Target Design, Cooling, and Diagnostics for Electron Accelerator Production of ^{99}Mo

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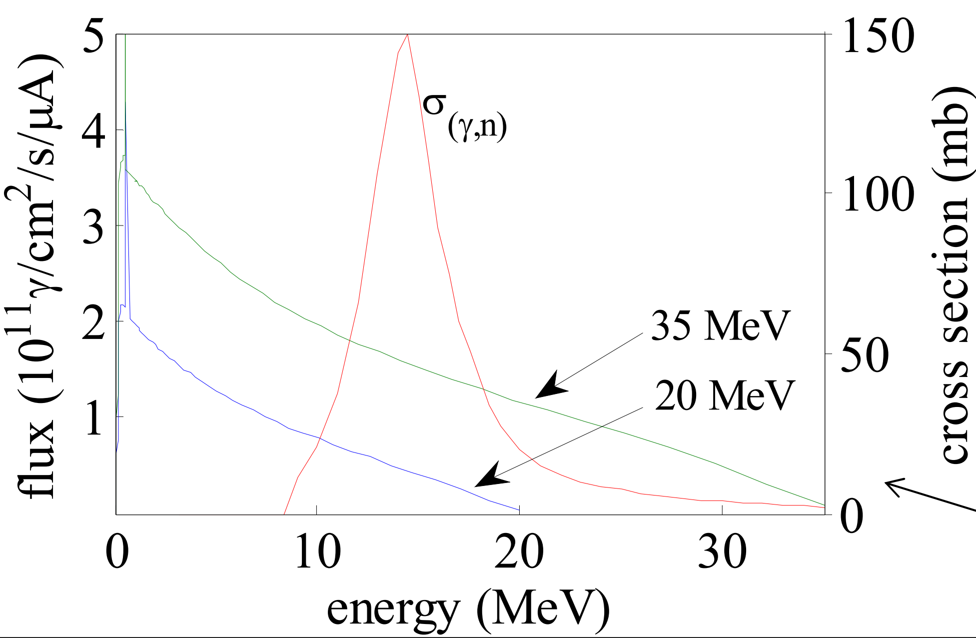
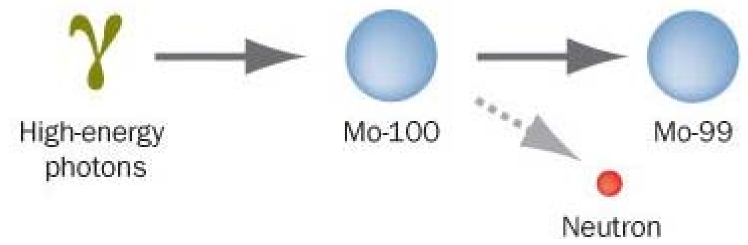
Proof of Concept Demonstrations for Electron Accelerator Production of ^{99}Mo

- **In partnership with NorthStar Medical Radioisotopes, LANL and ANL were tasked by NNSA to help demonstrate accelerator production of ^{99}Mo through the $^{100}Mo(\gamma,n)^{99}Mo$ reaction.**
  - The threshold for the reaction is 9 MeV.
  - The peak cross section is 150 mb at 14.5 MeV.
- **High energy photons are created with a high power electron beam through bremsstrahlung.**





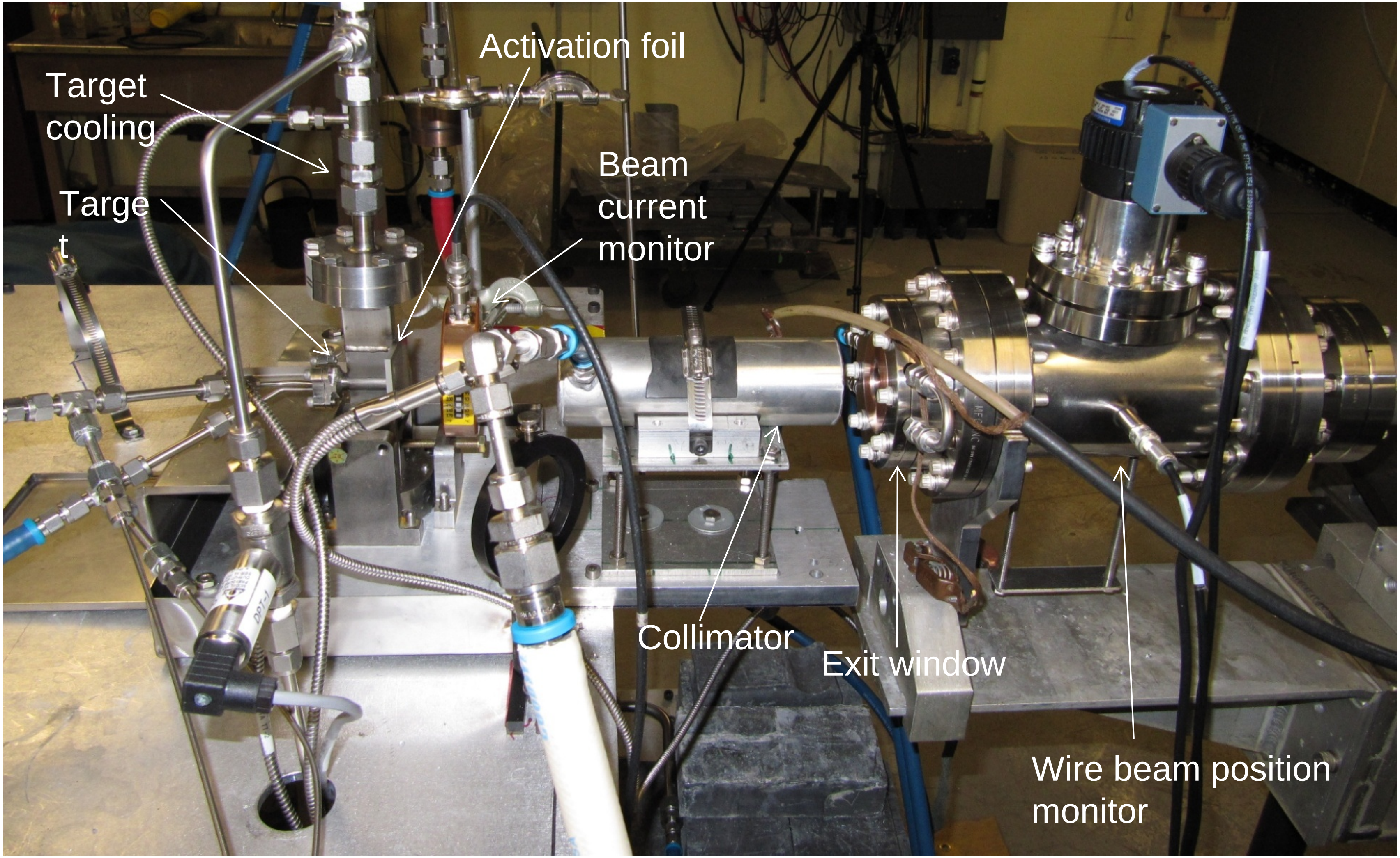
Average bremsstrahlung photon spectra produced with 20- and 35-MeV electron beams in a Mo target compared to the photonuclear cross section of ^{100}Mo.

