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SLOWPOKE-2

31 YEARS AND STILL GLOWING

Canadian Nuclear Society Conference

2012

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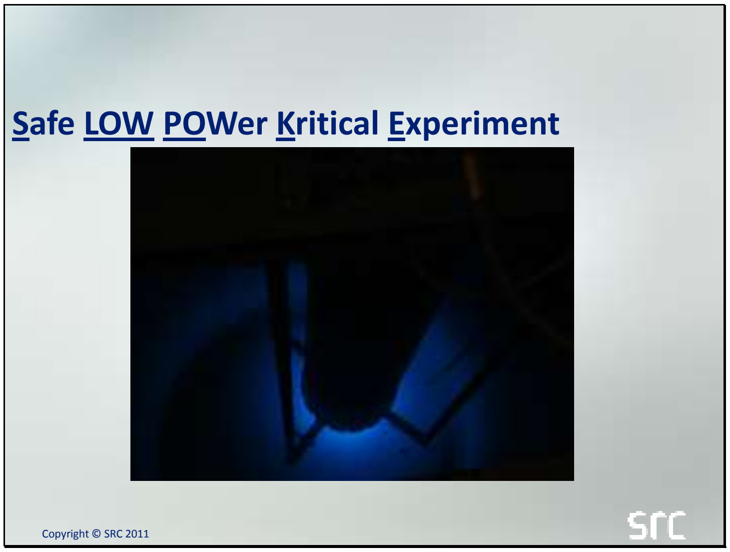

Slowpoke is an acronym for Safe Low Power Kritical Experiment.
Safe: because an inherent part of the design makes it fail-safe- it can't run into an uncontrolled power excursion (negative heat – power coefficient)
Low Power: max 20 kWatts. Power reactors are measured in megawatts. There is only about 830g of fuel.
Kritical: The point at which a nuclear fission reaction can be sustained is referred to as going critical.

The blue glow that can be seen in the pool water is 'Cerenkov radiation'- caused by high speed charged particles slowing down in the surrounding water.

Some features which make SLOWPOKE an excellent research tool are:
- Small critical mass with a useful neutron flux (maximum 1 E+12)

Excellent flux stability
- Minimum of heat
- Small fission product inventory
- no complex systems to maintain
- Essential features of operation can be mastered quickly

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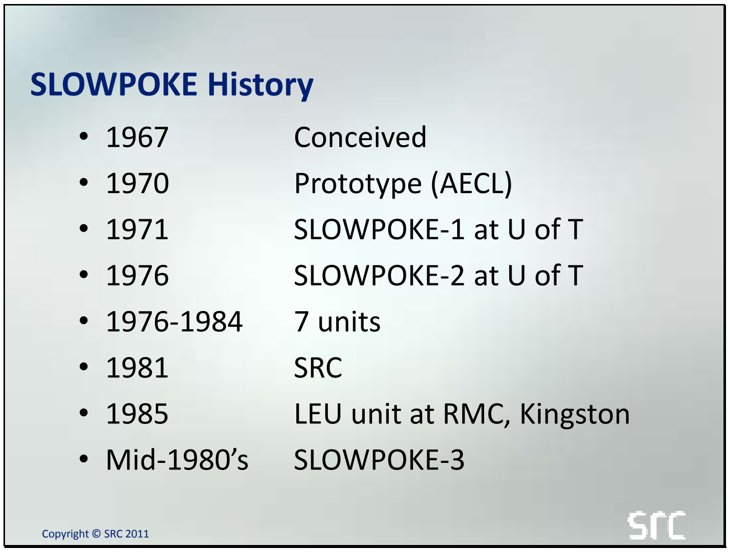

