A New DOE Research Reactor Study

C. D. West

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What initiated the study?

- A proposal from Pacific Northwest Laboratory to restart the Fast Flux Test Facility as research reactor for isotope production and irradiation testing.

- The Department of Energy did not decide either way, but committed to an Environmental Impact Statement (EIS) concerning a restart

- An EIS actually involves consideration of alternative actions (including "no action")
  - they decided to study, to the degree necessary, a new, purpose built research reactor and an accelerator neutron source for the same purpose

"Some Problems"

- The time scale was very short
  - One month between actually receiving funds (October) to start work and first scheduled input to DOE
  - a draft EIS for internal DOE use in January!

- It is now getting stretched out (of necessity)
  - follow-on funds to continue work have not arrived on schedule
  - however, no new schedule has been given

- The design criteria were not very well defined
  - the FFTF proposal, in my opinion, was based on what the FFTF could do (with extensive development work!)
  - I think a research reactor design should be based on what researchers need, rather than on what the proposer wants to provide

ORNL/UT Role

- ORNL gladly agreed to provide technical input on the new reactor design
  - we will not be doing the calculation of "source terms", or of the environmental impacts
  - I was asked to form and lead the team to define the reactor design concept
  - this was <u>not</u> a conceptual design project (too little time and money by a factor ~10-100

- Others at ORNL would consider design basis accident definitions for further analysis, construction and operating cost estimates, utility and infrastructure requirements (including hot cells), effluents and waste shipments

ORNL/UT Role (cont)

- UTK Department of Nuclear Engineering department head and staff were enthusiastic and willing to join the effort
  - their knowledge and experience have been and will be essential to producing a good, defensible concept
  - it was a great relief to me when they agreed to join the team

The Players

- It may be a surprise to learn how many people are needed to conduct even such a short and limited study as this (if it is to be done right)
  — these people, and more, have been or will be involved in the reactor design concept task alone

Name	Organization	Name	Organization
[redacted]			
Jim Bucholz	CPED	Igor Remec	CPED
Lee Dodds	UT	Art Ruggles	UT
Dave Felde	ETD	Doug Selby	CMO
Jess Gahin	CPED	Charles Slater	CPED
Mike Harrington	ENG	David Sulfredge	ETD
David Morris	ETD	Ken Thoms	ETD
Fred Mynatt	UT	Larry Townsend	UT
Ronald Pevey	UT	Colin West	CMO
Trent Primm	CPED	Grady Yoder	ETD

- We have had super cooperation and help from colleagues at the European Community Research Reactor at Petten, Netherlands
  — Ken Thoms visited them last week

Some Requirements from DOE

- Isotope production, including up to 5kg/yr of ^{238}Pu
- Irradiation testing (structural materials and fuels etc.)
  - for fission and fusion reactors
- Capability of adding neutron beam facilities for basic research
  - but, it is not clear how this would be accomplished at FFTF
  - and it is really hard to believe in a cold neutron source at FFTF
- Must use low enriched (<20% ^{235}U) fuel
  - but, FFTF uses highly enriched uranium, or plutonium
- First input to DOE on the design concept in November

Some Requirements We Placed upon the Design

- Operating cycle length ~25 days
- 80% availability goal
- Affordability (capital and operating)
- Unprecedented safety for a reactor of these capabilities
  - accident resistance and mitigation features to be incorporated
- ALARA principles incorporated into design
- Minimal generation and transportation of waste
  - to reduce environmental impacts

Origin of the New Research Reactor (NRR) Design Concept

- Although safety features and other innovations from the Advanced Neutron Source Project can be adopted, the basic ANS reactor design is unsuited to this mission
  - ANS was optimized for beam production, which mandates a very small core so that reducing the fuel enrichment exacts a heavy performance penalty
  - for the same reason, simply modifying the High Flux Isotope Reactor (HFIR) design (which was optimized for irradiation capabilities) would not be appropriate

- The only way (we felt) to define major parameters of an NRR in the few weeks allotted was to base it on an existing, successful and flexible design for which extensive data would be readily available