Scaled Accelerator Tests at Argonne National Laboratory

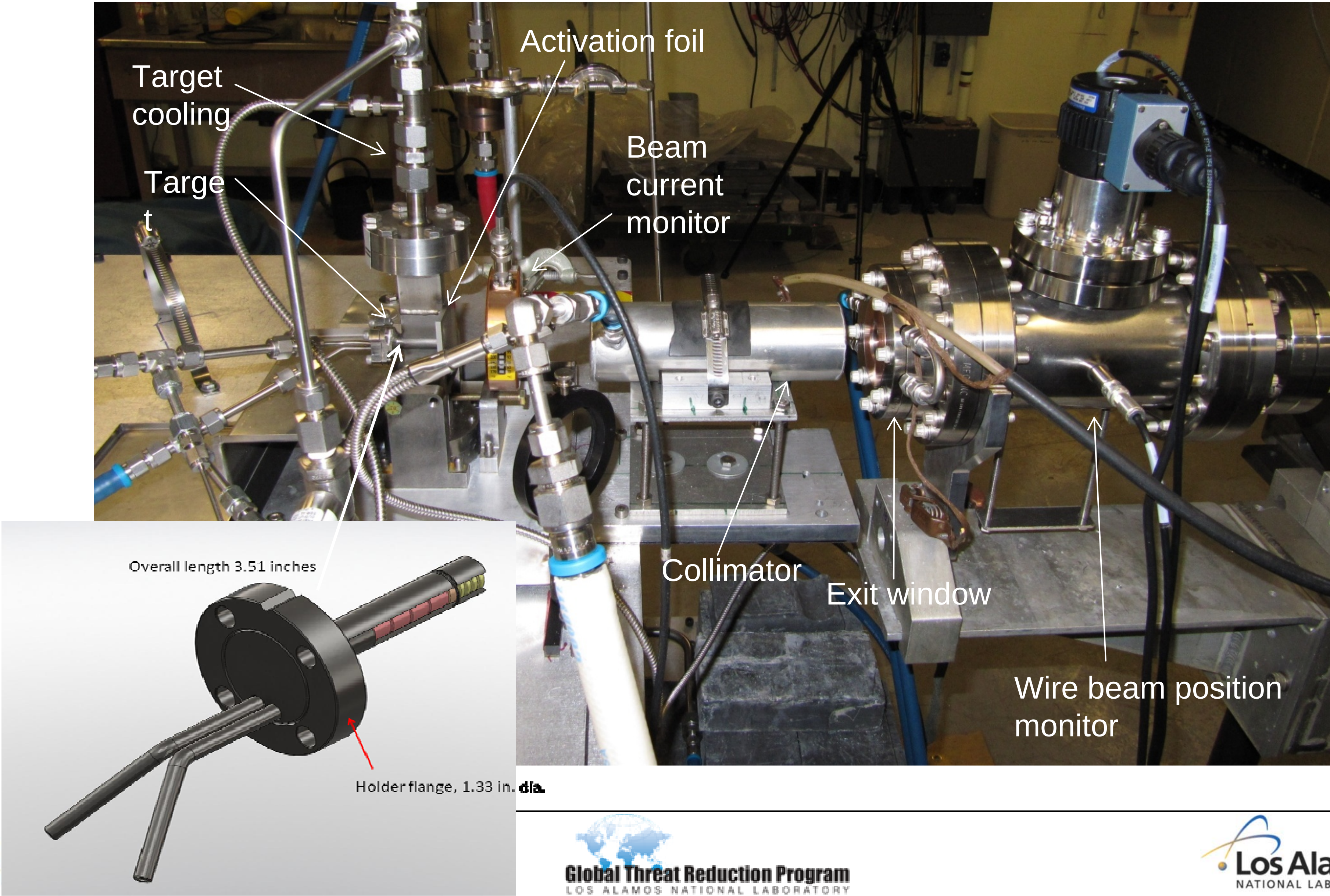
- **To test and validate the accelerator production process, including the performance of the ARSII generator, scaled production tests are being performed at the Low Energy Accelerator Facility at Argonne National Laboratory (ANL) .**

Date	Test
April 2010	Water cooled target test using natural Mo targets, produced 236 µCi of ^{99}Mo.
May 2010	Water cooled target test using natural Mo targets, produced 377 µCi of ^{99}Mo.
July 2010	Water cooled production test using enriched ^{100}Mo targets, produced 10.5 mCi of ^{99}Mo.
April 2011	Once through gaseous helium cooled thermal test using natural Mo targets, 145 µCi of ^{99}Mo.

Water Cooled Target Setup at ANL



Water Cooled Target Setup at ANL



Post Bombardment Target Processing

- **Each target was processed daily for 2 weeks following each irradiation.**
- **> 95% yields of ^{99m}Tc were observed, even though sample SA was 10^6 and 10^4 times lower than anticipated for production.**

Results of the Scaled, Low Power, Water Cooled ^{99}Mo Production Experiments

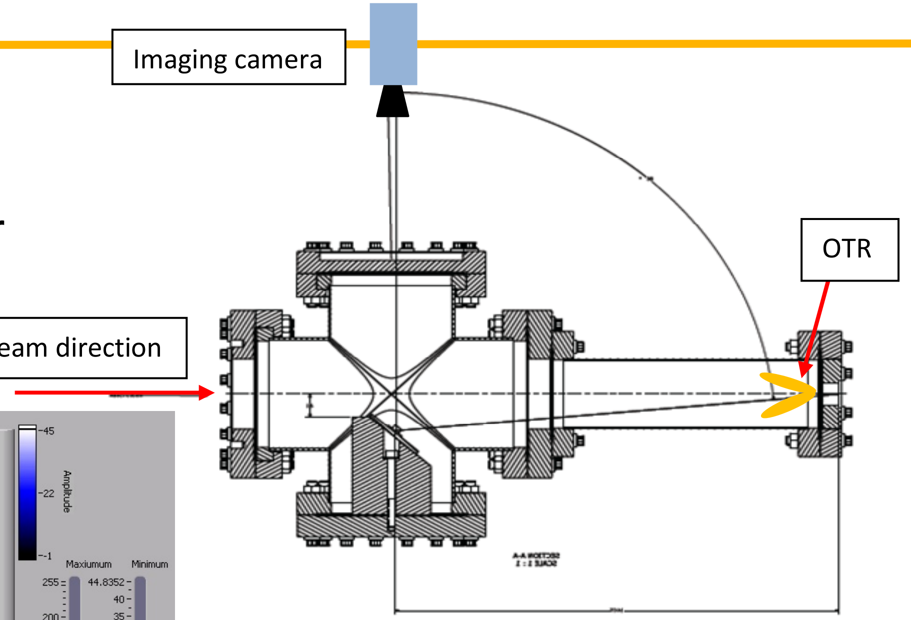
- **First low power scaled production test with natural Mo targets:**
  - Performed April 15, 2010.
  - ~ 20 minute run.
  - 20 MeV, 796 W average beam power on target.
  - Produced 236 μCi of ^{99}Mo.
- **Second low power scaled production test with natural Mo targets:**
  - Performed May 4, 2010.
  - 23 minute run.
  - 20 MeV, 804 W average beam power on target.
  - Produced 377 μCi of ^{99}Mo.
- **Low power scaled production test with enriched ^{100}Mo targets:**
  - Performed July 13, 2010.
  - 82 minute run.
  - 20 MeV, 900 W average beam power on target.
  - Produced 10.5 mCi of ^{99}Mo.

