B&W Medical Isotope Production System

Codes and Modeling Strategy
May 17, 2011

B&W Participants

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The Babcock & Wilcox Company

Government Operations

B&W Technical Services Group, Inc.

Manages and operates high-consequence facilities, provides technical services and support to government agencies and private customers

B&W Nuclear Operations Group, Inc.

Manufactures nuclear components for U.S. Department of Energy

Power Generation Systems

B&W Power Generation Group, Inc.

Manufactures and services coal, biomass, CNG, concentrated solar power plant equipment, & Nox, Sox, mercury scrubbers

B&W Nuclear Energy , Inc.

Manufactures commercial nuclear components and provides services to commercial nuclear market

High-Consequence Operations & Services

Advanced Engineering and Manufacturing

Covidien Reach Extends Globally and Locally

- 20,000+ U.S. employees, 41,000 worldwide
- Diverse healthcare products used in all clinical settings
- Products manufactured in 16 states

Nuclear Medicine:

- One of two U.S. suppliers of technetium 99m (Tc 99m)
- Covidien Tc 99m-based products sold in all 50 states

COVIDIEN

B&W MIPS – ^{99}Mo Production Using Aqueous Homogeneous Reactor

- Mid-90s: Dr. Russell M. Ball – LEU or HEU capable, uranyl nitrate, patented awarded 1997
- B&W acquires patent to uranyl sulfate AHR production of Mo-99
- Late 1990s B&W explored markets for building an AHR to produce Mo-99
- 2007 B&W re-initiates MIPS project
- 2009 B&W enters into agreement with major pharmaceutical supplier, Covidien
- 2009 B&W enters into cooperative agreement with DOE

AHR using LEU offers safety, safeguards, simplicity and waste advantages

US005596611A

United States Patent [19]
Ball

[11] **Patent Number: 5,596,611**
[45] **Date of Patent: Jan. 21, 1997**

[54] **MEDICAL ISOTOPE PRODUCTION REACTOR**

[75] Inventor: **Russell M. Ball**, Lynchburg, Va.

[73] Assignee: **The Babcock & Wilcox Company**, New Orleans, La.

[21] Appl. No.: **339,264**

[22] Filed: **Nov. 10, 1994**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 986,939, Dec. 8, 1992, abandoned.

[51] **Int. Cl.**^{6} **G21G 1/02**
[52] **U.S. Cl.** **376/189**; 376/186; 376/311; 376/313; 376/358
[58] **Field of Search** 376/186, 313, 376/354–358, 311, 189

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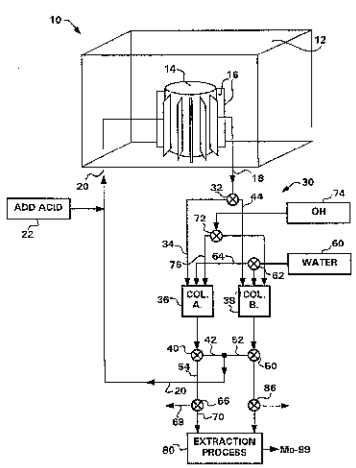
Primary Examiner—Harvey E. Behrend
Attorney, Agent, or Firm—Robert J. Edwards

[57] **ABSTRACT**

Medical isotopes are produced using a lower power, low cost nuclear reactor which permits the use of all the fission products produced in the reactor. Medical isotopes such as Molybdenum-99 are produced in a reactor operating at a power of 100 to 500 kilowatts.

