Considerations in the Design of a High Power Medical Isotope Production Reactor

Russell M. Ball
Ball Systems Company
Lynchburg, Virginia USA

H. William Nordyke, CEO, TCI
Roy Brown, VP, TCI
Albuquerque, New Mexico

Historical Background:

A nuclear reactor consisting of an enriched uranium salt (such as uranyl nitrate or uranyl sulfate) dissolved in ordinary light water was first suggested by Richard Feynman in 1944. Such a reactor was constructed at the (now) Los Alamos National Laboratory (LANL) that same year.

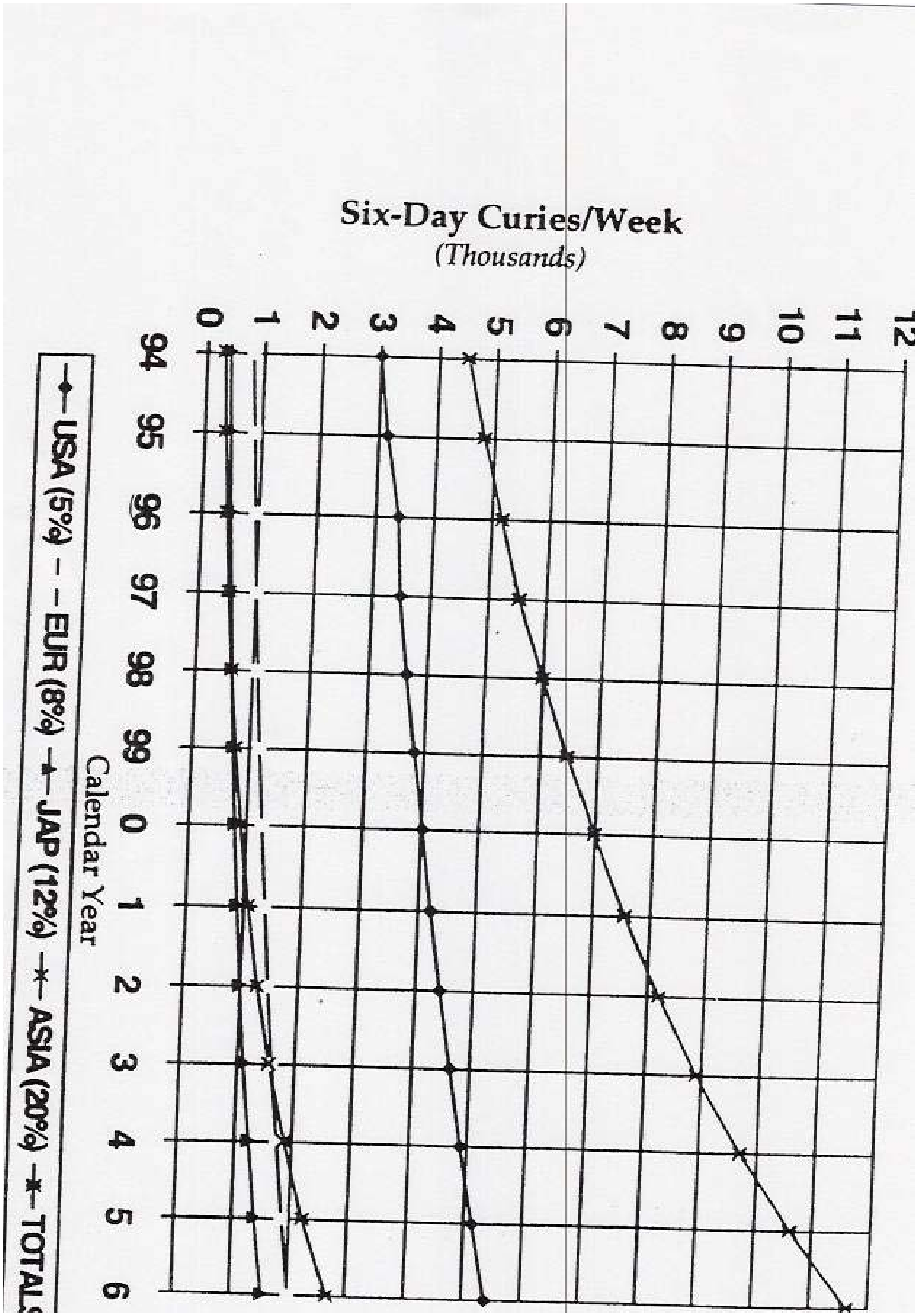
Several later versions at higher power were constructed at LANL and later, in the 1950's and 60's, commercial versions were designed and sold by the Atomics International Division of North American Aviation. One such 50 kW reactor was purchased, constructed and operated by the Walter Reed Army Medical Center in Washington, DC, USA. The reactor is described in the Hazards Summary Report, A.I. 3739 which wa documented on April 5, 1961[1].

