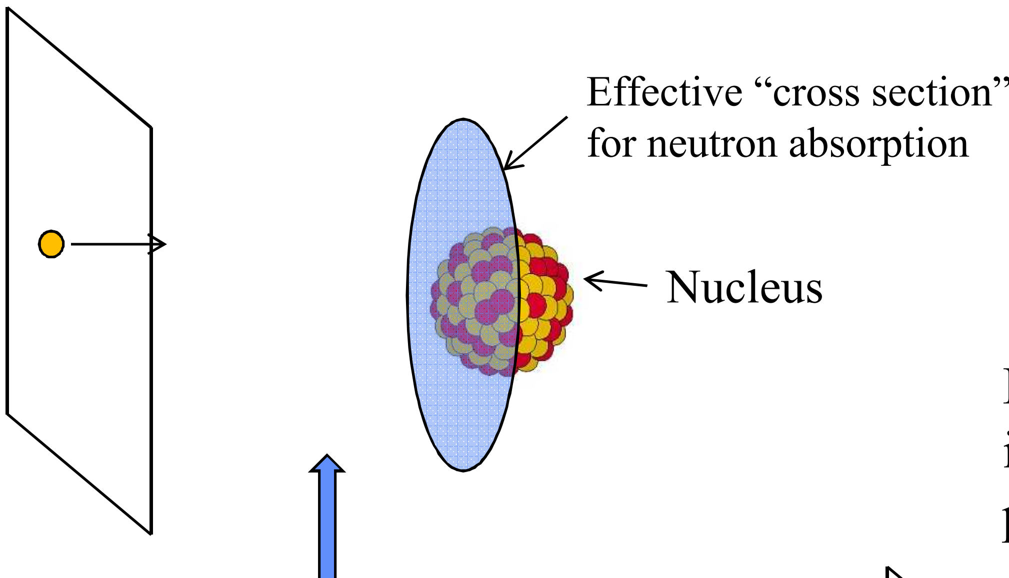
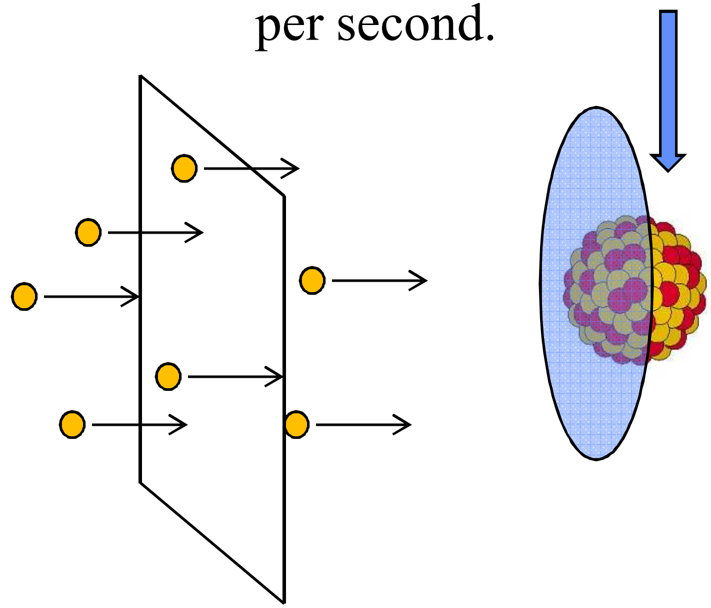
Research Reactors—with their high neutron fluxes—are ideal for producing these isotopes:



The probability of a reaction occurring is the cross section (how “big” the target is) times how many neutrons are impinging per second.

Increasing the neutron flux, increases the number of reactions per second.