16 Claims, 1 Drawing Sheet



B&W MIPS Fission Technology

Aqueous Homogeneous Reactor (AHR) Reactor Fission Power 220kW

Initial Fuel/Target Solution Preparation

Reactor fuel/target solution returned for subsequent irradiation

Extracted ^{99}Mo to Purification

^{99}Mo Shipped to Generator Facility

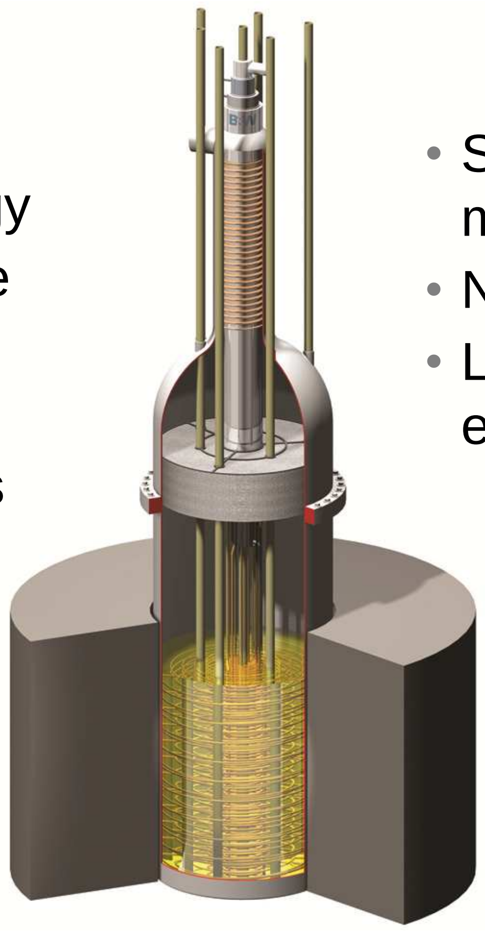
^{99}Mo Extraction

^{99}Mo Purification & Processing – Existing Technology

B&W Module

Features

- Aqueous homogeneous reactor – proven technology
- Low enriched uranyl nitrate solution
- ~220 kW modular units
- Large negative coefficients of reactivity
- 80°C and atmospheric pressure
- Small vessel



Benefits

- Simple, no separate target, much less waste
- Non-proliferation attributes
- Low power, low stored energy, small footprint

History and Physics of Aqueous Homogeneous Reactors

technical services group

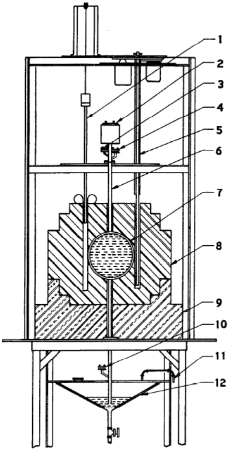
Erik Thomas Nygaard
Nuclear Analyst

Nuclear Regulatory Commission May, 17 2010

Outline

Short History of AHRs

- At Cavendish Lab in England, aqueous systems were early experimental platforms
- AHR LOPO first reactor to use enriched uranium; operated in the Summer of 1944 at Los Alamos [1]
- Experience with LOPO lead to other Los Alamos AHRs and many others
- AHRs were identified as excellent neutron sources and a good fit for research institutions [2]



International AHRs

Name	Country	S.S. Power [kW]	Year Critical	Year Shutdown
DR-1 (L-55)	Denmark	2.0	1957	2003
Mirene	France	0.0	1975	1988
Silene	France	1.0	1974	2010
FRF-1 (L-54)	Germany	50	1958	1973 [3]
BER-I (L-54)	Germany	50	1958	1973 [3]
Adibka (L-77A)	Germany	0.1	1967	1972
Purnima II	India	0.001	1984	1986
L-54M	Italy	50	1959	1979
Stacy	Japan	0.2	1995	Operating
Tracy	Japan	10	1995	Operating
JRR-1 (L-54)	Japan	50	1957	? [2]
Argus	Russia	20	1981	Operating
Hydra	Russia	10	1972	Operating
WBRL	Taiwan	100	1983	1989
Hazel	UK	0.0	1957	1958

- At least 12 AHRs in 9 different countries spanning 6 decades [4, 5]

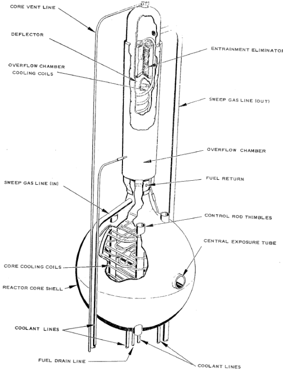
Domestic AHRs

Name	Location	S.S. Power [kW]	Year Critical	Year Shutdown
LOPO	New Mexico	0.0	1944	1944
HYPO	New Mexico	5.5	1944	1950
SUPO	New Mexico	25	1951	1974
L-85	California	3	1952	1980
LIWB	California	0.5	1953	1961
NCSU	North Carolina	10	1953	1961
L-54, ARR/IIT	Illinois	75	1956	1967 [3]
KEWB	California	50	1956	1967
L-47	California	0	1957	1958
L-77, U of Pr	Puerto Rico	10	1959	1979
L-77, U of Wy	Wyoming	0.01	1959	1974
L-77	California	0.01	1960	1974
L-54, WRRR	D.C.	50	1962	1970
L-77, U of Nv	Nevada	10	1963	1974
Kinglet	New Mexico	0	1972	1977
L-77, UCSB	California	0.01	1975	1986
SHEBA	New Mexico	2	1980	2000
LAPRE-1	New Mexico	2000	1956	1957
LAPRE-2	New Mexico	1000	1959	1959
HRE-1	Tennessee	1000	1952	1954
HRE-2	Tennessee	5200	1957	1961