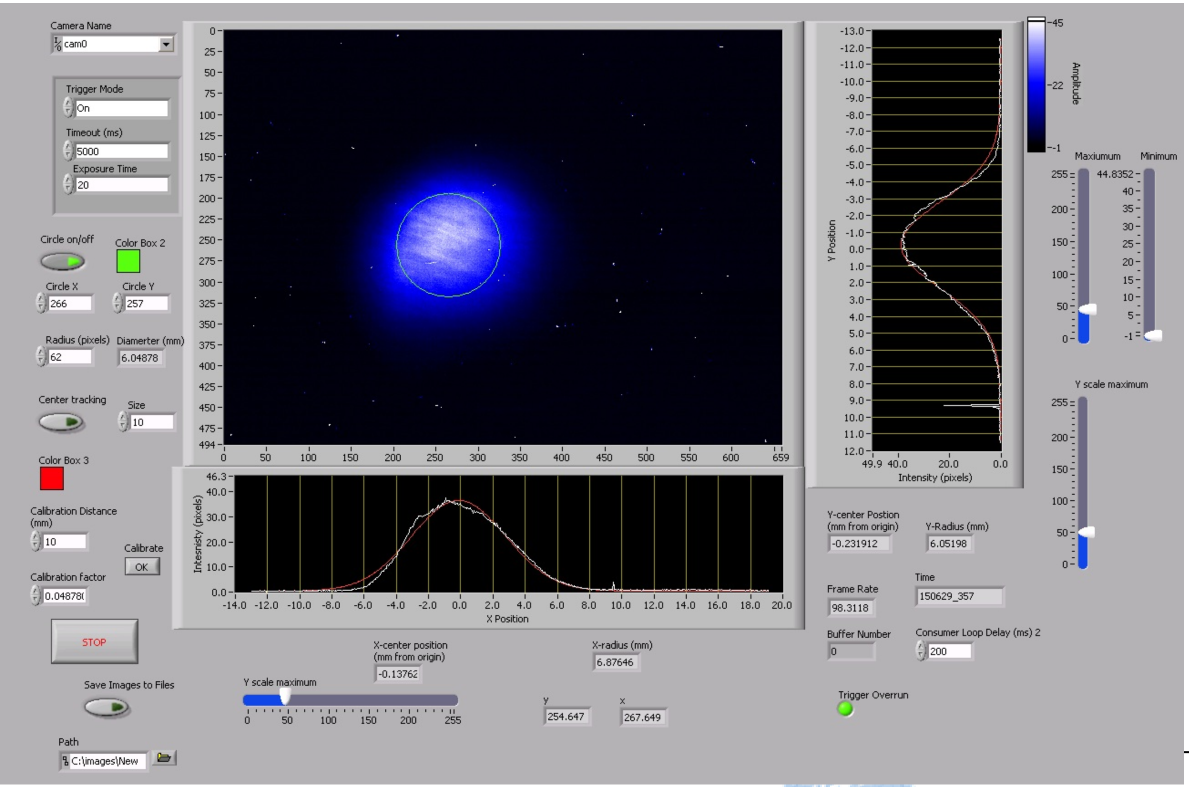
2010 Water Cooled Target Tests: Some Results and Lessons Learned

- **Successfully demonstrated the photon capture production process end to end, including the separation of ^{99m}Tc from ^{99}Mo with yields > 95%.**
- **Beam position and profile on target is a very important parameter.**
  - Need tools to aid with beam steering and focus.
  - Don't make beam steering harder than it needs to be.
- **Activated ^{99}Mo found in the water coolant after the tests.**
  - Believed that radioalysis of the cooling water was causing the formation of peroxides, which were corroding the targets.

Optical Transition Radiation (OTR) Beam Position and Profile Measurement

To address the beam steering and beam profile monitoring, LANL developed an OTR system looking at the exit window for measuring the ANL beam profile and position during the irradiation.





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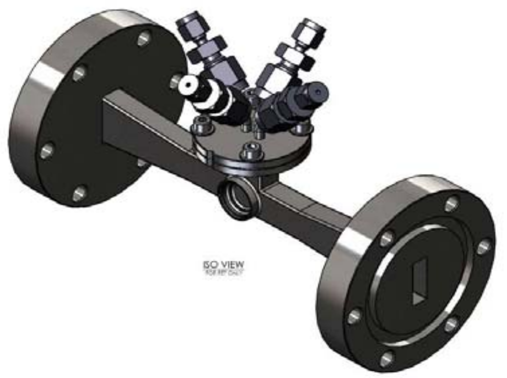
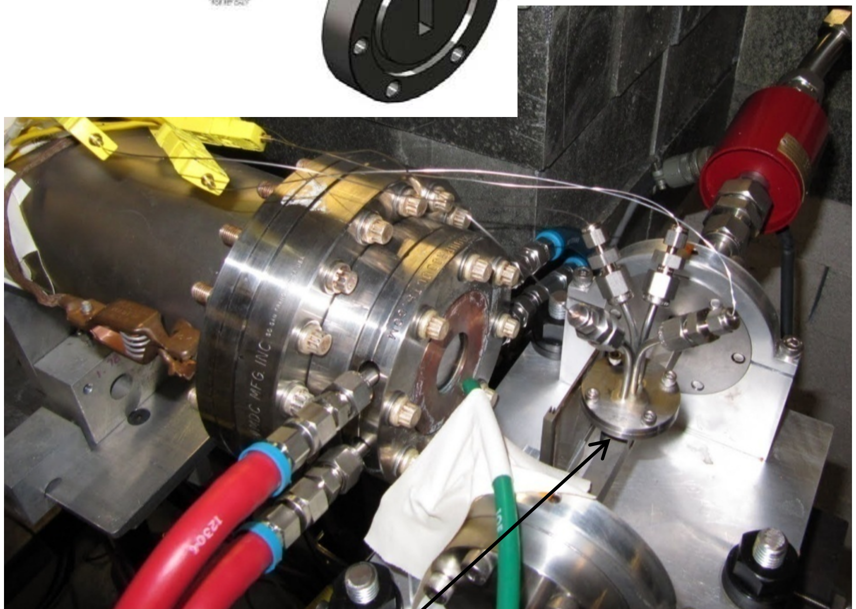
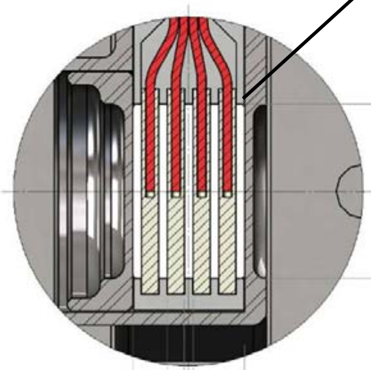
Once Through Gaseous Helium Target Cooling Experiment (April 2011)