Radioisotope Production: Types of Production Mechanisms

- Neutron Capture
  - $^{N}X + n \rightarrow {}^{N+1}X + \gamma$ Usually, these reactions use slow (or thermal neutrons) Also known as "(n,γ)"
    - Example: $^{59}_{27}Co + {}_{0}^{1}n \rightarrow {}^{60}_{27}Co + \gamma$
  - $^{N}X + n \rightarrow {}^{N+1}X + \gamma \rightarrow {}^{N+1}Y + \beta$ Here the final product, ^{N+1}Y, can be separated out chemically. Here too thermal neutrons are mainly used. Also known as "(n,γ) ➔ β"
    - Example: $^{130}_{52}Te + {}_{0}n^{1} \rightarrow {}^{131}_{52}Te^{*} + \gamma$

      $^{131}_{52}Te^{*} \rightarrow \beta^{-} + {}^{131}_{53}I$
  - $^{N}X + n \rightarrow {}^{N+1}X + \gamma \rightarrow {}^{N+1}Z + p$ These reactors usually use "fast" neutrons; neutrons with more energy than some threshold
    - Example: $^{58}_{28}Ni + {}_{0}n^{1} \rightarrow {}^{58}_{27}Co + {}_{1}p^{1}$

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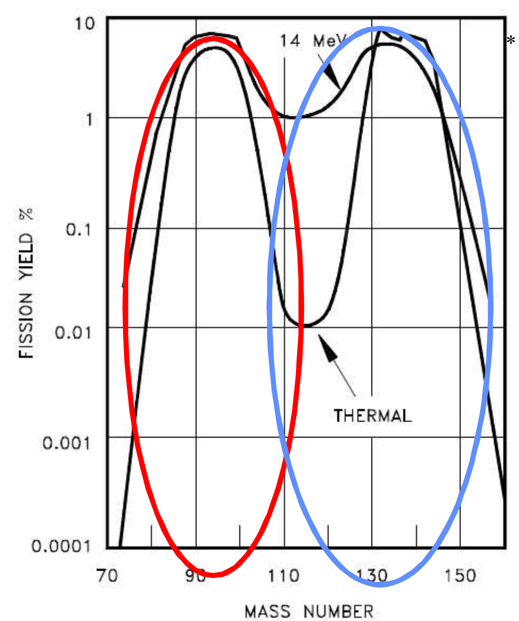
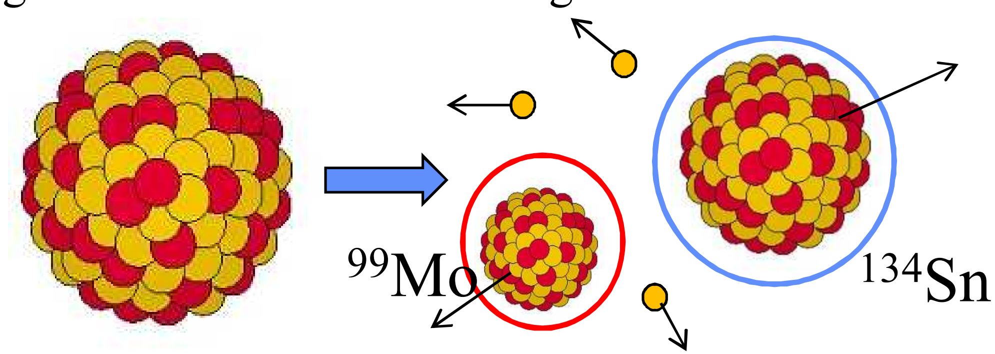
Isotope production reactions (continued)

- Neutron Capture (con't)
  - Multistage reactions: repeated absorption of a neutron by the same nucleus; these require much longer irradiation times.
    - Example: $^{186}W\ (n,\gamma)\ ^{187}W\ (n,\gamma)\ ^{188}W$

- Fission Products
  - $^{235}U + n \rightarrow$ fission products + neutrons



Fissioning U nuclei break into one large and one "small" nuclei:



* Source: DOE Fundamentals Handbook: Nuclear Physics and Reactor Theory DOE-HDBK-1019/1-93

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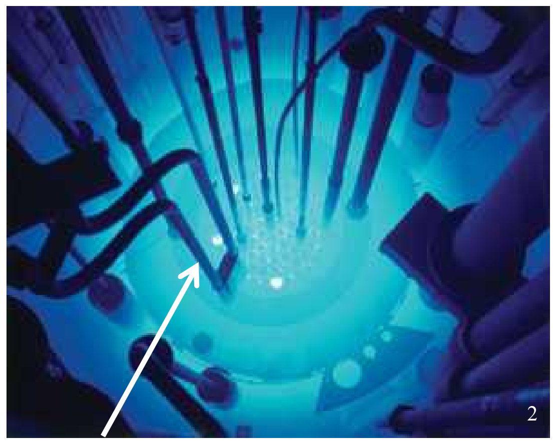
Radioisotope production/use sequence:

Package target element:

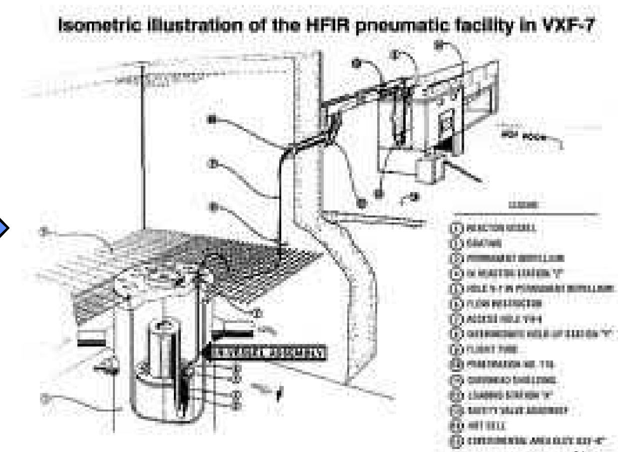
Irradiating different elements can change their physical characteristics

Irradiate target



Insert target into the core through a variety of possible channels

Transporting product



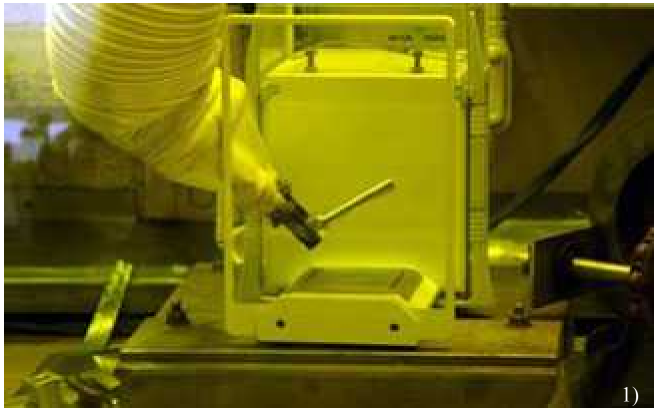
3)

The irradiated target can be transported by pneumatic tube directly from the reactor or transported in a canister (by hand)

1) http://www.ornl.gov/ornlhome/print/feature_print.cfm?FeatureNumber=f20101228-04;
2) https://www.llnl.gov/str/Dec07/libby.html;
3) neutrons.-ornl.-gov/-facilities/-HFIR/-experiment.-shtml

Radioisotope production/use sequence (con't):

Processing irradiated targets



Quality Control of product

Proper disposition of waste produced

Image sources: 1) https://inlportal.inl.gov/portal/server.pt?open=514&objID=1269&mode=2&featurestory=DA_62145
2) http://troopers.ny.gov/forensic_science/Lab_Sections/TOXICOLOGY/
3) http://www-naweb.iaea.org/napc/physics/research_reactors/database/rr%20data%20base/datasets/utilization/isotope_prod.html
4) http://www.etec.energy.gov/history/Major-Operations/Support-Ops/RMHF-History.html

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Radioisotope production/use sequence (con’t):

Package produced source

Use of radioactive sources

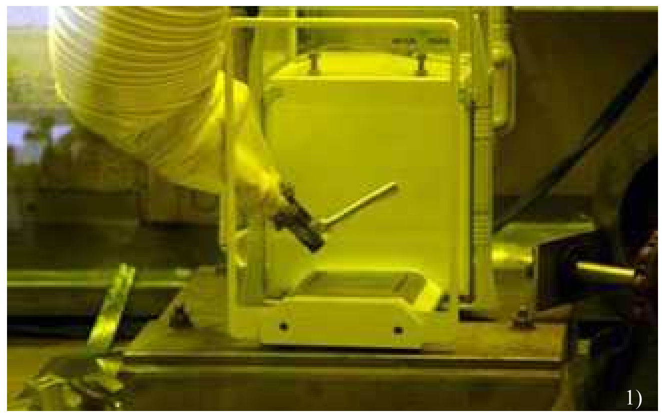
Take back/recovery of old radioactive sources

