Nuclear Research Reactors and their Applications

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Outline

- What are Research Reactors (RR)
- RR types and features
- How many are there
- RR Applications

Nuclear Research Reactors

Research reactors are nuclear reactors that serve primarily as a source of neutrons.

- Neutrons are NEUTRAL particles which are highly penetrating, can be used as nondestructive probes, and can be used to study samples in severe environments

- Neutrons have a MAGNETIC moment that can be used to study microscopic magnetic structure, study magnetic fluctuations, and develop magnetic materials.

- Neutrons have SPIN that can be formed into polarized neutron beams, used to study nuclear (atomic) orientation, and used for coherent and incoherent scattering.

- The ENERGIES of thermal neutrons are similar to the energies of elementary excitations in solids. Both have similar molecular vibrations, lattice modes, and dynamics of atomic motion.

- The WAVELENGTHS of neutrons are similar to atomic spacings and can help determine structural sensitivity, structural information from 10^{-13} to 10^{-4} cm, and crystal structures and atomic spacings.

- Neutrons "see" NUCLEI, and are sensitive to light atoms, can exploit isotopic substitution, and can use contrast variation to differentiate complex molecular structures.

Nuclear Research Reactors
Typical Features

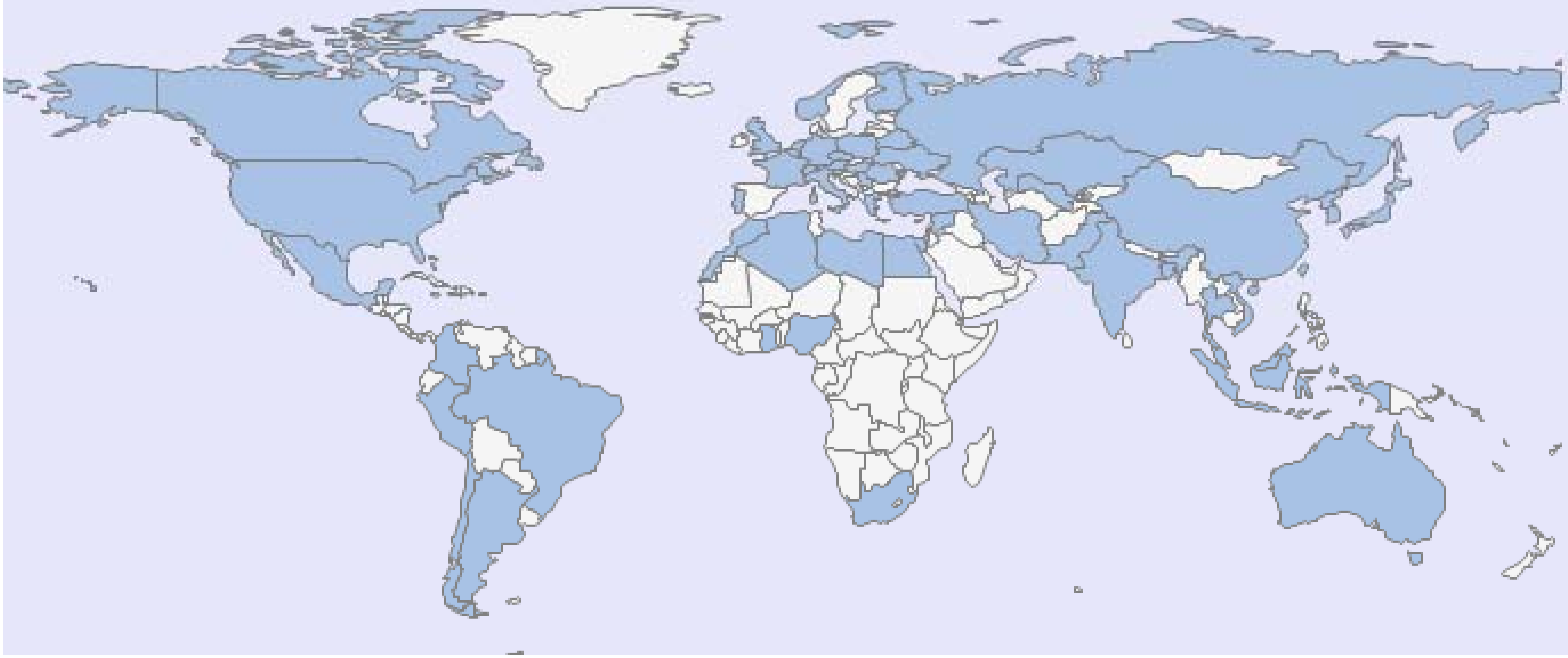
- Power levels 0 kW to 20MW (t)
- Intense source of neutrons. Typical steady-state neutron flux: 10^{11} to 10^{14} neutrons $cm^{-2}\,s^{-1}$
- Vertical and horizontal channels to avail neutrons
- Various coolants / moderators
  - light water, heavy water, organic liquids
- Various types of fuel
  - plates, rods, tubes, liquid in homogeneous RR
  - metallic, hydrides, silicides
- Natural and forced circulation cooling

Research Reactors Some Typical Characteristics

- Small volume cores
- **90% have power level less than 10 MW(t)**
- Generally higher enrichment fuel than in power reactors (though some RRs use natural uranium fuel)
- Natural and forced cooling
- May have pulsing capability

Research Reactors Around the World

Research Reactors (RR) have been operating for over 50 years, There are 246 are currently in operation in 56 countries (IAEA RR database, 2010). 5 new RR's are under construction. 5 have been completed within the last 5 years. 19 have been completed between 1994 and 2008.



Radioisotope Production in RR

- **Neutron Irradiation for Radioisotope Production**
- *Principle*: Target element's activation in RR for specified period to induce radioactivity
- *Typical Uses*: Production of radioisotopes for a variety of applications in medicine, industry, agriculture, biology and research

Radioisotope Production in RR

- Worldwide demand is > US$ 500 M
- BR-2 Belgium, HFR The Netherlands, NRU Canada, Osiris France, Maria Poland, Safari-1 South Africa, *Opal Australia*
- Mo-99 usage worldwide is about 12,000 6-day curies per week

Radioisotope Production in RR

- **Low n flux: <10^{13}**
  ^{24}Na, ^{32}P, ^{82}Br
- **Medium n flux: 2-8 x 10^{13}**
  ^{82}Br, ^{99}Mo, ^{125}I, ^{35}S, ^{131}I, ^{153}Sm, ^{177}Lu, $^{186/188}$Re, ^{192}Ir
- **High n flux: >10^{14}**
  ^{60}Co, ^{192}Ir, ^{75}Se, ^{89}Sr, ^{177}Lu, ^{99}Mo, ^{188}W

- **Food and Agriculture**
  - Tracer Techniques
  - Mutants - Productivity
  - Disinfestation – Safety, Shelf-life
- **Industry**
  - Radiography
  - Tracer Techniques
  - Radiation Technology
- **Medicine**
  - Diagnosis
  - Treatment