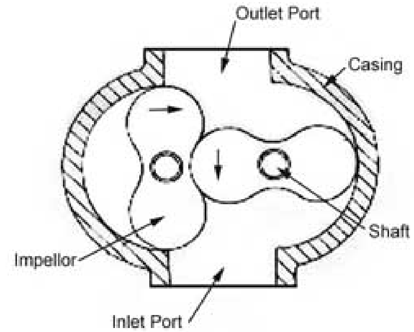
- Tested at 17 MeV and up to 10.3 kW beam power.
- Helium Velocity in the cooling channels ~ 197 m/sec.
- Target peak heat fluxes ~ 800 W/cm^2
- Determined that a goal of 1,000 W/cm^2 or more peak heat flux is within reach with gaseous He cooling.



Target assembly in the beam path holding 4 instrumented targets

Big size He bottles, about 1 minute of full power beam time per bottle

Gaseous Helium Flow Loop Using a Roots Blower

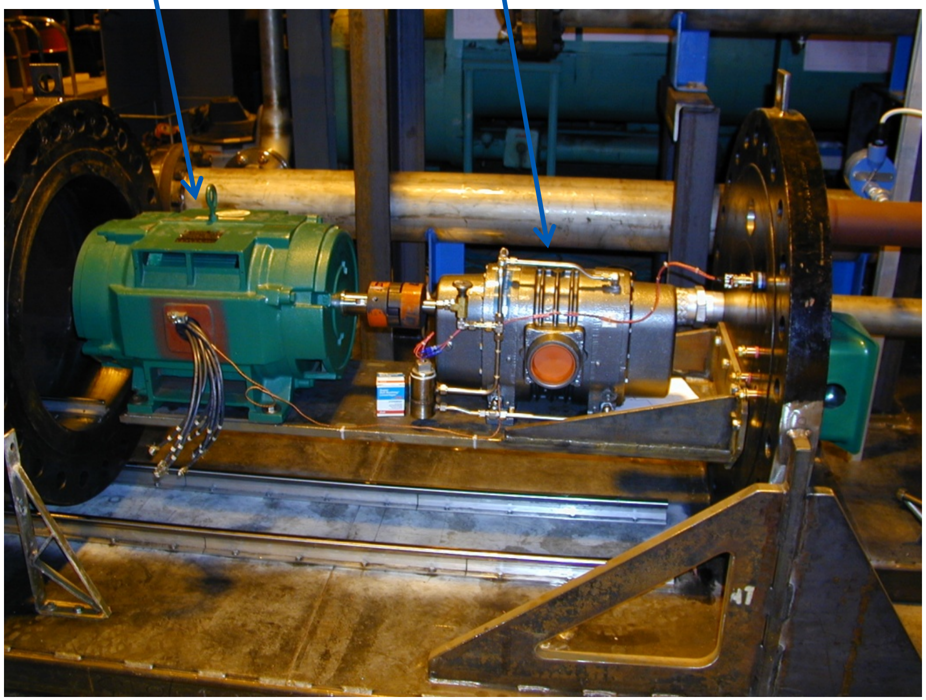


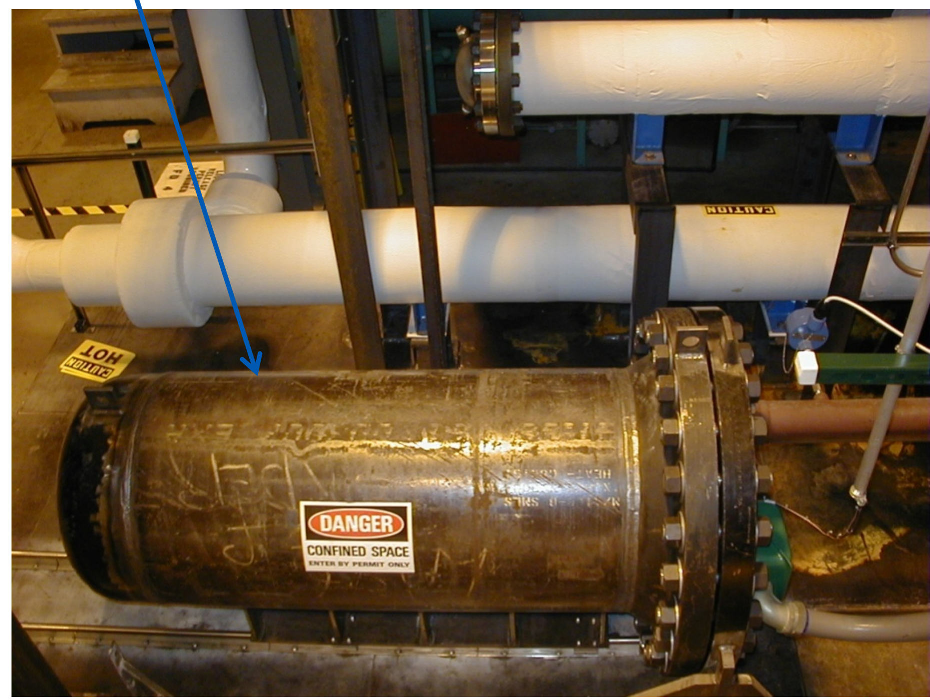
Roots Blower

Electric motor

Roots Blower

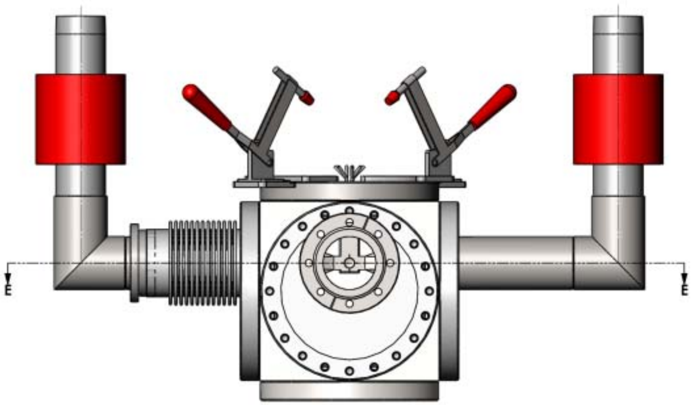
Pressure Vessel

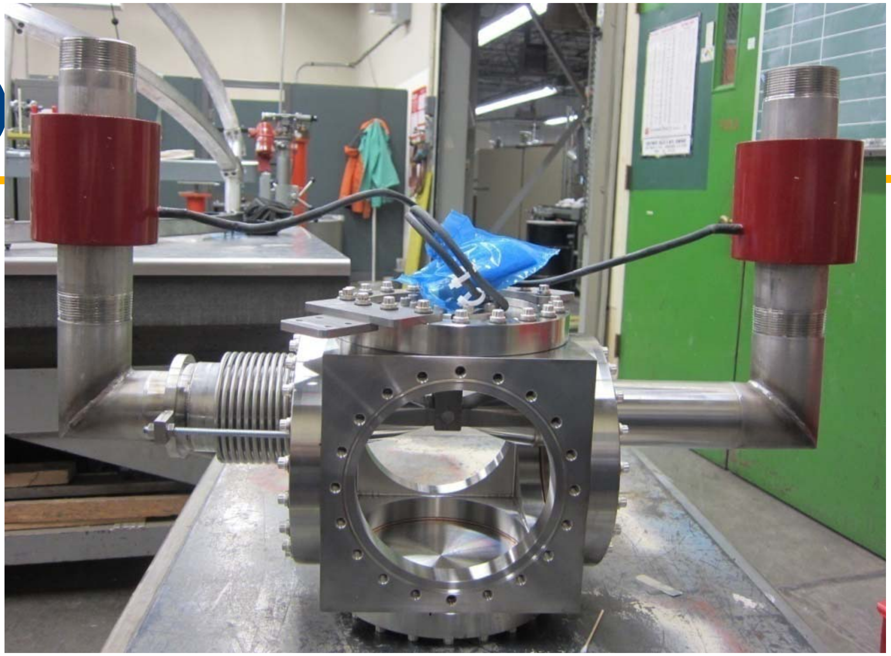




Figures from M. Kalish, et al., Fusion Engineering, 2002

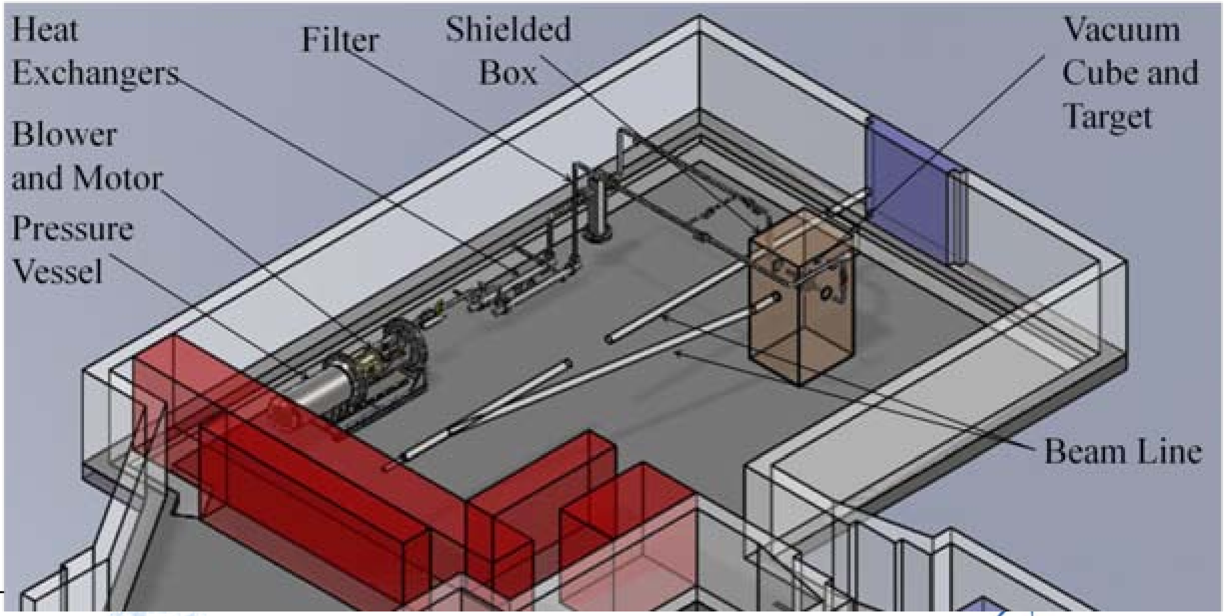
Closed Loop Gaseous He Cooling System (Spring 2012)