Origin of the New Research Reactor (NRR) Design Concept (cont)

- The chosen baseline was the European Community's High Flux Reactor (HFR) at Petten in the Netherlands

- The HFR was originally a sister to the Oak Ridge Research Reactor, but major improvements have been made to it
  - other nations typically update their research reactors to a new level of capability, and build new ones as necessary

- HFR is truly a multipurpose facility, performing isotope production, fuel testing, materials testing, safety experiments, neutron beam experiments (but no cold source), and boron neutron captive therapy
  - it currently operates at 45MW, but in the 1980s was fitted with a new reactor vessel designed for 60MW

Origin of the New Research Reactor (NRR) Design Concept (cont)

- The HFR uses so called MTR fuel elements, which are curved, aluminum clad plates fitted into square section boxes, about 4" on a side, assembled into a core
  - this is very flexible
  - each element is very subcritical (safety)
  - [redacted] and used for control rods, reflectors, or irradiation capsules

- The initial team members guessed (of course, I mean "estimated on the basis of their extensive experience and knowledge, combined with sound engineering judgement") that a power level of up to 100MW might be needed to generate the required amount of 238-Pu

- One team member (Ken Thoms) had spent a year on assignment at the HFR
  - with lightening speed (by ORNL/DOE standards) he was despatched to Petten to gather more data
  - we spent a lot of time deciding, and listing, what were the most important questions for him to ask
  - his visit was very successful

Reactor Design Concept

- Based on the HFR Petten/ORR tank-in-pool configuration
- 40 year design life
- MTR type fuel elements
  - 50% longer than the HFR elements to reduce power density and provide more irradiation space
- Light water cooled and moderated

Reactor Design Concept (cont)

- Aluminum clad fuel
  - — axial grading of fuel thickness to maximize thermal hydraulic safety margins
  - — 19.75% enriched uranium

- Pending core physics calculations, fuel is U_3Si_2/Al mixture with 4.8gU/cc
  - — ^{10}B burnable poison

- Power level 100 MW
  - — pending core physics calculations

Reactor Design Concept (cont)

- Minimum cycle length 25 days
  - goal of 80% availability
- Upflow coolant
  - HFR and ORR designs are downflow, ANS design has upflow
- Reactor and pools housed in a containment building of <1% per day leakage with 50 kPa pressure differential
- On-site dry storage of spent fuel
  - after cooling in-pool
- In-core and ex-core irradiation positions
  - some positions accessible during operation
  - direct, straight line access from above
  - ability to accommodate spectral tailoring
- Minimum of 3 in-core rabbit facilities

Reactor Design Concept (cont)

- Capability of accessing irradiation positions during [illegible]

- Poolside hot cell facility for dismantling irradiation capsules
  - canal access to processing hot cells

- Capability for fission and fusion reactor fuel and structural material irradiations

- Capability for radioisotope production (including 238-Pu)

Reactor Design Concept (cont)

- Capability of installing special purpose fuel elements for high fast flux isotope or fusion materials irradiations
  - fuel elements with some plates replaced by irradiation capsules

- Provision for installation of four beam tubes and a cold neutron source if desired

- Provision for installation of epithermal beam for boron neutron-capture therapy if desired

HFR and NRR Parameters

Characteristic and unit	HFR (est)	NRR (not optimized)
Operating power, MW(th)	45	100
Core inlet temp, °C	40	40
Core outlet pressure, bars	2.3	2.3
Core velocity in channels, m/s	6.8	10
Primary coolant flow in core, kg/s	1.17×10^3	1.72×10^3

HFR and NRR Parameters (cont)

Characteristic and unit	HFR (est)	NRR (not optimized)
Core pressure drop, bars	1.1	3.3
Core inlet pressure, bars	3.65	5.6
Core outlet temp, °C	51	54
Core volume, L	145	217.5
Power density, kW/L	310	460
Average heat flux in mid position, MW/m^2	1.00	1.48
Peaking factor (?)	1.6?	1.4?
Max heat flux in mid position, MW/m^2	1.6	2.1