Radioisotope Production in RR

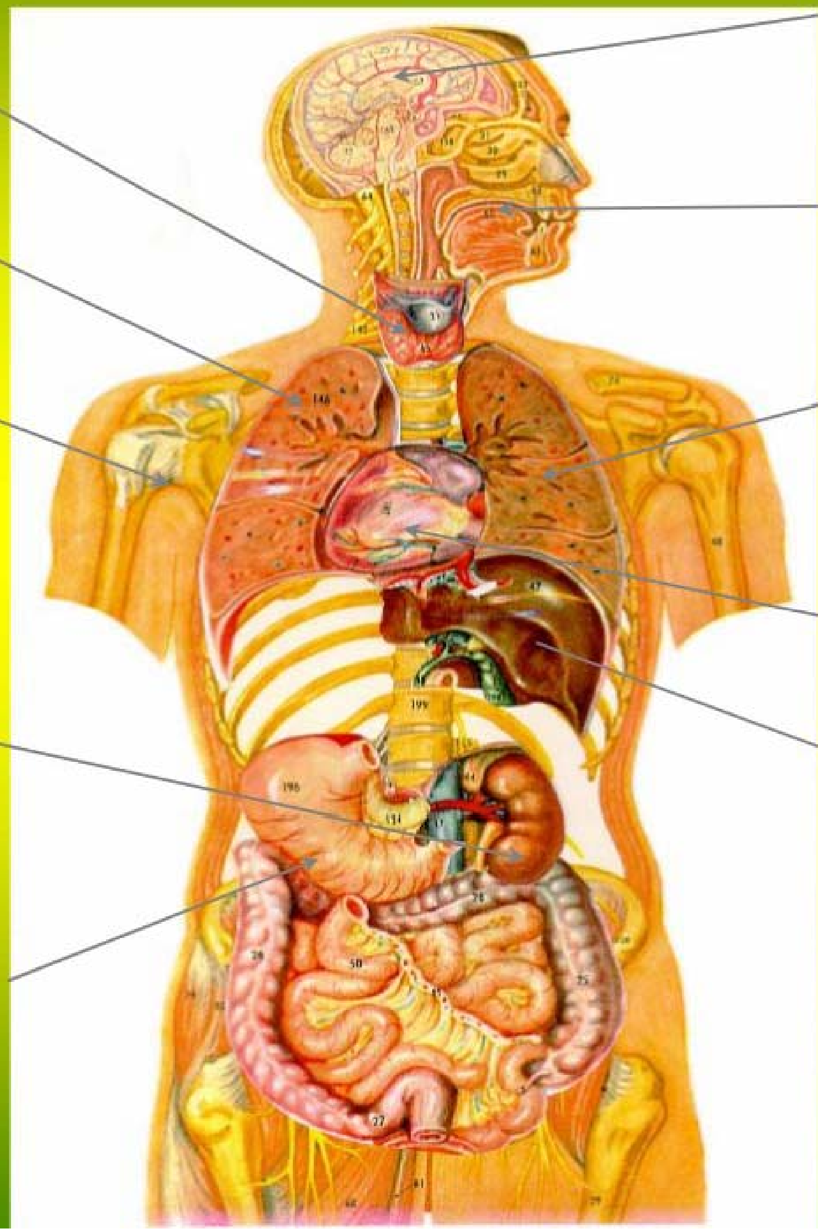
Thyroid
^{99m}Tc-Pertecnetate

LInphatic system
^{99m}Tc Dextran 500/70

Bone
^{99m}Tc MDP
^{99m}Tc Pyrophosphate

Kidneys
^{99m}Tc DTPA
^{99m}Tc Glucoheptonate
^{99m}Tc DMSA
^{99m}Tc Ethilenedicysteine

Stomach
^{99m}Tc Pertecnetate



brain
^{99m}Tc DTPA
^{99m}Tc Ethylenedicysteine diethyl esther

Salivary grands
^{99m}Tc Pertecnetate

Lungs
^{99m}Tc Human serum albumin macroagregate

heart
^{99m}Tc Pyrophosphate
^{99m}Tc MIBI

Liver/spleen
^{99m}Tc Tin colloical
^{99m}Tc Fitate
^{99m}Tc DISIDA

Radioisotope Production in RR

^{131}I, with a half-life of 8 days, is used to diagnose and treat thyroid disorders. It is usually taken as sodium iodide in drinking water, and almost all of it will find its way to the thyroid. The rate of ^{131}I uptake, indicates whether the thyroid glands are functioning properly

Former President George Bush and First Lady Barbara Bush are some notable people who were successfully treated for Graves' disease, a thyroid disease, with ^{131}I. Radioactive iodine treatment is so successful that it has virtually replaced thyroid surgery.

Radioisotope Production in RR

Sodium chloride containing ^{24}Na, can be injected into the bloodstream to study blood circulation. The beta particles emitted by the ^{24}Na are followed and an impaired circulation is immediately detected.

A ^{201}Tl compound injected into the bloodstream will concentrate in normal heart muscle but will not remain in damaged tissue. A photograph with a nuclear scintillation camera allows the physician to locate the damaged areas.

Radioisotope Production in RR

Tracing Chemical

Vitamin B 12 can be tagged with a radioisotope of cobalt to study the absorption of the vitamin from the gastrointestinal tract.

Compounds tagged with ^{59}Fe and ^{55}Fe are used to study the absorption of iron.

Glucose tagged with ^{11}C (half-life, 20.3 minutes and positron decay mode) circulates through the body, and the positrons emitted in the heart, brain or some other organ are monitored by a PET detector. A computer uses this information to construct an image (called a PET scan) of the organ that is being examined. PET scans have been used to study the effects of drugs on cancers, to measure damage in victims of stroke or heart attack, and to study chemical changes that occur during epileptic seizures.

Radioisotope Production in RR

Pain suppresser

•^{153}Sm

•Bone cancer caused mainly by breast and prostrate primary cancer.

•Approximately 90% reduction in pain.

Neutron Scattering

- *Principle*: RR neutrons incident on sample and record the angular and energy distribution of scattered neutrons.

- *Typical Uses*: order and dynamics of atoms and molecules in condensed matter, non-destructive testing of materials – residual stress in engineering components; surface studies - thin films, polymers and biological materials, magnetic specimen
- e.g. ILL, Grenoble; HMI, Berlin; HFIR, ORNL; HFR, Petten etc.