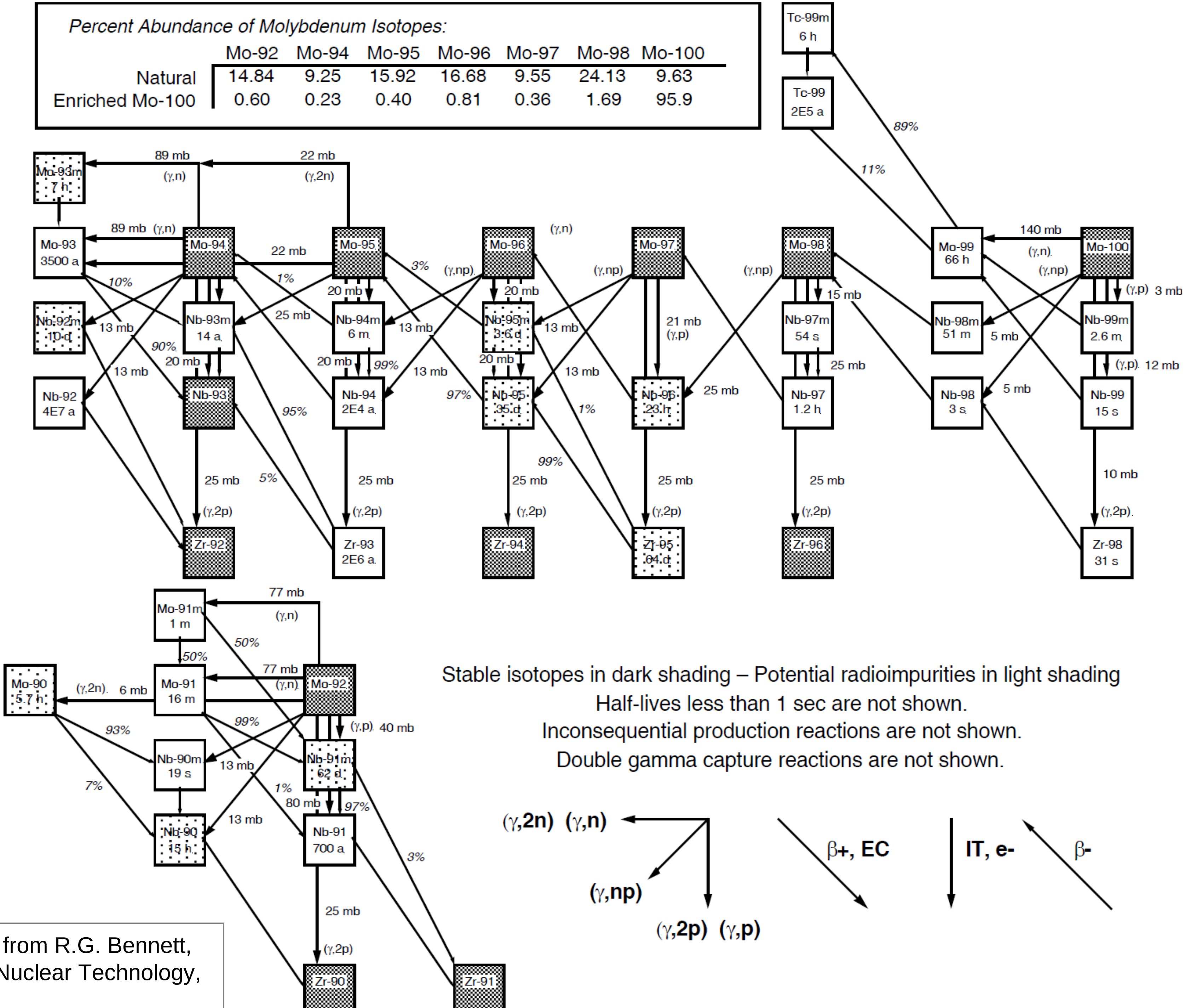
A gaseous helium flow system is being installed at ANL for tests in the spring of 2012.

The ANL accelerator is also being upgraded for higher energy and power.



Percent Abundance of Molybdenum Isotopes:

	Mo-92	Mo-94	Mo-95	Mo-96	Mo-97	Mo-98	Mo-100
Natural	14.84	9.25	15.92	16.68	9.55	24.13	9.63
Enriched Mo-100	0.60	0.23	0.40	0.81	0.36	1.69	95.9



Stable isotopes in dark shading – Potential radioimpurities in light shading
Half-lives less than 1 sec are not shown.
Inconsequential production reactions are not shown.
Double gamma capture reactions are not shown.

Figure from R.G. Bennett, et al., Nuclear Technology, 1999

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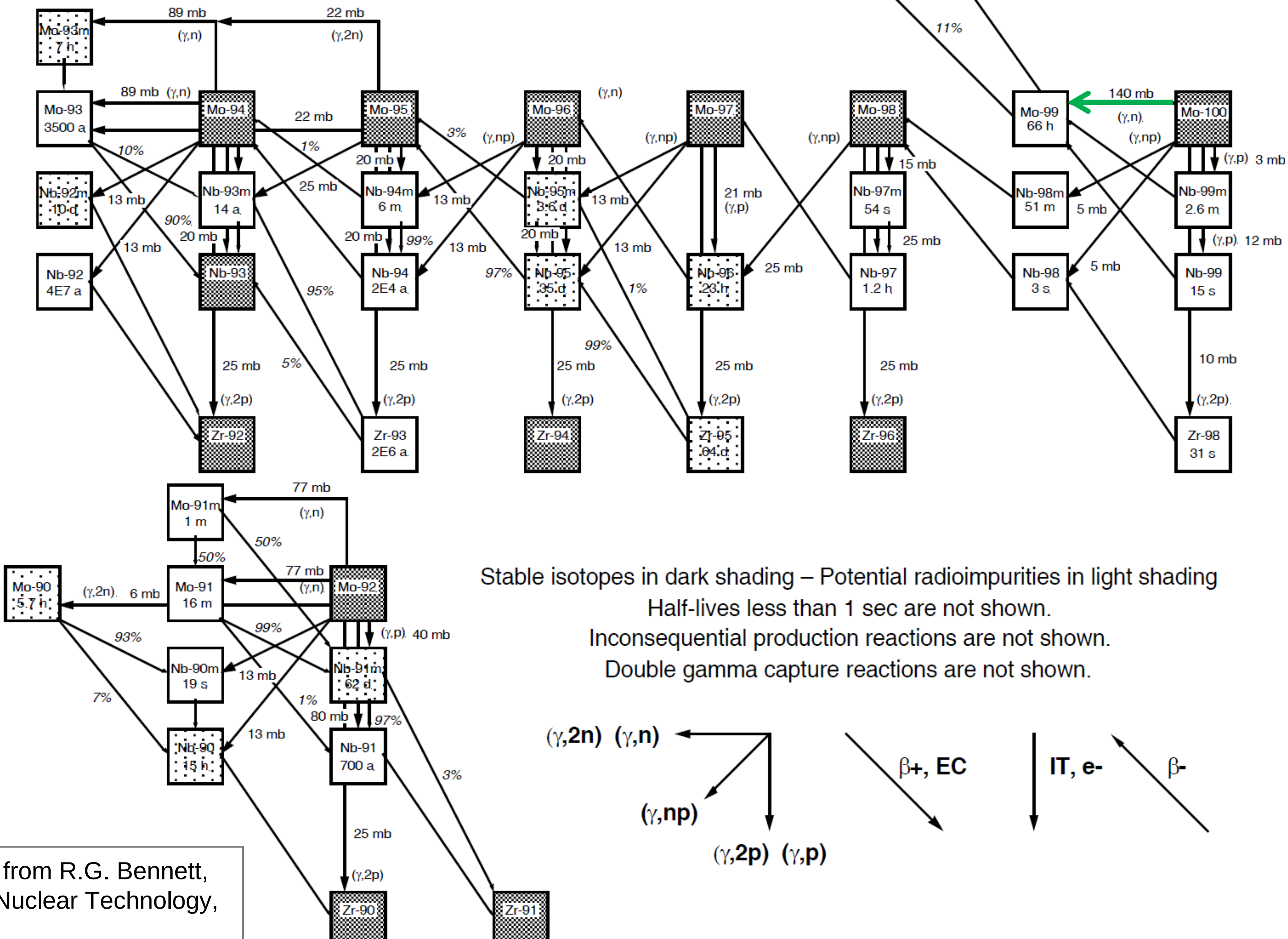