- The SLOWPOKE reactor was conceived in 1967 at AECL's Whiteshell labs. The idea stemmed from experiment at Los Alamos to determine the smallest mass of uranium that could be configured to go critical
- Prototype designed and built at Chalk River Laboratories in 1970
- Primarily intended for Universities to provide a higher neutron flux than available from small commercial accelerators, but avoid high cost and complexity of existing nuclear reactors.
- Chalk River prototype went critical in 1970 and moved to U of T in 1971. (5 kw power initially, increased to 20 kw in 1973)
- In 1976 a commercial design of Slowpoke- 2 was installed at U of T, replacing the original SLOWPOKE 1 unit.
- 1976 – 1984, 7 Highly Enriched Uranium reactors were installed in 6 Canadian cities and Kingston Jamaica (Edmonton, Saskatoon, Montreal, Halifax, Toronto, Kanata, Ont)
- In 1985 Low Enriched Uranium reactor was installed at Royal Military College in Kingston, Ont.
- In mid-1980's AECL developed a small power reactor called SLOWPOKE-3 (2-10 MW) for use in remote communities (tried to sell one to the U of S to replace their steam power plant). It was initially estimated to be competitive with conventional fuels, but interest dwindled due to low cost of natural gas. However, with the recent higher costs of oil and natural gas, their has been renewed interest in small nuclear reactors for power generation. Only built one SLOWPOKE-3 at Whiteshell Laboratories in Pinawa, MB.

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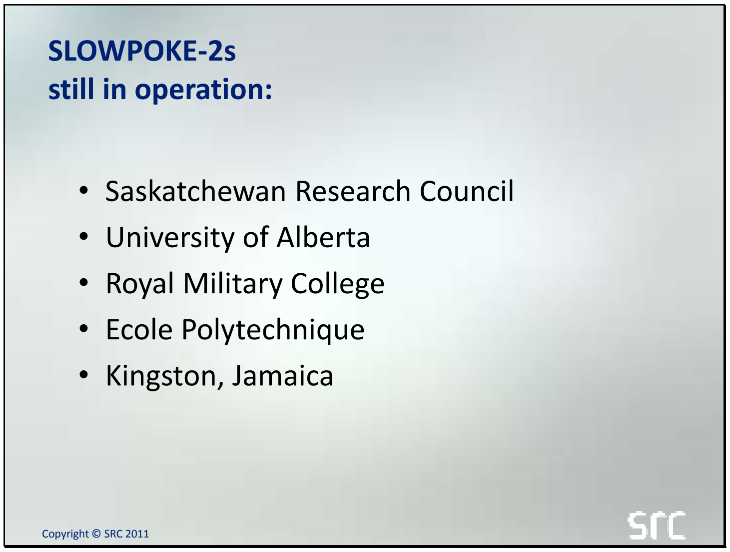

- There are 5 reactors still in operation – Saskatchewan Research Council in Saskatoon; U of Alberta in Edmonton; Royal Military College in Kingston, Ontario; Ecole Polytechnique in Montreal; Kingston, Jamaica
- U of T decommissioned in the late 90's
- Dalhousie University decommissioned over the last couple of years.
- Ecole polytechnique was refueled in 1997 with LEU (5 kg of 19.9% enriched U)
- Others still with HEU, however the Jamaica reactor will be converted to LEU through an initiative sponsored by IAEA and USA

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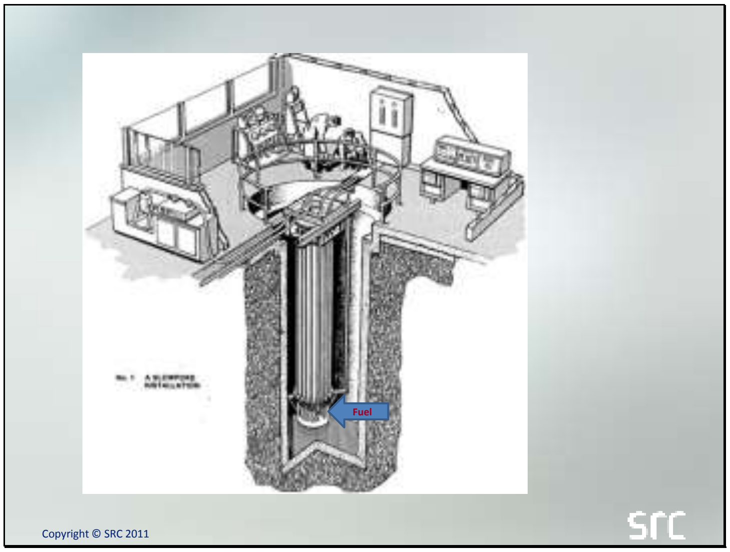

- SLOWPOKE-2 is a pool type reactor using light water. Pool is about 20 feet in depth
- Water serves two purposes

    -as a coolant-cooling is provided via natural convection.