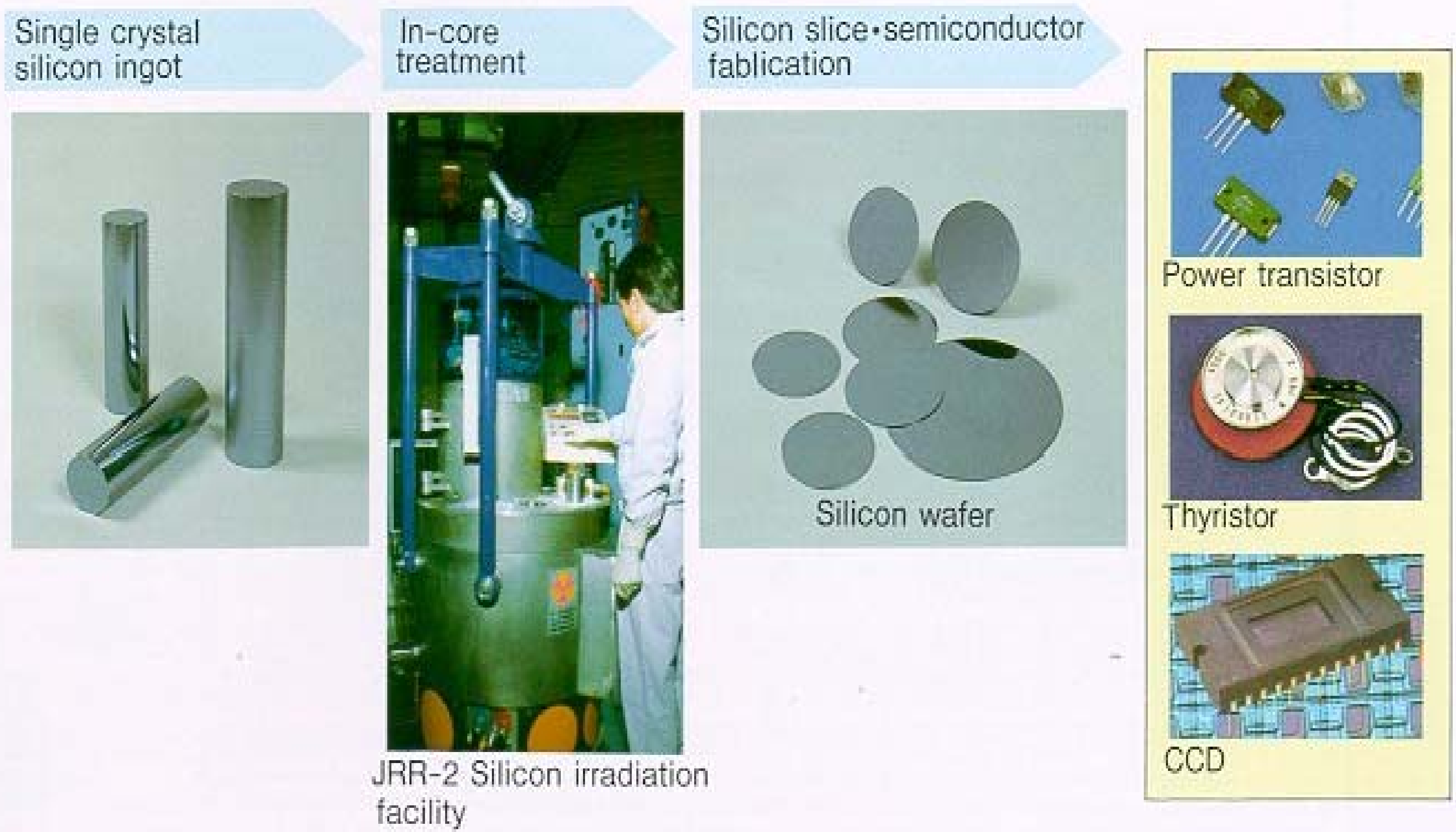
Neutron Scattering

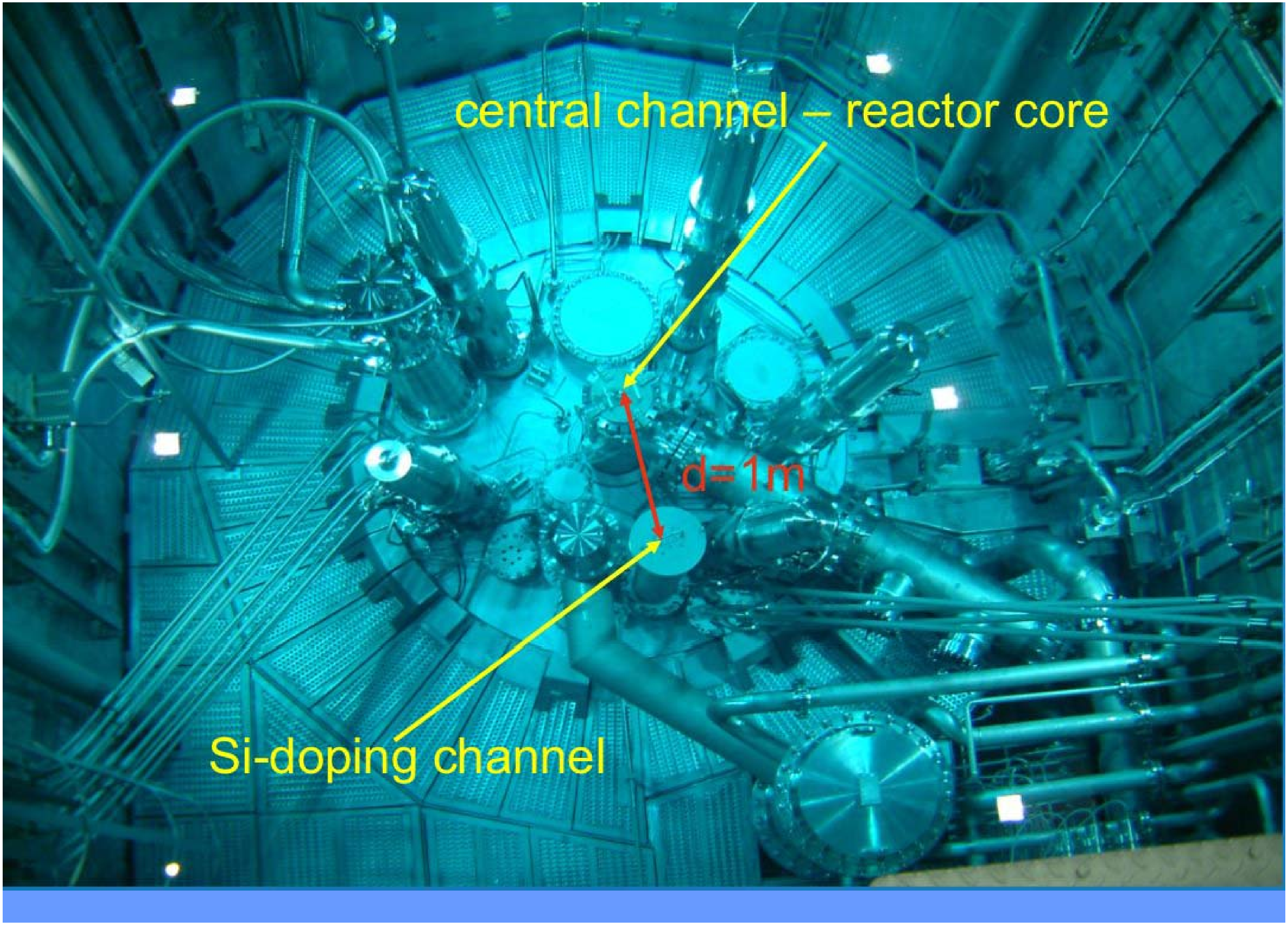
- By performing neutron scattering Biologists understand how bones mineralize during development, or how they repair themselves and decay during osteoporosis.
- Chemists improve batteries and fuel cells, while physicists create more powerful magnets.
- Neuron experts study proteins essential for the complex functions of the brain. Structure is the key to many breakthroughs in science.

Neutron transmutation doping

- Irradiation of Si by neutron transmutes some of the Si atoms to P change in electrical conduction
- A neutron flux of 2×10^{12} n cm^{-2} s^{-1} can be used to produce useful quantities of doped silicon. For the production of commercial quantities of doped silicon, 10^{13} - 2×10^{14}.
- *Typical Uses*: Semiconductor devices
- e.g. Safari-1, HANARO etc.

Neutron transmutation doping




central channel – reactor core
d=1m
Si-doping channel

Main handling steps (1)

Insertion of Si ingots into the loading basket

Lowering the Si into the reactor pool

Gamma Irradiations

With low investment a gamma irradiation facility can be easily developed at a research reactor for such purposes as irradiating plants and seeds.

