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Reflections on the MSRE Experience

Molten Salt Reactor Workshop 2018

Syd Ball
Reactor and Nuclear Systems Division (retired)

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ORNL is managed by UT-Battelle, LLC for the US Department of Energy

U.S. DEPARTMENT OF ENERGY

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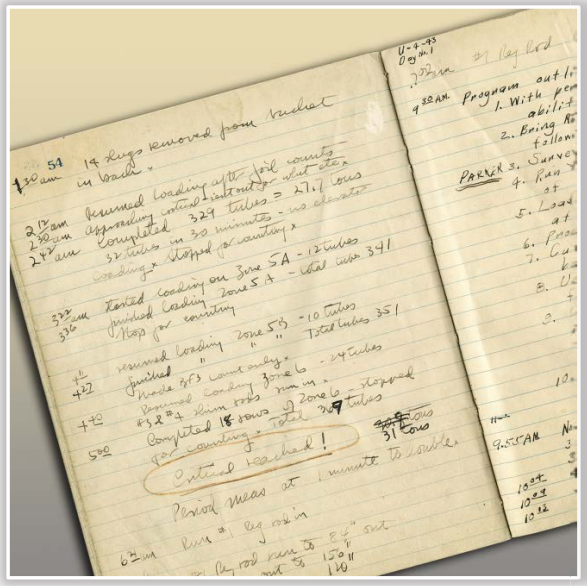
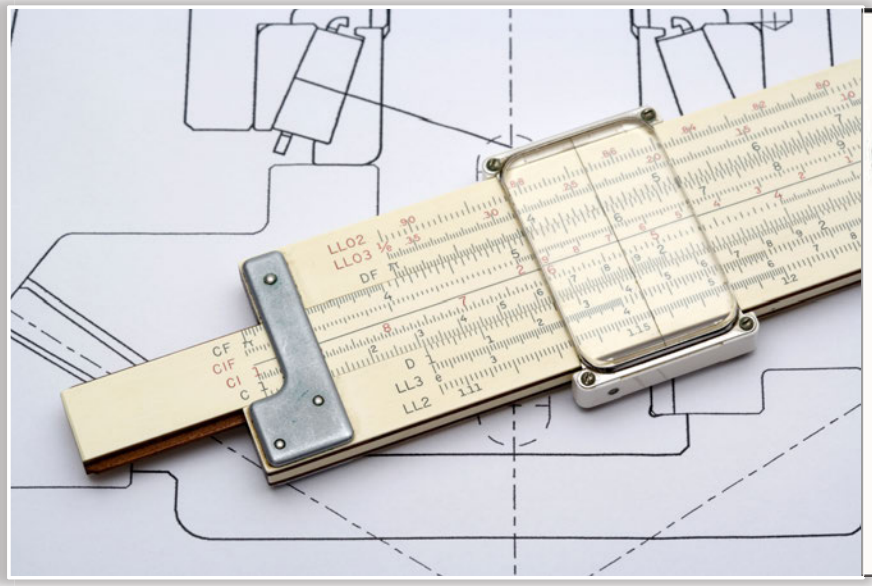
Inspiration in 1957

- Why should I move to East Tennessee?
- Alvin Weinberg's vision for peaceful uses of nuclear energy!

1950s analytical capabilities were modest





ORNL Graphite Reactor
"Data Logger"

ORACLE digital computer: “State of the art”

2k word core memory (vacuum tubes) with speed ~14 kiloflops (40-ton a/c)

Speed of ORNL’s new Summit system: ~200 petaflops (>10 trillion times faster)

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So how did it go for Alvin's vision?