    -as a moderator for neutrons (slows them down so they can react with the Uranium fuel).

Slowpoke uses light water-light water absorbs more neutrons than heavy water so light water reactors must use enriched Uranium rather than natural U as fuel, otherwise criticality (chain reaction) is impossible.
Heavy water increases the efficiency of the nuclear reaction. Candus use heavy water.

- Fuel is HEU (less than 1 kg of 93% U 235). This enriched U is alloyed with Al to a final concentration of about 28%.
- Could operate with LEU (<20%) which is the barrier to weapons production. Need about 5 kg. (1100g U-235)
- Fuel is contained in a cage (Aluminum), 297 fuel pins, cage is 22 x 22 cm.

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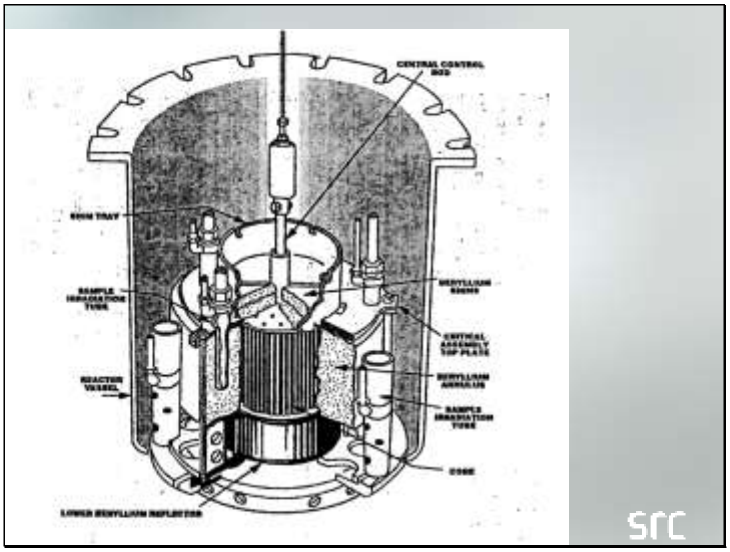

- The small core is approximately 22 centimeters high and 22 centimeters diameter.
- The critical assembly is comprised of the core and beryllium reflectors. The Be annulus and lower reflector are of fixed size. The upper reflector consists of a variable number of Be shims of different thickness and known reactivity worth.
- By adding shims to increase the thickness of the upper reflector it's possible to extend the life of the original fuel core to several decades. The SRC SLOWPOKE has had several shim additions (4 to 8 year intervals), the most recent one in 2009 .
- The maximum allowable excess reactivity under the terms of our license is 4.0 mk. When the reactor is re-shimmed the appropriate shims are added to increase the reactivity to as close to 4.0 mk without going over 4.0 mK.
- The reactor can be operated until the reactivity drops to about 2.0 to 2.2 mk at which point the reactor cannot sustain a full day's operation at 50% power. At full power it will only operate for about an hour and a half.
- There are 5 irradiation sites in the Be reflector and 2 stationed outside the reflector (larger dm sites)
- Control of the neutron flux in the reactor is effected by raising and lowering a cadmium control rod attached to a control motor by a wire. Key switch start up which causes the control rod to withdraw, system excess reactivity rises to <0.4% and reactor power rises within min period of 8 sec.
- In automatic operation a self-powered neutron flux detector governs rod control and movement. A control shutdown system shuts down the reactor if the control rod moves out of the core for three seconds continuously, limiting problems that could arise from the failure of the flux detector or signal processors.

- Since starting reactor necessitates full withdrawal of the control rod, the shutdown system must be disabled during startup, otherwise the reactor would not operate.
- A manual operation option is available for research, teaching and troubleshooting purposes.
- Cooling is achieved by natural convection – water enters via lower orifice between lower Be reflector and side annulus and exits through upper orifice between annulus and upper shim tray. Heat transfer through container walls into pool and on into surrounding earth. Additional cooling available via a cooling coil suspended in the pool. Optimal operating temp is 19.6 C at startup.
- Reactivity gradually decreases with use as U 235 is consumed and poisons build up in the fuel. Compensation for this decrease is effected by periodically increasing the thickness of the top reflector by addition of Be plates of small and known reactivity. We have burned about 1g of our fuel in 31 years.