Irradiation as a Phytosanitary Treatment

- The objective of conventional quarantine treatments is rapid mortality, e.g., heat, cold, fumigation etc.
- Irradiation doses that will produce rapid kill for insects on or in fresh fruit/vegetables are highly likely to detrimentally affect the quality of the commodities.
- Ultimate objective of a quarantine treatment is to prevent the establishment of pests that do not exist or are not fully established in a country.
- Therefore, **it is not necessary to kill the pests as long as the treatment can prevented the pests from reproducing**.

Spoilage Reduction . . .

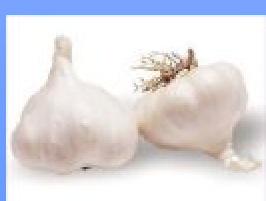
Spoilage reduction for . . .

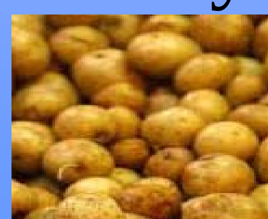
- Potatoes
- Yams
- Onions
- Garlic
- Other tubers

Technical Benefit(s)

1. Sprout inhibition
2. Ext'd shelf-life
3. Meet phytosanitary
   or sanitary requirements

Dose range 50 – 150 Gy





Control of microorganisms . . . Beef / Pork / Poultry

Technical Benefit → 1. Reduce levels of microorganisms; 2. Meets sanitation requirements.

Dose range:
- Pork = 0.3 kGy minimum to 1 kGy maximum*
- Beef/poultry = 4.5 kGy refrigerated/7 kGy frozen**

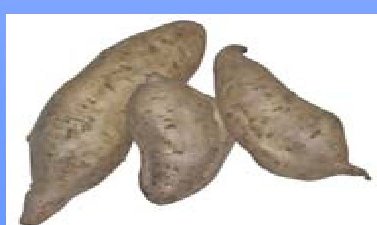
*minimum and maximum doses; may be changed to only maximum dose

**maximum dose; no minimum doses established

Commodity	Quarantine Pests
Hawaiian sweet potatoes	Ginger weevil Sweet potato scarabee Sweet potato stem bore

Technical Objective → Control of ginger weevil, sweet potato scarabee and sweet potato stem borer; meet Federal quarantine Requirements to US mainland.

Dose requirement = 400 Gy (Plus inspecting for hitchhikers and product packaging requirements)

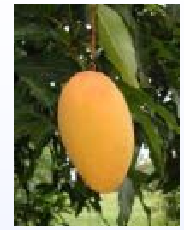
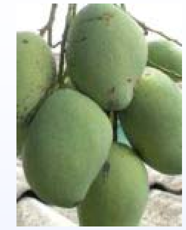


Hawaiian Tropical Fruits

Papayas	Rambutan	Fruit fly Complex	Med fly
Carambola	Abiu		Oriental fly
Litchi	Atemoya		Melon fly
Sapodella	Longan		

Technical Objective → Prevent adult emergence of fruit fly complex.

Dose = 150 (250) Gy plus product inspection

<u>Tropical Fruits from Thailand</u>


Proposed fruits

Litchi	Mangosteen
Longan	Pineapple
Mango	Rambutan

Technical objective → To control plant Pests on 6 Thai fruits to meet US Phytosanitary requirements.


Dose = 400 Gy (generic dose)

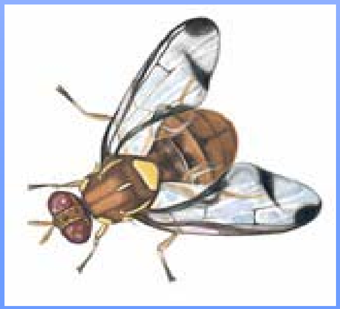
Mexican Fruits

Fruit	Plant Pests	Dose
Mango[1]	fruit flies	150 Gy
Guava[2]	fruit flies, plus pests etc.	400 Gy

[1]**Dose for mango** = 150 Gy (assuming fruit flies are only quarantine pests of concern).

[2]**Dose for guava** = 400 Gy (fruit tolerability to irradiation is limited ~150 Gy); may have other pests and could require the full generic dose 400 Gy; becomes very unlikely that guavas can tolerate that dose level.)

Guava

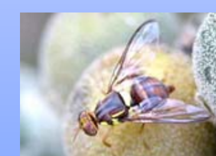


Fruitfly

MMango

Irradiation for Certain Plant Pests in Imported Regulated Articles

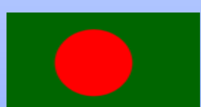
Scientific Name	Common Name	Dose (gray)
Anastrepha ludens	Mexican fruit fly	70
Anastrepha obliqua	West Indian fruit fly	70
Anestrepha serpentina	Sapote fruit fly	100
Anestrepha suspensa	Caribbean fruit fly	70
Bactrocera jarvisi	Jarvis fruit fly	100
Bactrocera tyroni	Queensland fruit fly	100
Brevipalpus chilensis	False red spider mite	300
Conotrachelus nenuphar	Plum curculio	92
Croptophlebia ombrodelta	Litchi fruit moth	250
Cryptophlebia illepida	Koa seedworm	250
Cylas formicarius elegantulus	Sweetpotato weevil	150
Cydia pomonella	Codling moth	200
Euscepes postlasciatus	West Indian sweetpotato weevil	150
Grapholita molesta	Oriental fruit moth	200
Omphisa anastomosalis	Sweetpotato vine borer	150
Rhagoletis pomonella	Apple maggot	60
Sternochetus mangiferae	Mango seed weevil	300
Fruit flies of the family Tephritidae not listed above		150
Plant pests of the class *Insecta* not listed above except pupae and adults of the order Lepidoptera		400



Sampling of Countries Actively Taking Measures for Using Irradiation to meet Import Phytosanitary Requirements

Country	*Target Market(s)*
Brazil	**United States**
Australia	**New Zealand, United States**
Thailand	**Australia, New Zealand, United States**
Philippines	**United States**
Chile	**United States**
Mexico	**United States**

Sampling of Countries Actively Taking Measures for Using Irradiation to meet Import Phytosanitary Requirements *Continued …*