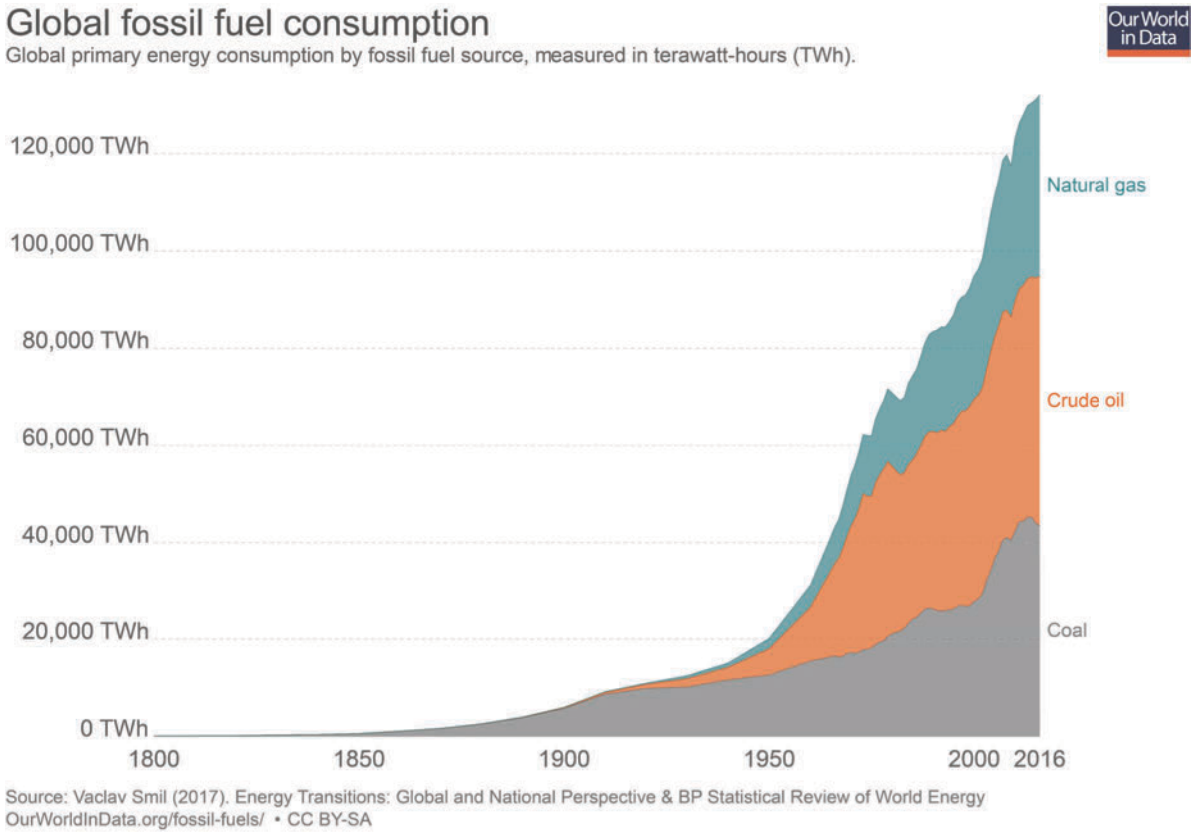
- Technology: Lots of progress!
- Nuclear power: "Lots" also, and "Great Potential"!

Weinberg's early goals for nuclear power:

Education for nuclear power	Reduce fossil fuel use	Explore reactor concept options	A solution: Fluid fuel reactors!
Oak Ridge School of Reactor Technology (ORSORT)	Resource depletion and pollution Later (1976): "Climate change problems in 21st century"	"New Piles Committee"	Safety improvements (over LWRs): No core melt accidents! Higher temperatures for greater efficiency: Gas turbine Expand nuclear fuel resources: Thorium fuel cycle

Good reasons to reduce fossil fuel use

- Air pollution: "6 million early deaths per year" (International Energy Agency – IEA)
- Resource depletion: Fuels "gone forever"



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Tough job handling pollution from a coal-fired plant!

One day of a 1-gigawatt coal-fired plant uses 80 rail cars of coal

Each coal car weighs 100 tons

Spent fuel from one human lifetime's worth of nuclear electricity

TED.com

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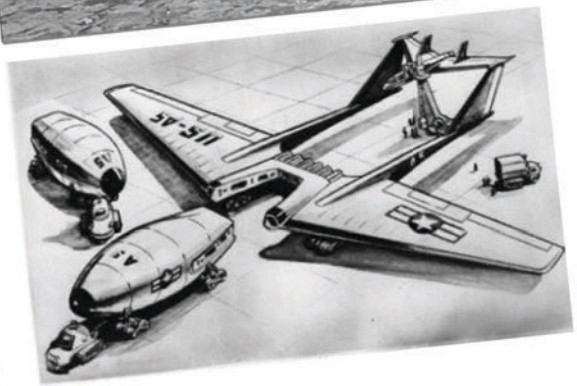
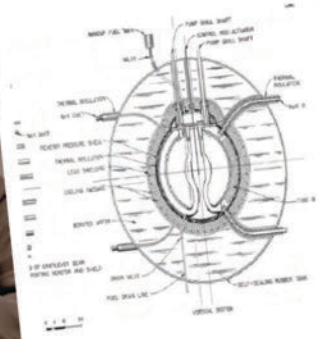
ORSORT

- ~Master's degree (Doctor Of Pile Engineering)
- Admiral Rickover
- "Labs" @ ORNL reactors
- "Buttermilk reactor"
- Missing: Uncovering problem with LNT (Linear No Threshold) theory for health effects due to radiation

ANP: Early support for ORNL fluid fuel reactor development (pre-ethics committees)

Aircraft Nuclear Program Allowed ORNL to Develop Reactors





It wasn't that I had suddenly become converted to a belief in nuclear airplanes. It was rather that this was the only avenue open to ORNL for continuing in reactor development.