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SLOWPOKE-2
Control and Auxiliary Systems

- Control Console
- Water Purification
- Pool Water Cooling
- Headspace Purge
- Irradiation Controllers
- Radiation monitoring

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A key switch-initiates start up of SLOWPOKE to a preset power level, causes a single control rod to withdraw, system excess reactivity rises to 0.4% within < 8 seconds.

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- This is a photo of the SRC SLOWPOKE-2 reactor. The room is about 400 square feet. It is kept locked at all times.
- The pool is a concrete cylinder with an internal diameter of 260 cm. and an internal height of 6.4 meters.
- The reactor pool is covered by 6 concrete blocks (75 cm high by 55 cm thick x 300 cm long)
- Cover sections are moved individually by hydraulically lifting each end on dollies that traverse a set of tracks.
- Level of water in pool is maintained 114 cm from top by an overflow pipe which flows into a sump

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- The sample handling areas consist of the U analysis lab and the NAA lab. This is the U analysis system.
- U analysis system automatically transfers samples to and from the reactor, performs the delayed neutron counting and then ejects the analyzed sample into a container in the storage room.

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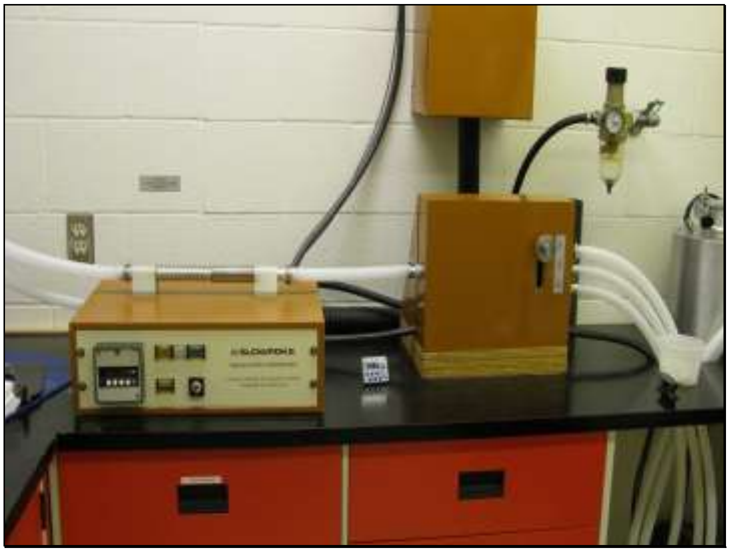

- This is a photo of the Neutron Activation lab.
- Irradiations for NAA are performed manually using controllers(shown is one of 3),
- If not counted immediately, the capsules are stored in the storage room.
- Access to the U and NAA labs is restricted to licensed operators, authorized users and authorized experimenters. Other persons may visit this area if a licensed operator or user is in attendance.
- Access to the reactor room itself is restricted to Licensed operators only. No other persons are allowed to enter the reactor room unless supervised by a licensed operator.

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- Samples are weighed and stored in capsules.
- Disposal of irradiated capsules is done by one of 2 methods:

-Once the radiation level has decayed to <0.1mR/h at 10 cm, their reactivity is measured. If the surface radiation reading is < or equal to 0.03 mR/h they are disposed of as ordinary waste.

-Active capsules are either returned to the client if they are allowed to receive them, or sent to a CNSC approved disposal site.

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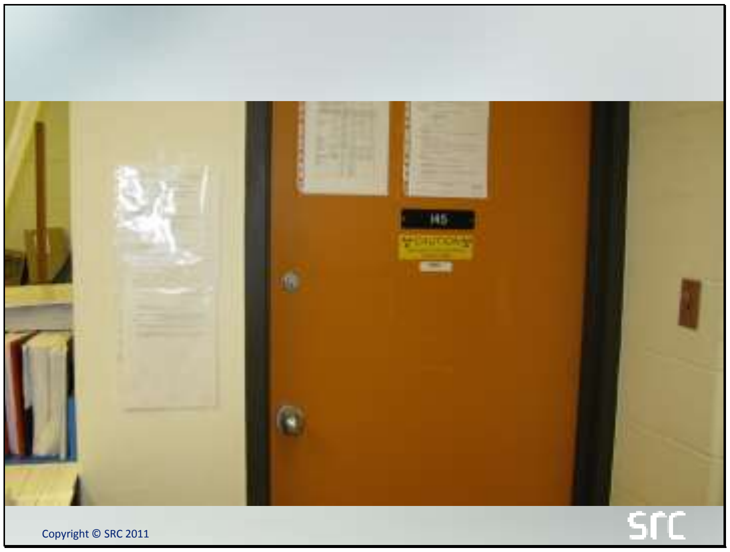