Unless radioactive sources are properly disposed of they can end up in society and harm people

1) http://www-naweb.iaea.org/napc/physics/research_reactors/database/rr%20data%20base/datasets/utilization/isotope_prod.html
2) http://radioisotopes.pnnl.gov/about.stm
3) http://www.arb.ca.gov/cap/manuals/cntrldev/baghouse/301baghouse.htm
4) http://www.epa.gov/rpdweb00/source-reduction-management/sources.html

An <u>independent</u> regulatory agency helps keep all <u>these steps Safe, Secure, and Safeguarded.</u>

Is the reactor being run in a safe and secure fashion? Is it fulfilling its international obligations?



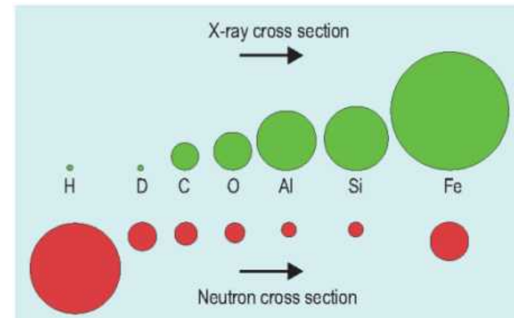
Is the production facility properly ventilated? Are the operators properly trained?

Are the end users licensed? Do they regularly account for their sources?

1) https://inlportal.inl.gov/portal/server.pt?open=514&objID=1269&mode=2&featurestory=DA_62145
2) https://www.llnl.gov/str/Dec07/libby.html
3) http://www.epa.gov/rpdweb00/source-reduction-management/sources.html

Production Details and Reactor Parameters

http://www.ncnr.nist.gov/AnnualReport/FY2003_html/RH2/

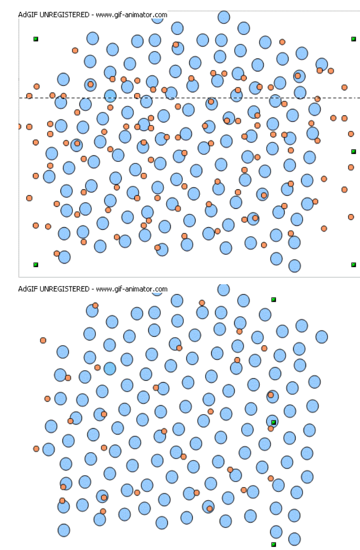


Things that effect the production of radioisotopes:

- The “cross section” for the reaction—how likely the reaction is to happen

- The neutron flux—how many (thermal) neutrons are in the reactor at any given moment