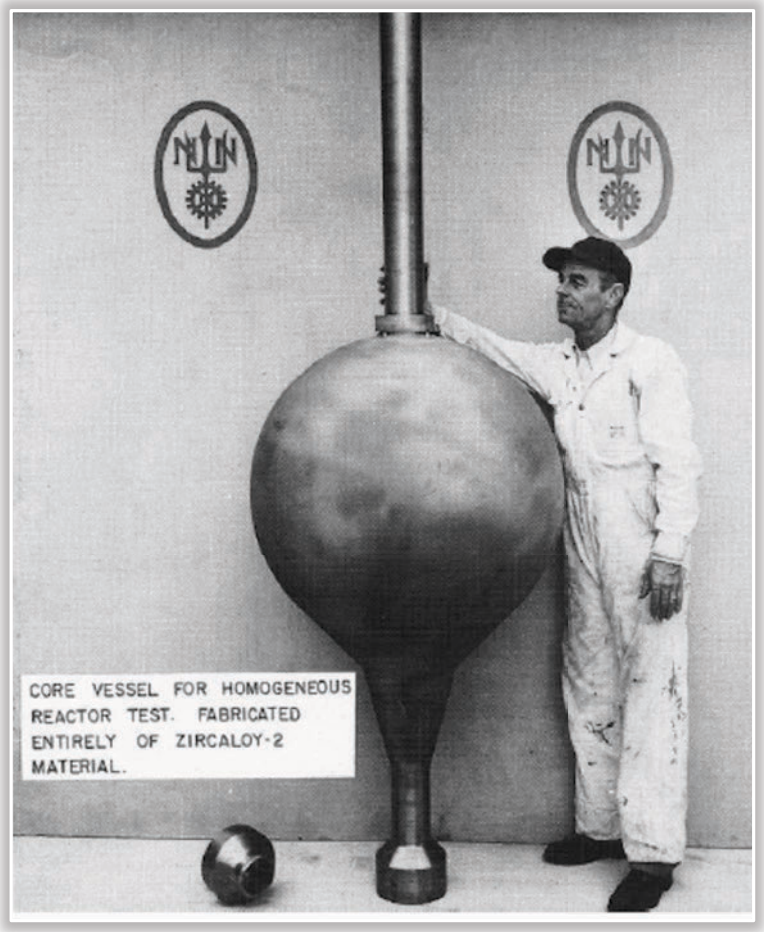
That the purpose was unattainable, if not foolish, was not so important:

A high-temperature reactor could be useful for other purposes even if it never propelled an airplane...

—Alvin Weinberg

Homogeneous Reactor Test (HRT)

- Uranyl sulfate in heavy water: Demonstrate stability, reliability, and safety
- Precursor to planned version with thorium in the blanket region for U-233 production



HRT core vessel

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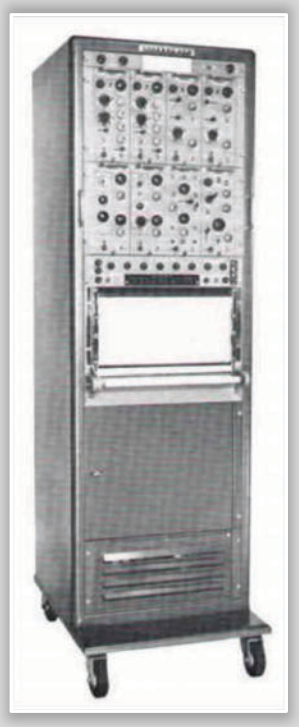
HRT scale model in control room