- Here is a photo of the entrance to the storage room
- This room has 16 inch cement walls with an in-floor storage pit, 1m3, lead cover on track so it can be rolled back

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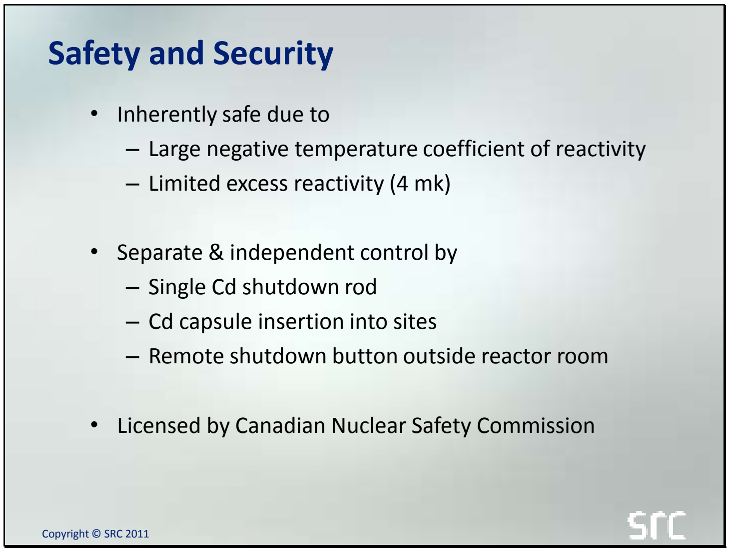

- Basic cornerstones of SLOWPOKE safety philosophy are:

  -limited max excess reactivity during all normal and conceivable abnormal conditions

  -safe self-limiting power excursion behavior for reactivity excursions in excess of the max 0.4% reactivity.

  -The SLOWPOKE -2 has been designed with a large negative temperature reactivity coefficient (ie heating of the fuel and moderator cause system reactivity to decrease

  -a limited excess reactivity (4 mk maximum).

  -the moderator density reduces with increased temperature, rendering the SLOWPOKE -2 inherently safe.
- Therefore, it is licensed for automatic unattended operation
- There is no hazard to reactor or operator, should the reactor’s control system malfunction, alternate methods of shutting reactor down by inserting 5 Cd-containing capsules into the 5 small (inner) irradiation sites. (each capsule has reactivity worth 0.15%)
- Reactor shutdown is initiated manually and can be effected by the insertion of either one of two absorber systems.(Cd control rod or cd capsule)
- Start up is with a key switch
- There is also a remote shutdown button outside the reactor room.

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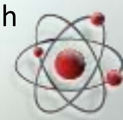
SLOWPOKE-2 Applications

- Radioisotope Production for tracers
- Neutron Radiography
- Neutron Activation Analysis (NAA)
- Teaching and research



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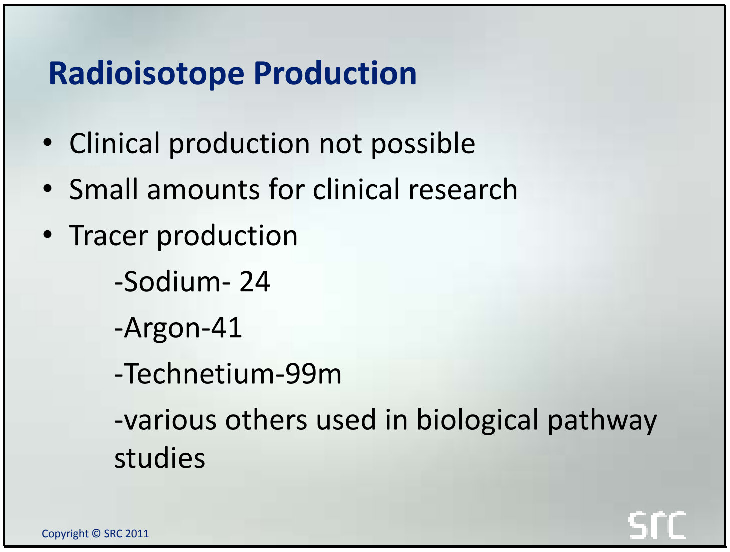