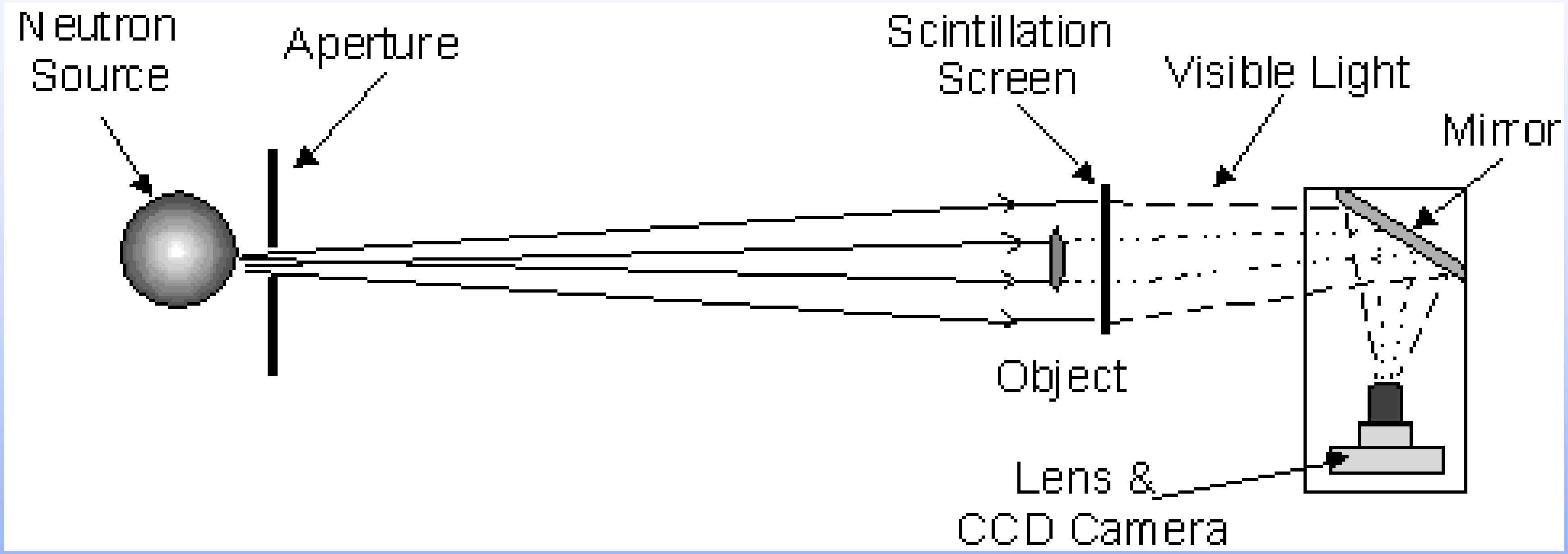
	Country	*Target Market(s)*
	**Ghana**	**United States**
	**Republic of South Africa**	**United States**
	**India**	**United States**
	**Bangladesh**	**United States**
	**Peru**	**United States**

Gem Stone Colouration

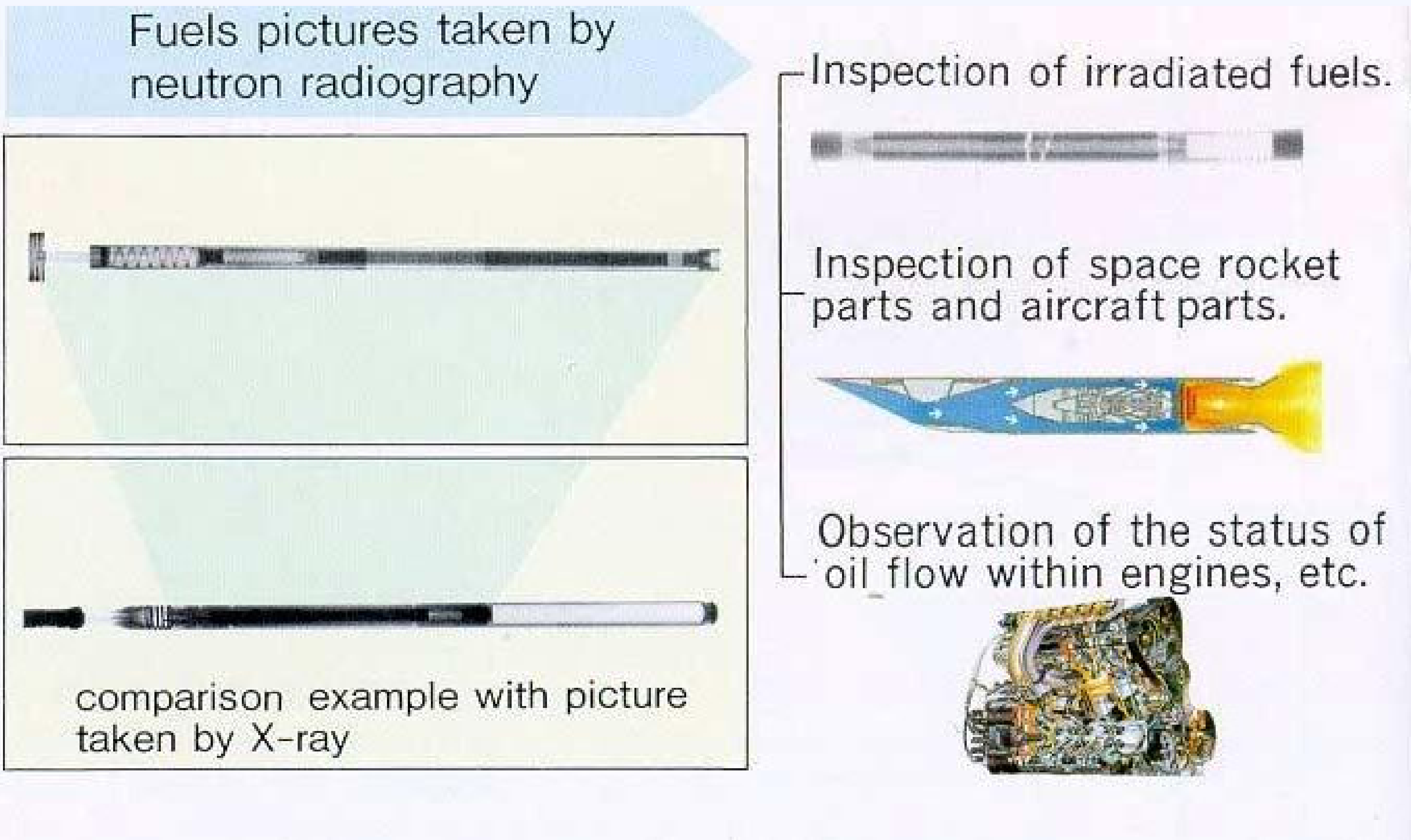
The colour in topaz is induced by the interaction of fast neutrons. The required fluence is dependent on the specific batch of topaz stones and the depth of the desired blue coloration. The fast neutron fluence is typically of the order of 10^{17}–10^{18} n cm^{-2}s^{-1}.

For a 2 MW research reactor, about 50 to 100 hours of irradiation is required to achieve this fluence.