HRT's Sanborn recorder with Syd hiding in the corner

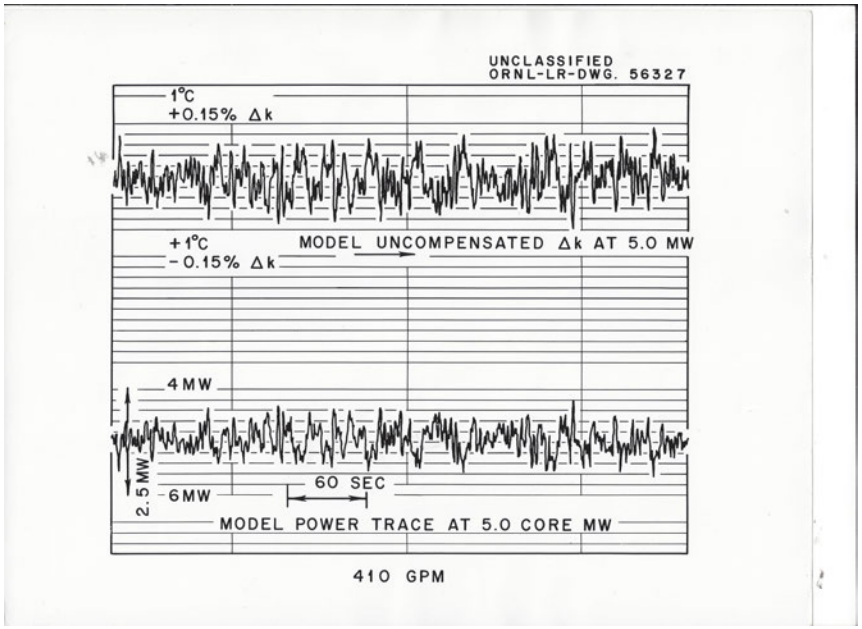


JFK: "Which pipe did the $5 million go down?"

“Early” noise analysis: Why HRT power fluctuations?

- Full-scale hydraulic mockup vessel, salt solution, conductivity probe
- Signal to analog computer (“home made”) simulating neutronics power and thermal hydraulics at various reactor power levels
- Good matches with reactor: Varying fractions of inlet fluid short-circuiting core changes average fuel residence time*

* Ooops!



Power and outlet temperature noise signals from model and reactor were similar

HRT R.I.P.

- Middle of the night
- Bob Moore (Syd's I&C boss) gets phone call from HRT operator:
  - "Hey, Bob, your instruments are screwing up again." (...usual)
- Bob checks it out: "I&C OK"
- Diagnosis:
  - Some uranium stayed in the core "too long," overheated, plated out on the core vessel, and burned a hole in it....

Shortly after HRT:
The Molten Salt Reactor Experiment (MSRE) Project

Molten salt

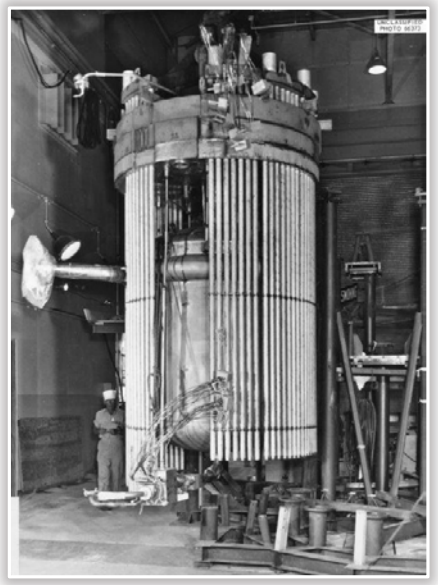
- Great chemical stability!

MSRE major goals

- High temperature (for efficiency)
- Passive safety
- Demonstrate reliable/ predictable operation
- Feasibility as precursor for thorium fuel cycle (operated with U-235 and U-233, but not with thorium)

Young Syd's MSRE roles

- I&C (instrumentation and controls) design
- Dynamic analysis and experiments
- Operator training simulator



Reactor vessel (with heaters)

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MSRE's famous air-cooled radiator

- 8 MW instead of 10 MW – Oops h-calculation
- Its temperatures were all Fahrenheit

MSRE air-cooled radiator with its door open

MSRE dynamics

How well can MSRE dynamics be predicted over its full power range?

- Inherent safety, stability, controllability
- Low-power oscillations (predicted)
- Opportunity: Case made for a detailed study – theory and experiment (with funding!)