- 3 types of isotope production
  - -clinical production (short lived radioisotopes observed by gamma camera)
  - -clinical research
  - -tracer production
- Slowpoke-2 could not be modified for purpose of producing medical isotopes for clinical use. Unlike higher powered research reactors, low power reactors cannot routinely produce radioisotopes used in radio pharmacy. Reactors capable of this such as NRU at AECL are physically much larger in size and contain much larger amounts of fuel.
- It is possible to produce some tracers and very small of amounts of radioisotopes for medical research without modification to the reactor. However, we would need to add some special handling facilities as some isotopes are much more radioactive than material currently handled at SRC
- Tracers used for ground water studies and pipeline studies could be produced

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Neutron Radiography

- RMC open pool reactor
- 2-Dimensional structural fault analysis

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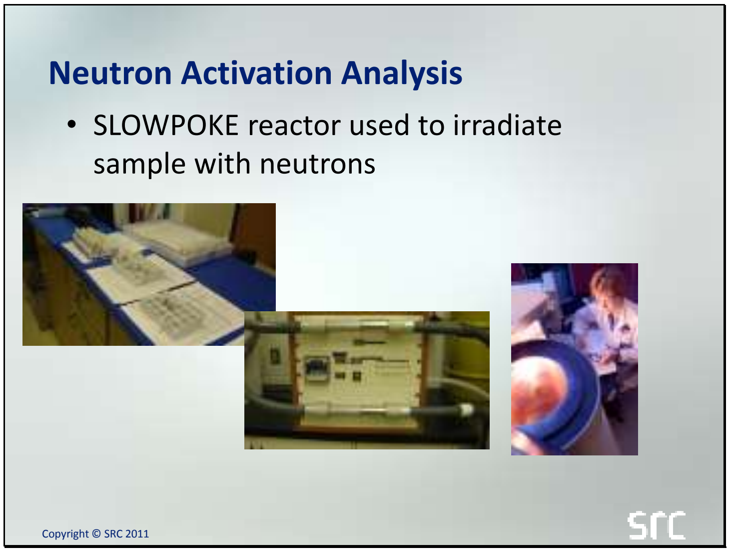

- By bombarding a sample with neutrons a radioisotope of the element of interest can be produced, then gamma emissions are measured.
- For most samples, all that is required is to weigh sample into plastic capsule and seal it.
- A pneumatic transfer system sends the sample into the reactor where the neutrons emitted by the reactor interact with the nuclei of the elements atoms to generate radioisotopes.
- Subsequently, these radioisotopes decay by emitting gamma rays, which are unique in half-life and energy. The intensity of the gamma radiation can be measured using a gamma spectrometer equipped with a germanium detector. After the sample has been analyzed, any radioactive isotopes produced are allowed to decay until the activity reaches an acceptable level.

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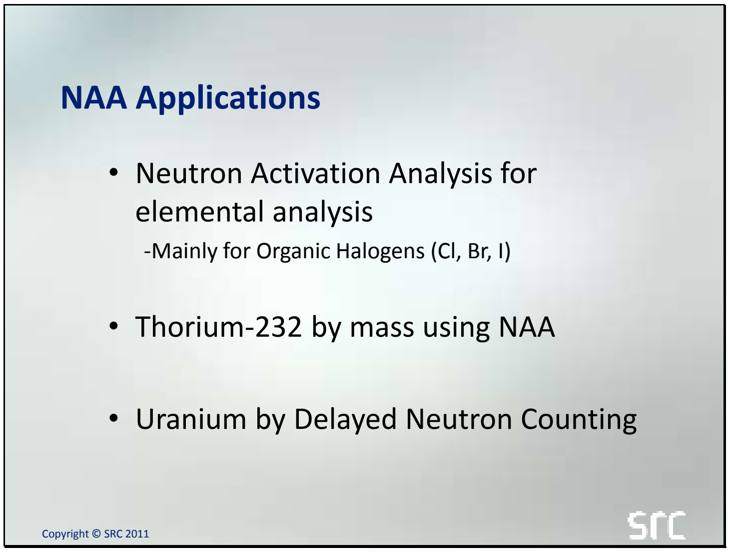

- NAA can be used to determine concentration of organic halogens.
- This is a screening test. These compounds can enter the environment from both natural sources and other sources such as industrial waste streams (generated by oil industry).
- The lab separates the organically bound species from inorganic using various extraction procedures- then chlorine, bromine and iodine can be measured individually by NAA.
- This is the industry preferred method.