Neutron Radiography

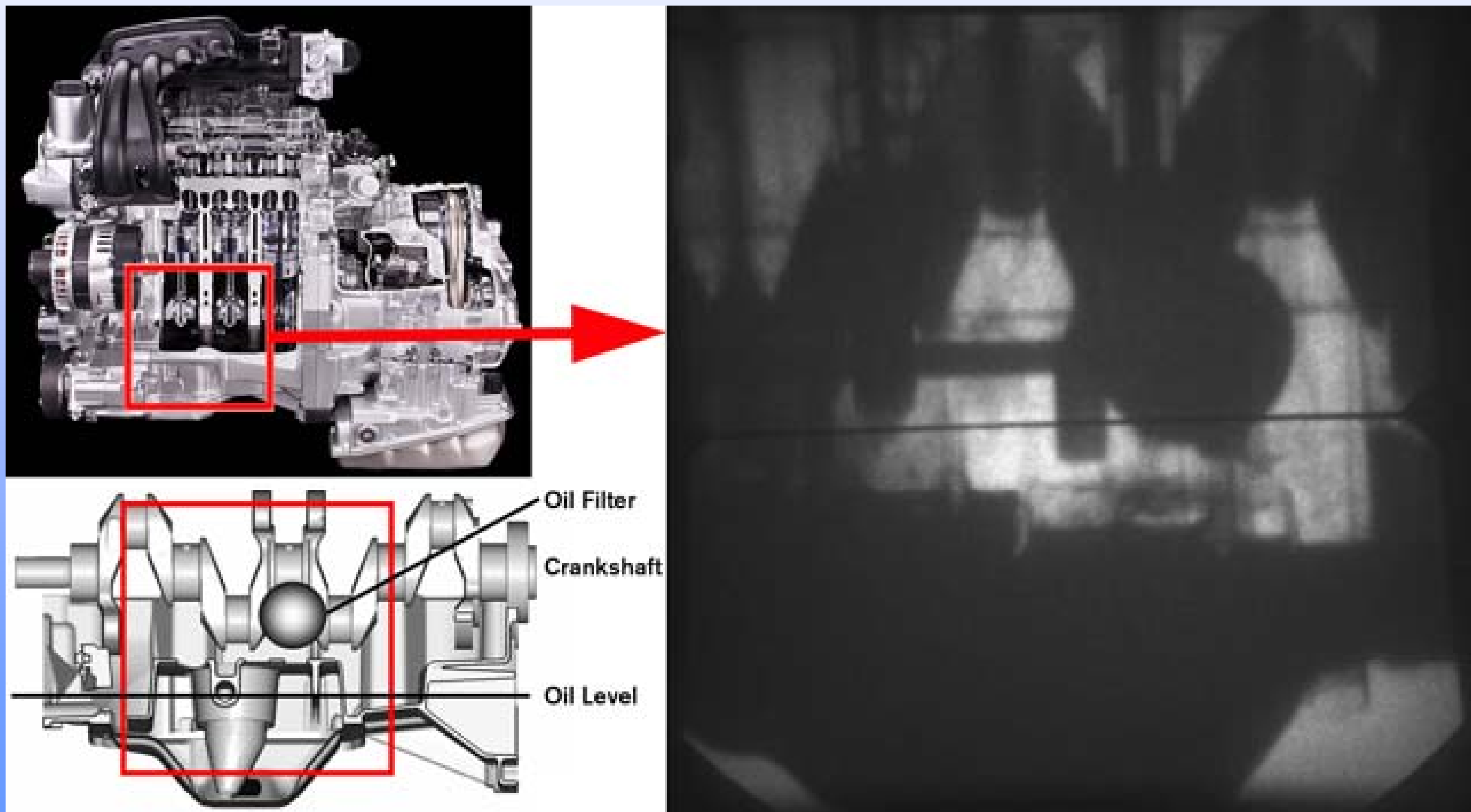


Neutron Radiography



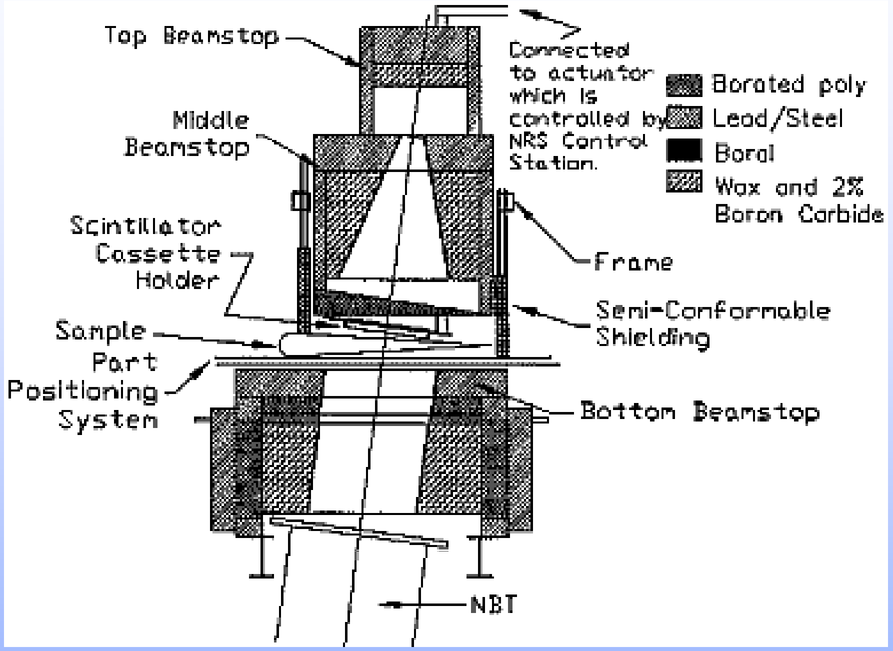
Neutron Radiography

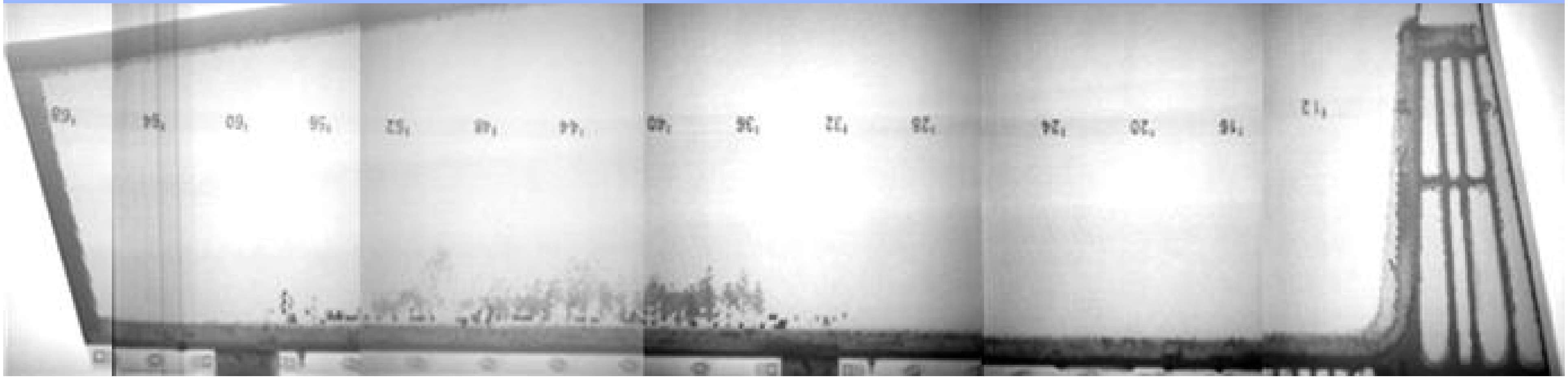
Nissan uses neutron radiography on engines to determine the causes of friction loss from the recorded behaviour of internal lubricating oil flow. The goal of the study is to redesign engines for optimal oil circulation with reduced friction in order to reduce fuel consumption and CO_2 emissions in vehicles.



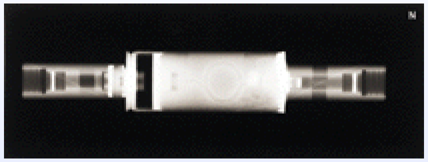
Neutron Radiography

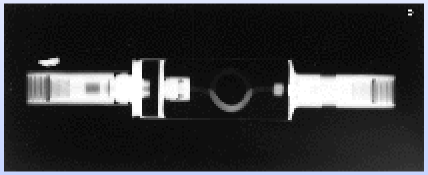
The presence of water is a degradation mechanism within the composite structures of aircraft wings, and its detection may be used to identify potentially compromised structures. The image shows a F/A-18 rudder with water within its honeycomb cells.