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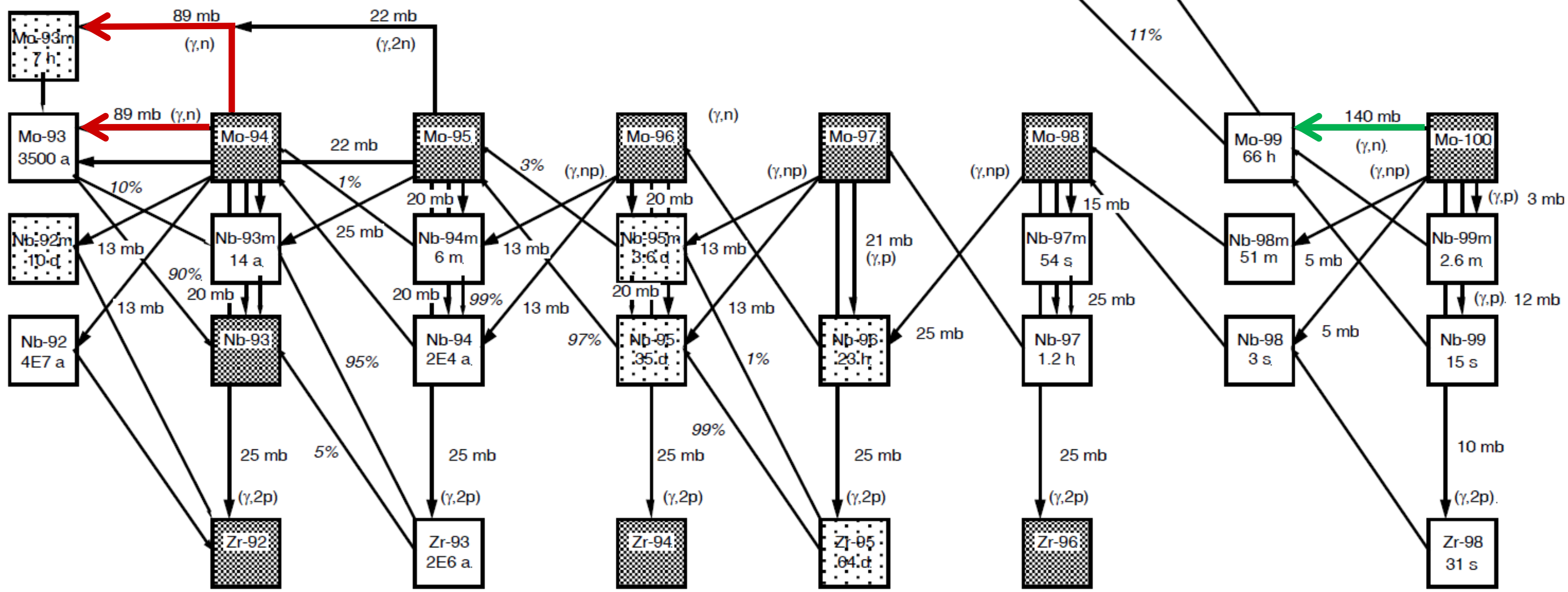

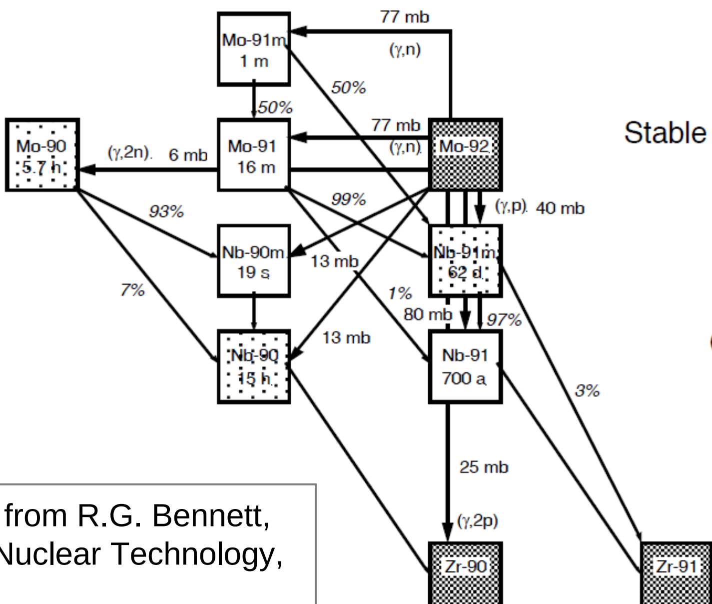

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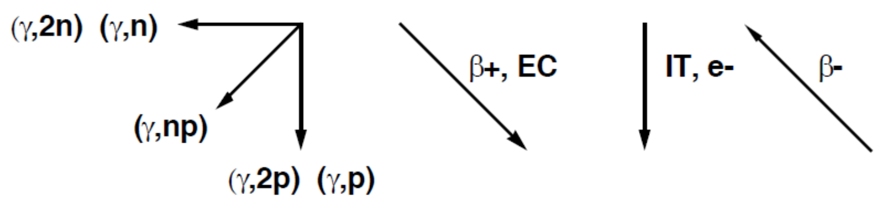