- U by DNC-exposure of U to neutrons in the reactor results in the emission of a beta article, followed by emission of neutrons, which are measured. Sensitive and rapid technique for U at ppm or % levels. Other technique commonly used is ICP-MS, which has lower detection limits, but requires sample preparation

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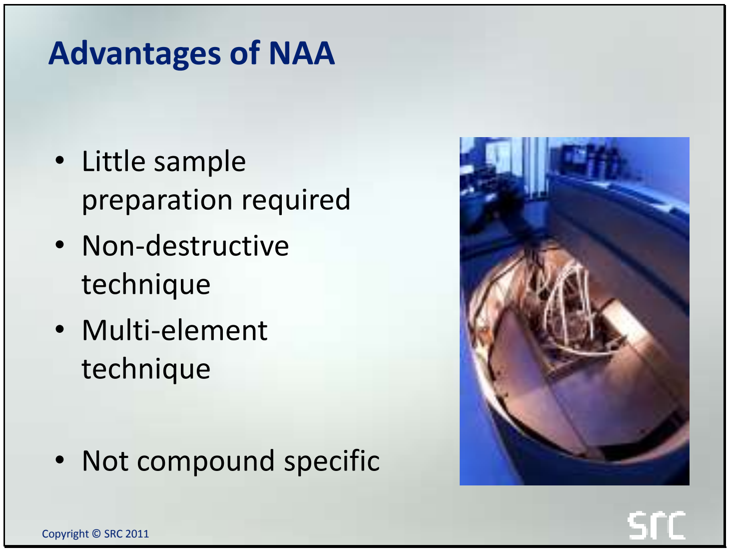

- Detection limits vary depending on the individual elements and the total amount of radioactivity created in the sample.
- The advantages of this technique are:

-many elements can be determined in a single analysis,

- very little sample preparation is required – most materials can be weighed directly into an irradiation vial as is

-it is a non-destructive technique, so after the induced radioactivity has died out the sample can be used for other tests.

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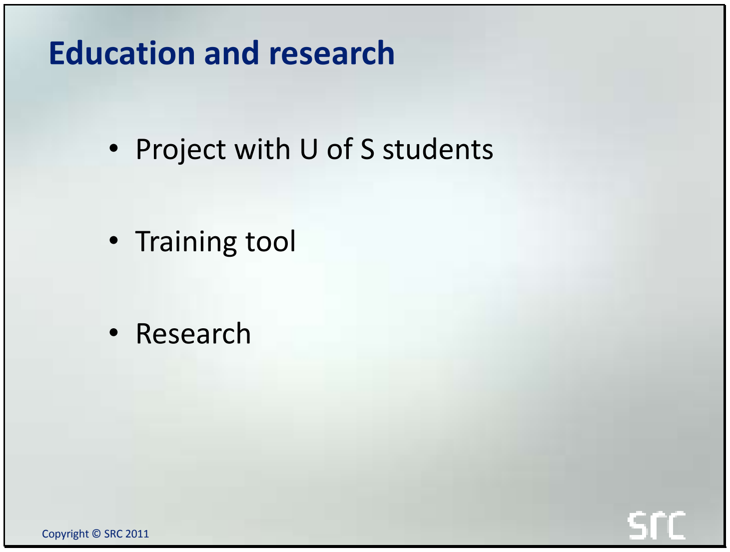

- U of S students from physics and engineering physics department have used the reactor for projects.
- Looking for opportunities to work with others to use it as a teaching tool, research projects
- Recent Projects include:
  - -Irradiation of concrete & rebar to simulate activation of pool infrastructure
  - -Mo-99 production
  - -Nuclear Battery (neutro-voltaic cell)

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Questions??