Similar designs were developed in Russia, Taiwan and elsewhere at national laboratories and universities.[2] These reactors were used for research, principally as neutron sources.

In 1992, Ball[3] described how an aqueous homogeneous reactor (AHR) could be designed to produce medical isotopes, such as Mo-99, without the use of targets. In 1999, the Argus reactor, a 20 kW AHR at the Kurchatov Institute in Moscow, Russia, was adapted to produce Mo-99 for medical diagnostics.

The need for higher power:

Figure 1, "World Demand for Mo-99 vs Years", shows the projected demand for Mo-99 based on information available in 1998. A Medical Isotope Production Reactor (MIPR) operating at 100 kW on a five day cycle each week can produce 3500 curies of Mo-99 (700 six-day curies). As discussed in the IAEA TecDoc on M0-99 production technologies, at the estimated cost for construction and operation, this is about the break-even point for a commercial reactor[4]. Thus, the power level of the MIPR should be about twice that of AHRs constructed in the 1960's.


Six-Day Curies/Week
(Thousands)
0 1 2 3 4 5 6 7 8 9 10 11 12
94 95 96 97 98 99 0 1 2 3 4 5 6
Calendar Year
USA (5%) EUR (8%) JAP (12%) ASIA (20%) TOTAL

Several design considerations must be evaluated to assure that a power level of 100 kW (or higher) can be safely achieved. These are:

1. Heat removal from the solution
2. Recombination of radiolytic gases
3. Adequate radiation shielding
4. Stabilty of reactor power with fluctuating reactivity
5. Adequate cooling of the reflector
6. Independent shutdown mechanisms
7. Reactor volume

Heat Removal:

The commercial aqueous homogeneous reactors, such as the L-54, sold by Atomics International in the 1960's were rated at 50 kW and their technical details[5] on heat removal can be extrapolated to higher powers.

Heat was removed from the reactor solution through the use of 10 parallel sections of stainless steel cooling coils. The outside diameter of the tubes was 6.35 millimeters. The total length of the immersed tubes was 27.4 meters and the area of the cooling surface was 0.547 square meters.

The temperature rise at 50 kW with a coolant flow of 1 liter/second was 13.3 oC. The average reactor fluid temperature was 79 C and the inlet coolant temperature was 29.4 C and the outlet 42.8 C. One can compute that the average temperature drop across the tubing and heat transfer film (inside and outside the tubing) was 42 oC.

At a reactor power of 100 kW, the temperature drop for the same surface area would be 84 oC which is unacceptably high, thus the surface area should increase in proportion to the reactor power and 20 parallel sections of coils is the selected design point. The cooling coil volume is about 1.8 liters.

Further improvement in cooling is possible by reducing the inlet temperature of the primary coolant from 29.4 C to 5 C. This is readily done using package cooling units such as those built for air conditioning units. For redundancy, several units would be installed. A 30 ton system (consisting of four units), adequate for 100 kW, would cost about $20,000.

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1 "Hazards Summary Report", A.I. 3739, April 5, 1961..In the U.S. Nuclear Regulatory Commission document room.

2 Voronen, A.A., et. al., Avtomatisantsia Preprint, IAS-1689, 1968

3 "Medical Isotope Production Reactor" filed December 8, 1992 by Russell M. Ball as 07/986,939 at the U.S. Patent office

4 "Production technologies for molybdenmum-99 and technetium-99m", IAEA-TECDOC-1065

5 Nuclear Engineering Handbook, Harold Etherington, Editor, Section 13-130, 1958