- The amount of material in the target/time spent being irradiated



Source: G. Forden

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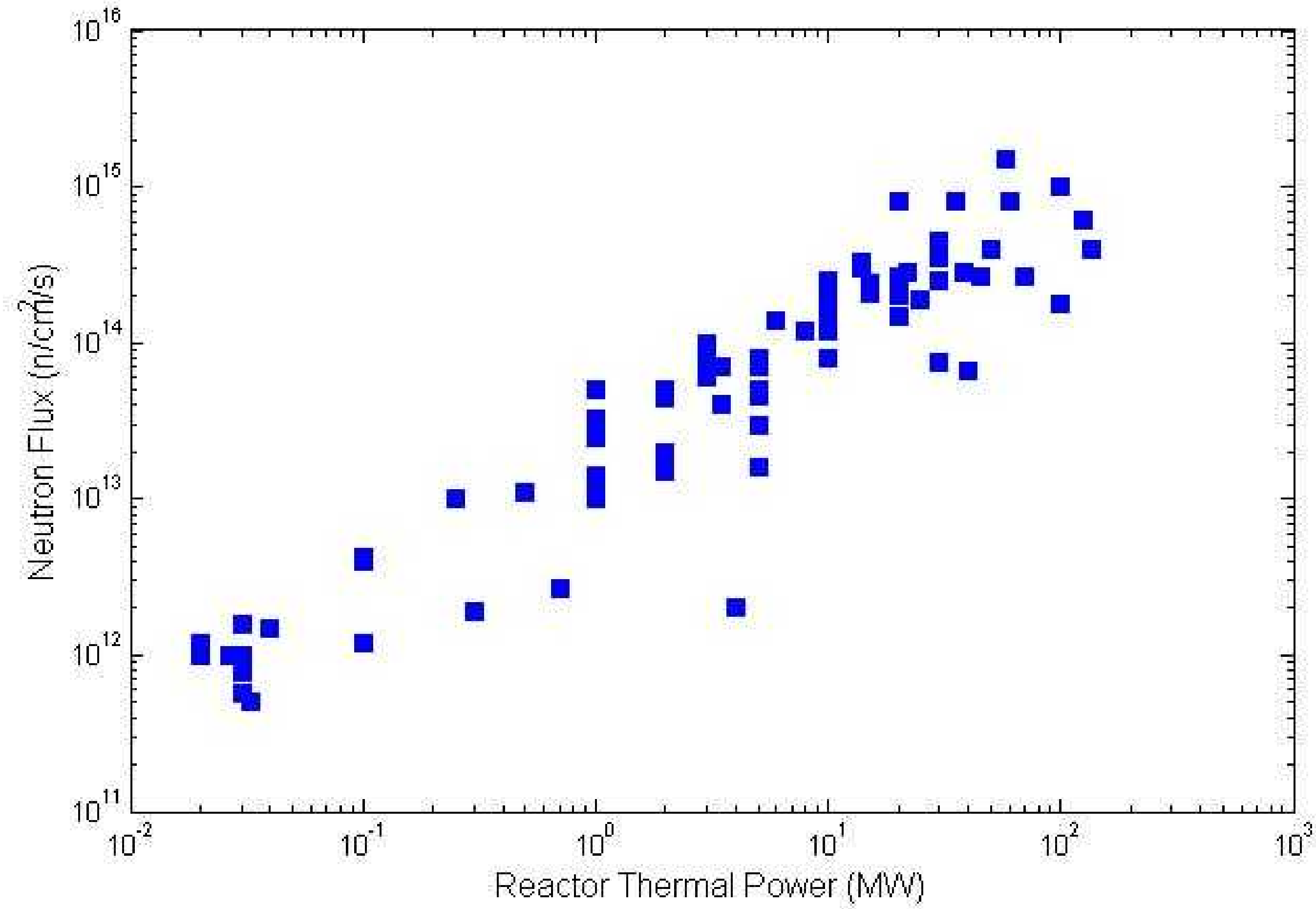
Many things influence the neutron flux: Reactor Power



Source: G. Forden, based on data at http://nucleus.iaea.org/RRDB/RR/ReactorSearch.aspx?rf=1

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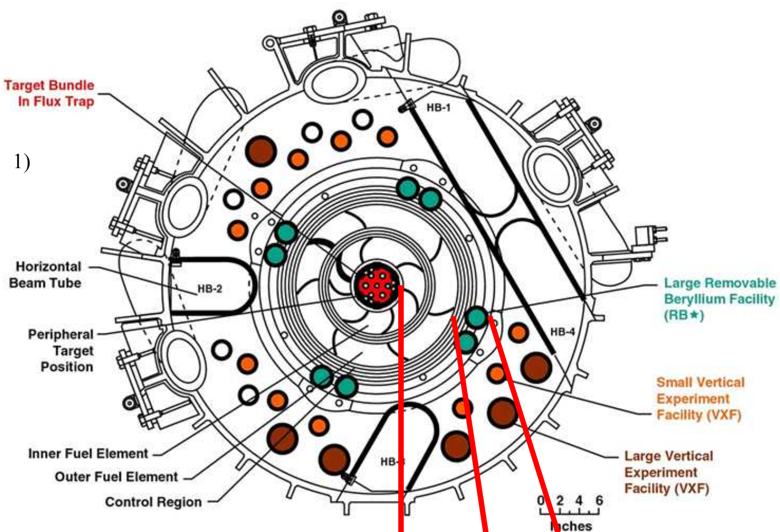
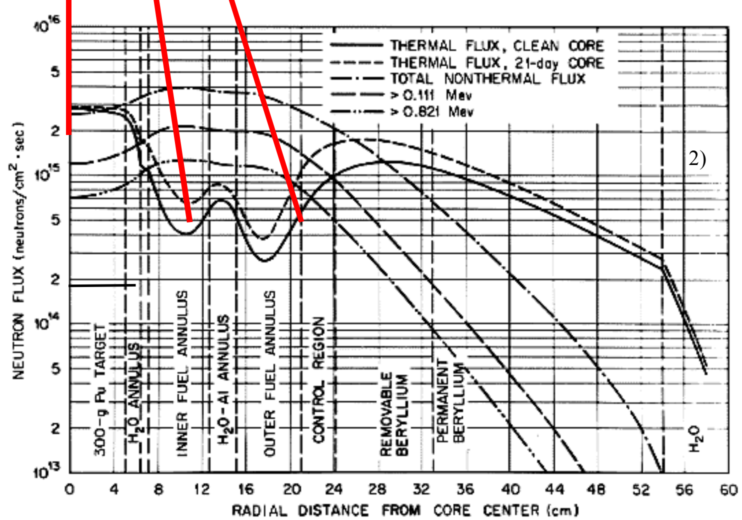
Many things influence the neutron flux: Position inside the core