Neutron Radiography





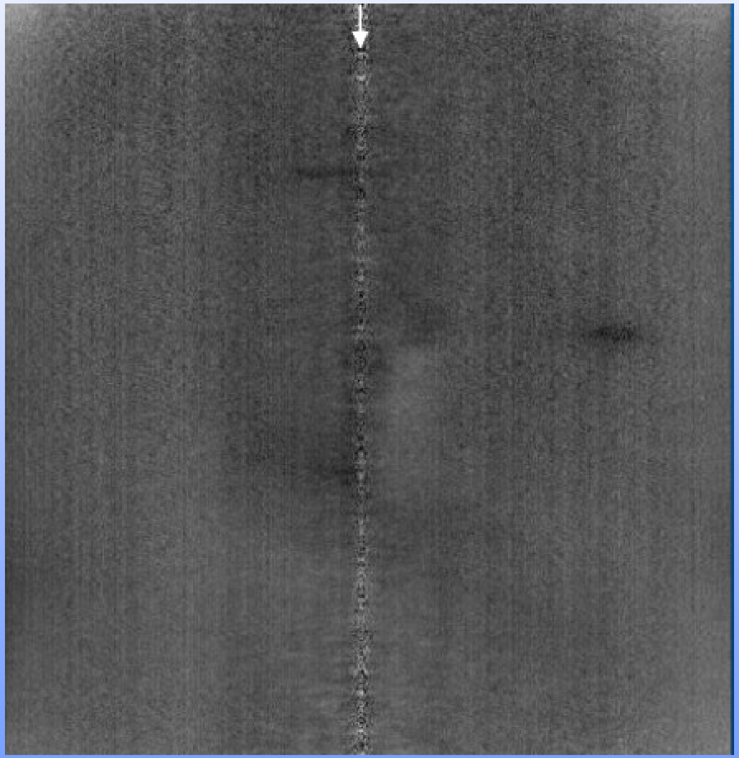
Comparison of neutron radiography and X-ray radiography of an ARIANE cartridge fuse

At the present time, Neutron Radiography is one of the main NDT technique able to satisfy the quality-control requirements of explosive devices used in space programmes. Most of the detonating devices of the Ariane space programme have been systematically examined for more than 20 years. The detection of cracks of 0.1 mm thickness in the explosive charge is common and the efficiency of the technique enables easily distinguishes differences in the compression of the explosive even through different metallic containers such as lead, aluminium or steel. The ability to detect compounds containing hydrogen atoms is also used to inspect oil levels and insulating organic materials. Neutron radiography also facilitates the checking of adhesive layers in composite materials ,surface layers (polymers, varnishes etc). All types of O-rings and joints containing hydrogen can be observed even through a few centimetres thickness of steel.

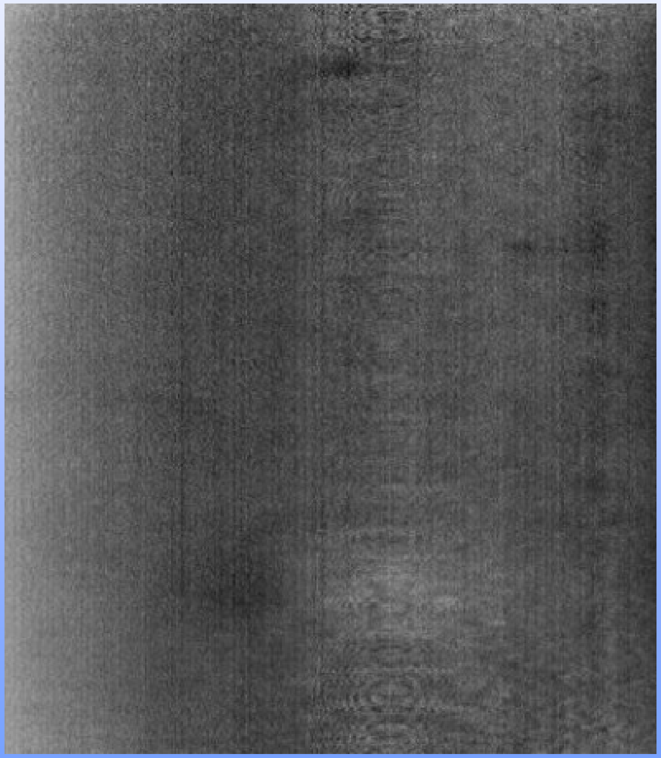
Neutron Radiography

Stability of wooden constructions

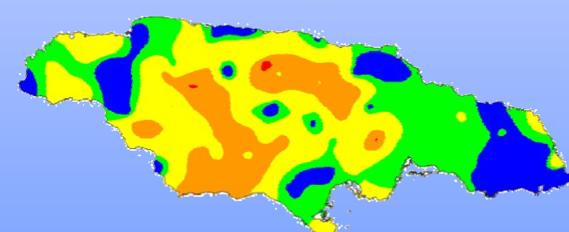
Glue not biodegradable (Artefact)

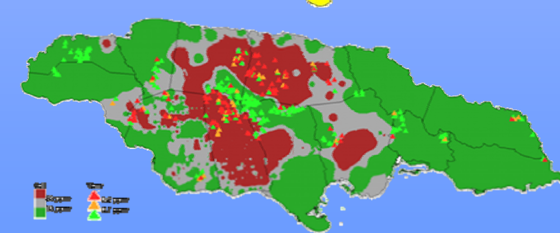


Biodegradable Glue



Neutron Activation Analysis



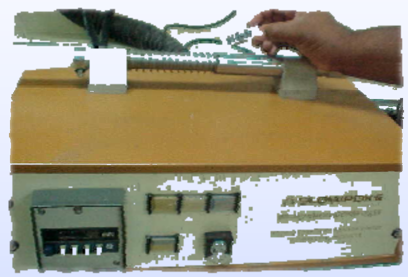


Irradiation schemes

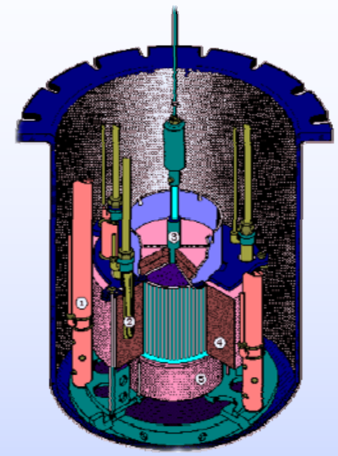
	ANALYSED ELEMENTS			
Nuclides	**Very-Short**	**Short**	**Medium**	**Long**
Product half-life	**<12 min**	**12 - 1440 min**	**1 - 3 d**	**>3 d**
Neutron flux level (n.cm-2.s-1)	**2×10^{11}**	**5×10^{11}**	**10×10^{11}**	**10×10^{11}**
Irradiation time	**5 min**	**5 min**	**1 - 4 h**	**1 - 4 h**
Cooling time	**3 - 6 min**	**15 min**	**2 - 5 d**	**20 - 30 d**
Counting time	**5 min**	**30 min**	**1 h**	**3 h**
Elements	**Mg, Al, S, Ca, Ti, V, Cu**	**Cl, K, Ga, Br, Sr, I, Ba, Dy, W**	**As, Br, Mo, Cd, Sb, La, Sm, W, Au, Lu, U, Na**	**Sc, Cr, Fe, Ni, Zn, Se, Rb, Zr, Ag, Sb, Cs, Ba, Ce, Eu, Tb, Yb, Hf, Ta, Th**