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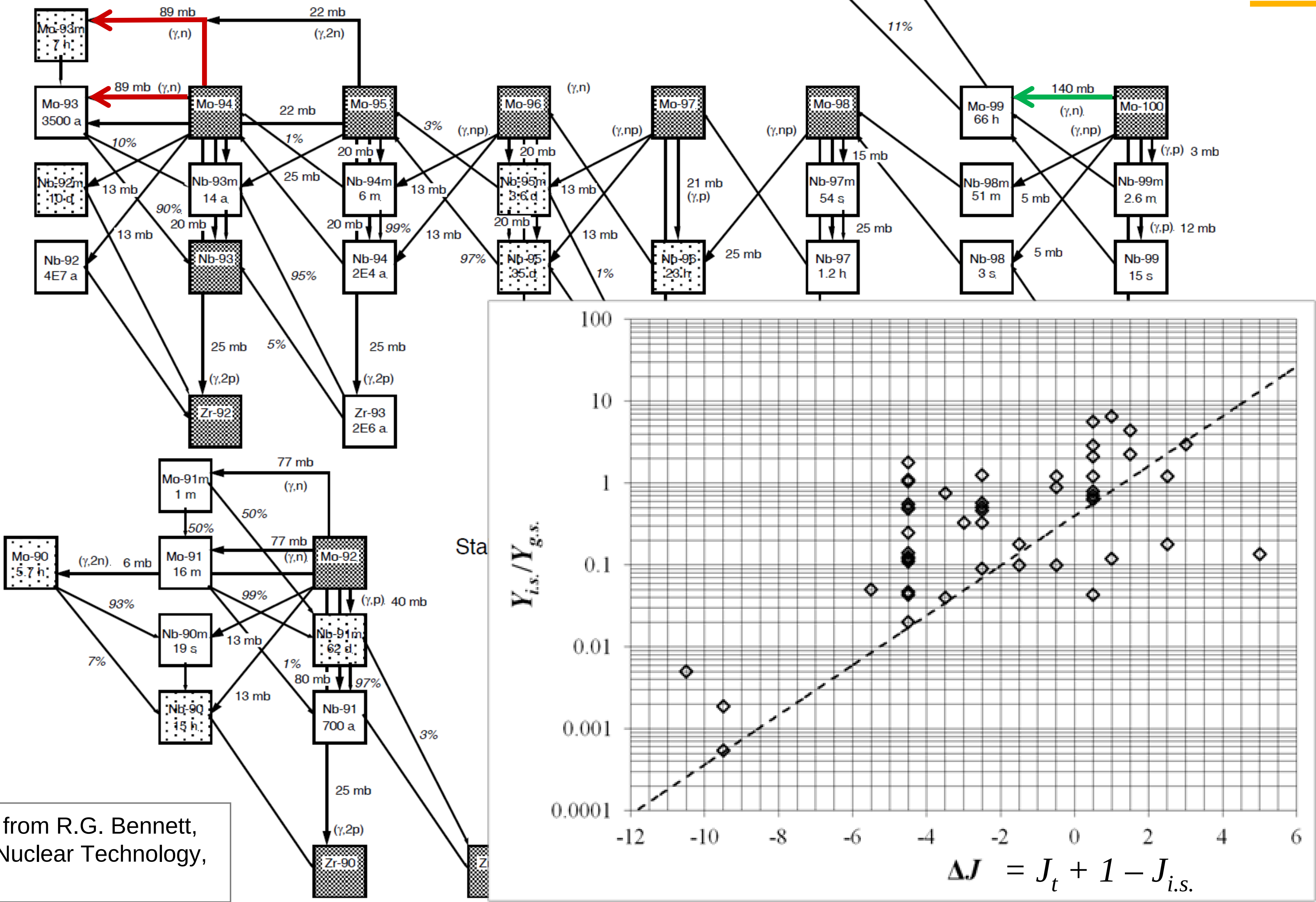

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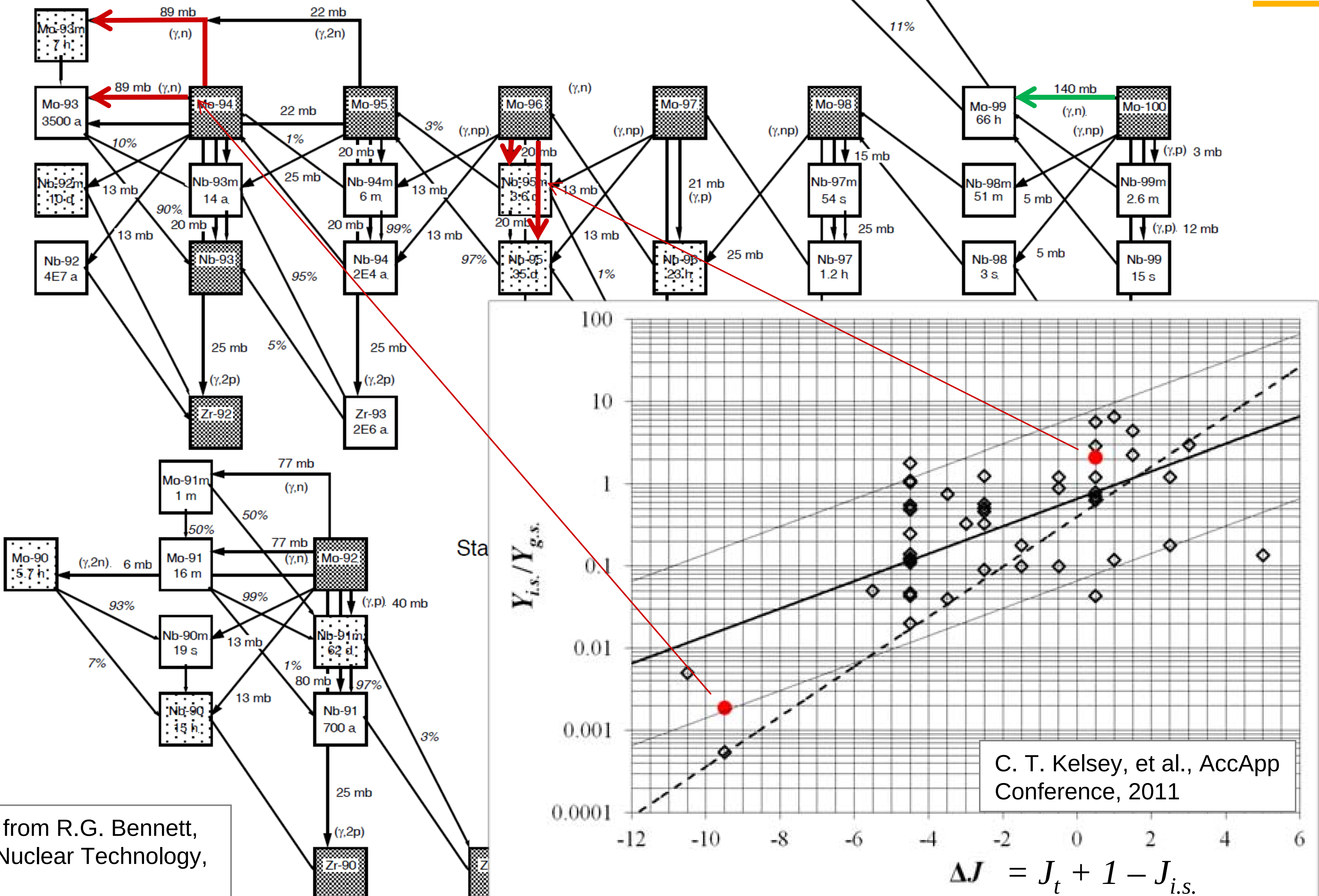

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Summary

- **Several scaled production tests have been performed using the electron linear accelerator at ANL.**
  - Natural Mo and enriched ^{100}Mo targets have been irradiated and processed using the NorthStar TechneGen Generator with ^{99m}Tc yields > 95%.
  - Gaseous helium target cooling demonstrated at production relevant peak heat fluxes.
- **Assembly of components for a gaseous helium flow loop for the ANL accelerator is currently underway.**
- **The electron accelerator is also being upgraded for higher energies and powers.**
- **LANL is developing beam diagnostics that will be useful in a production system.**
- **LANL is also measuring photonuclear cross sections relevant for photon capture production of ^{99}Mo.**