1)



The highest flux occurs at the center of the core, but this is fairly small and the number of targets you can place there is low.



2)

1) http://www.ornl.gov/~webworks/cppr/y2001/pres/124343.pdf; 2) http://www.ornl.gov/sci/rrd/images/hfir6.gif

For a given production reaction…

…an equilibrium is established between production and decay of the desired isotope:

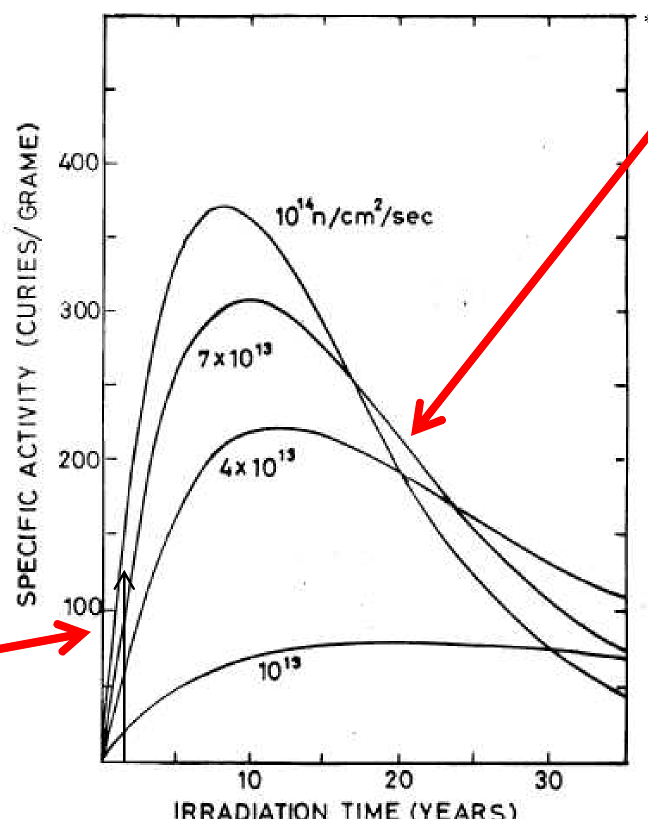
Example:

$^{59}Co + n \rightarrow {}^{60}Co + \gamma$

^{60}Co has a lifetime of 5.3 yr

Argentina's reactor, with a flux of 2×10^{14}, is used to irradiate for 18, 24, or 36 months.

For times very small compared to the lifetime of the product, the specific activity increases almost linearly with flux.



The remaining ^{59}Co (nuclei that have **not** been transmutated) are starting to disappear and those ^{60}Co that have been reduced are decaying.

* Source: IAEA-TECDOC-1340

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Considerations before starting a radioisotope production program:

- Economics of indigenous production
  - Does it make sense to import or produce (medical/industrial) isotopes indigenously?
  - Are there local industries that might use radioisotopes?
    - Outreach programs to educate local industries on potential benefits of radioisotopes

- Human capabilities and infrastructure
  - develop the human infrastructure to produce and use radioisotopes

Questions?

Thank you for your attention!