- Over 18 AHRs were operated in the US between the 1940s and 1990s [4, 5, 1]

Summary of AHR History

- AHRs date back to Manhattan Project
- Became very popular, international technology for research reactors in late 50s, early 60s
- In 1958, AHRs had "a longer history of operation than any other type of research reactor utilizing enriched fuel" [2]
- *AHRs are not a new technology*
- *History has proven that AHRs are safe and reliable*



Outline

Basic Physics of AHRs

- Uranium dissolved in solution; concentration limited by solubility in the fuel solution
- Large kinetic energy transfer between fission products and solution results in radiolysis
- Radiolytic gases create voids in the reactor core; must be managed as gases leave the core
- Primary reactivity feedback mechanisms are void creation and temperature change

Advantages and Challenges of AHRs

- **Advantages:**
  - High neutron economy
  - Simple fuel preparation and fuel addition
  - Simple control systems
  - Inherent negative reactivity feedback
  - Limited upper temperature
  - Favorable dynamics

- **Challenges:**
  - Sustained boiling
  - Mitigating precipitation
  - Combustible radiolytic products
  - Multi-physic results of gas production

Understanding and Controlling Challenges

- **Boiling:**
  - Boiling has been demonstrated as a stabilizing phenomena in AHRs [6, 7]
  - Main concern is the chemistry effects associated with the pH gradient
- **Precipitation:**
  - Precipitation products threaten the fission product boundary
  - Maintaining solution properties mitigates precipitate formation
- **Radiolytic gases:**
  - Gases produced are flammable and subject to detonation
  - Gas management system must perform safety functions
- **Gas production physics:**
  - Dynamic behavior must not jeopardize pressure boundary
  - Collapse in void would result in positive reactivity insertion

Summary of AHR Physics

- AHRs behave very differently than solid fueled reactors
- AHRs have two primary reactivity feedback mechanisms:
  - Temperature
  - Voiding
- Size and fuel form of AHRs provide them with significant technical advantages
- Challenges of AHRs become major factors in design of the system

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Codes and Code Usage for MIPS Reactor Analysis

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Codes for MIPS Reactor Analysis

- B&W has identified, procured, and developed several codes capable of modeling the MIPS reactor
- The codes B&W intends to use are:
  - MCNP
  - SCALE
  - WARP
  - FETCH-MIPS
- MCNP and SCALE are industry standard codes
- WARP is an internally developed calculation sequence; FETCH-MIPS is being developed under contract with Imperial College - London (ICL)

MCNP

- *Monte Carlo N-Particle* transport code is developed and maintained by Los Alamos National Lab
- MCNP may be used to solve for the transport of neutrons, photons and/or electrons; it can also determine the eigenvalue for critical systems
- Current version used by B&W is MCNP5-1.51
- B&W will either use MCNP5-1.60 or MCNP6 (depending on release date)

SCALE

- *Standardized Computer Analyses for Licensing Evaluation* is a modular code system developed and maintained by Oak Ridge National Lab

- SCALE may be used to solve many different types of problems which include:
  - Criticality
  - Radiation source terms
  - Shielding
  - Isotopic depletion
  - Reactor physics
  - Sensitivity and uncertainty

- Current version used by B&W is SCALE6.0

- B&W will either use SCALE6.0 or SCALE6.1 (depending on release date)

WARP

- *Williams's Analytics Represented in Python* is a B&W developed calculation sequence based on the work of Professor M.M.R. Williams of ICL

- Program couples point reactor kinetics with temperature and voiding feedback

- Initial development has been completed

- Additional capabilities must be incorporated before conclusively demonstrating safety

FETCH-MIPS

- *Finite Element Transient Criticality* for a *MIPS* reactor is a code developed and maintained by Applied Modeling and Computation Group (AMCG) at ICL
- FETCH-MIPS is a specialized version of FETCH that includes additional features
- Multi-physics code that couples fluid dynamics and neutronics in both 2- and 3-dimensional geometries
- FETCH-MIPS development is ongoing and "final" version will be released in October 2011

Code Usage for MIPS Reactor Analysis

- Codes may be characterized by their functionality and intended usage
- For functionality, code may categorized as either:
  - *Static* or
  - *Transient*
- For intended usage, code may be categorized as either:
  - *Necessary for the demonstration of safety* or
  - *An additional tool*

	Demonstration of Safety	Additional Tools
Static	SCALE	MCNP
Transient	WARP	FETCH-MIPS