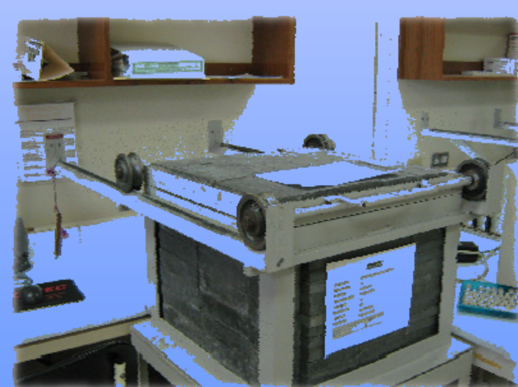
NAA Workflow

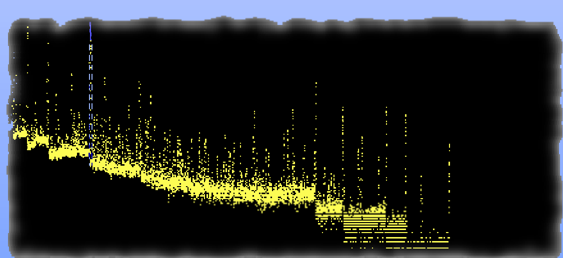
Sample preparation
(sample treatment, sample weight, sample type, ...)



Irradiation
(flux, time, ...)







Counting
(decay time, count time, ...)

Sustainable Land & Water Management

^{137}Cs is used to obtain quantitative estimates of soil erosion and deposition on medium-term (30–40 years) erosion and deposition rates and spatial patterns of soil redistribution, without the need for long term monitoring programmes. Other radionuclides, such as ^{210}Pb and ^{7}Be can be used to assess erosion and sedimentation rates and patterns at several spatial and temporal scales. This will help identify promising soil conservation measures for controlling and mitigating soil erosion and sedimentation, which will lead to the development of strategies for sustainable watershed management and environmental protection.

Other RR Applications

- Education and Training for HRD
- Science teachers & students
- Engineering teachers & students
- Nuclear power plant operator trainees
- Operational health physicists
- Regulators
- Public awareness
- Precursor to a countries NPP

A Survey of Nuclear Power in Developing Countries

by O.B. Falls, Jr.

It is generally recognized that within the coming decades nuclear power is likely to play an important role in many developing countries because, usually, such countries have limited indigenous energy resources and, in recent years, have been adversely affected by increases in world oil prices. Consequently, many of the smaller, less-developed countries have expressed concern about the unavailability of nuclear power reactors of a suitable size for application in their system.

At present only eight developing countries[1] have nuclear power plants in operation or under construction – Argentina, Brazil, Bulgaria, the Czechoslovak Socialist Republic, India, the Republic of Korea, Mexico and Pakistan. The total of their nuclear power commitments to date is only about 5200 MW, as compared to an estimated 1972 installed electric generation capacity for
estimated that by 1980 only 8
countries of the world will be r
than 16% of total electrical cap

OBJECTIVE AND IMPLEMENTATION

In response to the recommendations of the Working Group, the Director General decided that a survey should be conducted. The major objectives of the survey, as finally undertaken, were to determine the size and timing of the installation of nuclear power plants in each participating country that, for economic reasons, could justifiably be commissioned during the period of 1980 to 1989 (study period) and to determine the sensitivity of the results to certain key economic and technical parameters. Fourteen of these countries expressed an interest in participating in the survey and agreed to provide relevant basic data and provide counterpart staff to work with the visiting teams of experts. These countries are:

Argentina	Egypt	Korea	Philippines	Turkey
Bangladesh	Greece	Mexico	Singapore	Yugoslavia
Chile	Jamaica	Pakistan	Thailand	

[1] As classified under the United Nations Development Programme.

TABLE 1. SUMMARY OF POPULATION AND GNP

Country	Population[a] (10^6) 1972	1980	1990	GNP[b] (10^9 US $/yr) 1972	1980	1990
Argentina	24.0	27.3	31.8	28.9	45.4	73.2
Bangladesh	72.1	88.6	114.5	3.8	6.1	11.0
Chile	10.2	11.9	14.5	6.7	10.0	16.4
Egypt	34.7	40.6	49.5	7.4	11.9	21.5
Greece	8.9	9.3	9.9	10.6	17.3	29.8
Jamaica	1.9	2.2	2.6	1.3	2.2	4.2
Korea, Republic of	32.3	36.5	42.3	10.0	19.0	37.7
Mexico	54.2	71.5	96.0	39.4	68.3	129.3
Pakistan	55.7	65.2	79.5	11.3	17.9	31.7
Philippines[c]	20.7	25.2	30.9	5.7	9.9	18.7
Singapore	2.1	2.4	2.8	2.7	5.6	9.8
Thailand	38.3	48.6	62.5	8.3	15.1	29.2
Turkey	37.3	45.4	58.2	16.4	27.3	48.5
Yugoslavia	20.8	22.5	24.9	16.5	27.1	49.0

[a] Population forecast used for Market Survey forecast

[b] In 1 January 1973 US dollars (converted from 1964 US $ at a 4%/year inflation rate)

[c] Luzon only

TABLE 2. FORECASTS OF SYSTEM LOAD CHARACTERISTICS

Country[a]	Energy generation MWh × 10^6		Energy generation growth rate 1980 - 1990	System load factor (%)	Peak demand in MW	
	1980	1990	%/year	1980 - 1990	1980	1990
Argentina	42.0	84.2	7.2	58.3	8 230	16 500
Bangladesh-L	3.1	8.1	10.1	55.0	640	1 690
Bangladesh-H	4.8	21.7	16.3	55.0	1 000	4 500
Chile	11.4	23.7	7.6	60.5	2 150	4 470
Egypt	20.7	47.0	8.5	68.0	3 280	8 380
Greece	26.8	55.3	7.5	65.0	4 710	9 720
Jamaica-L	3.9	8.3	8.0	68.0	650	1 400
Jamaica-H	4.8	13.3	10.8	68.0	810	2 240
Korea	31.2	76.7	9.4	66.0	5 360	13 200
Mexico	72.7	178.9	9.5	61.2	13 500	33 200
Pakistan	17.0	36.2	7.9	58.2	3 320	7 090
Philippines[b]	14.8	35.2	9.0	65.0	2 610	6 190
Singapore-L	8.5	17.3	7.4	65.0	1 500	3 040
Singapore-H	9.1	27.8	11.8	68.0	1 520	4 650
Thailand	15.7	39.3	9.7	66.0	2 710	6 800
Turkey-L	23.4	51.3	8.2	63.7	4 200	9 200
Turkey-H	29.0	81.5	10.9	63.7	5 190	14 600
Yugoslavia-L	64.4	122.4	6.7	67.5	10 900	20 700
Yugoslavia-H	87.5	165.5	6.6	67.5	14 810	27 990

[a] L = Market survey forecasts H = Country forecasts [b] Luzon only


Thank You for Your Attention