Results

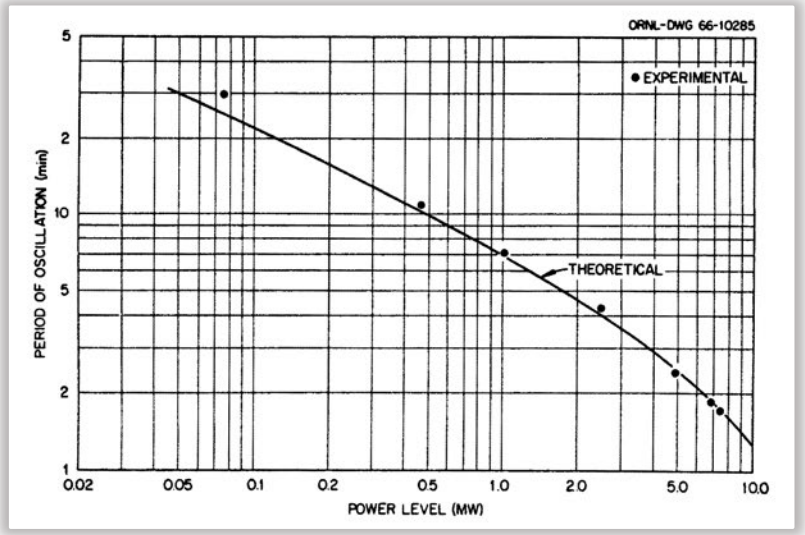
- Dynamics were well understood – full range of power
- Inherent safety features were confirmed

MSRE was fun!

- Concern for dynamic stability:
  - Funding for Syd and Tom Kerlin
  - Extensive simulation predictions for all power levels
  - Confirmatory tests using pseudo-random binary sequences (PRBS) rod jog inputs
- Results: Bingo! (and stable)

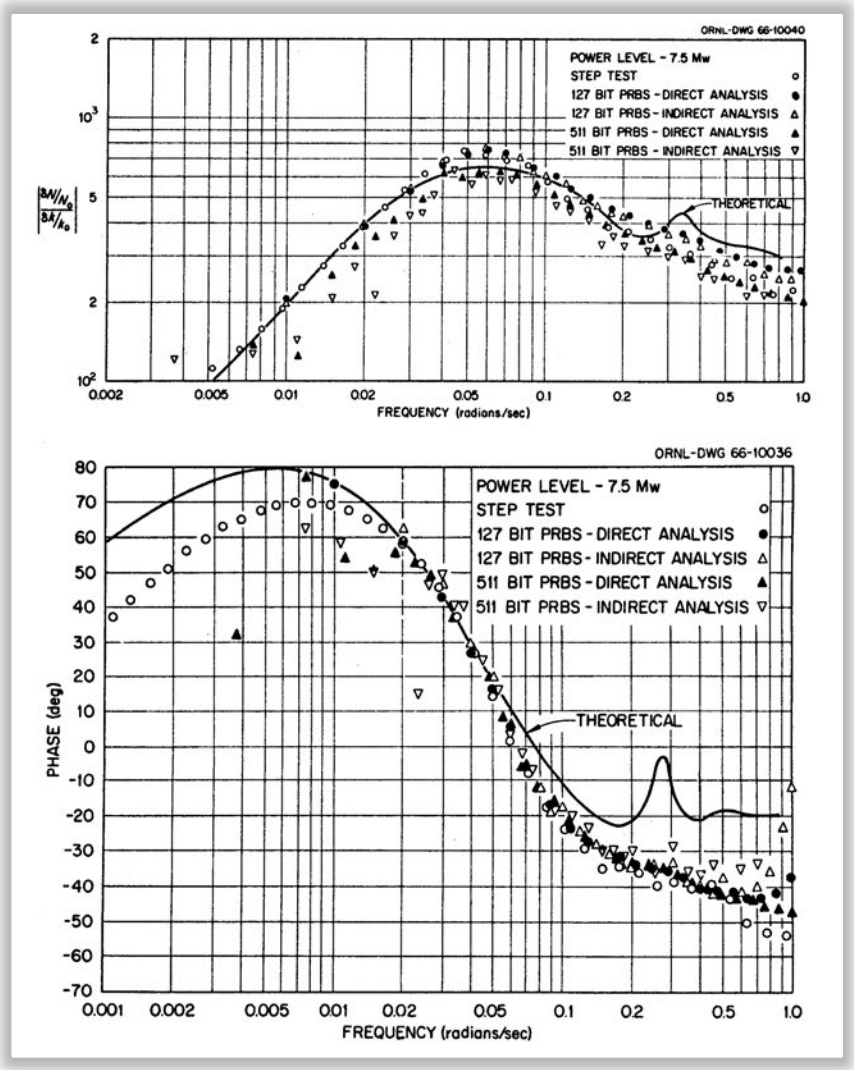
PRBS control rod jogging: Input signal

MSRE natural periods of oscillation:
As power increases, oscillations are more damped, and at higher frequencies



Why the oscillations at low power?

- Neutronics: Critical, ~0-power
- Thermal: ~Adiabatic with ~0 air coolant flow in the salt-to-air cooled radiator
- (Each ~ an “integrator” with 90° phase shift)
- Coupled: 180° phase shift = “oscillator”

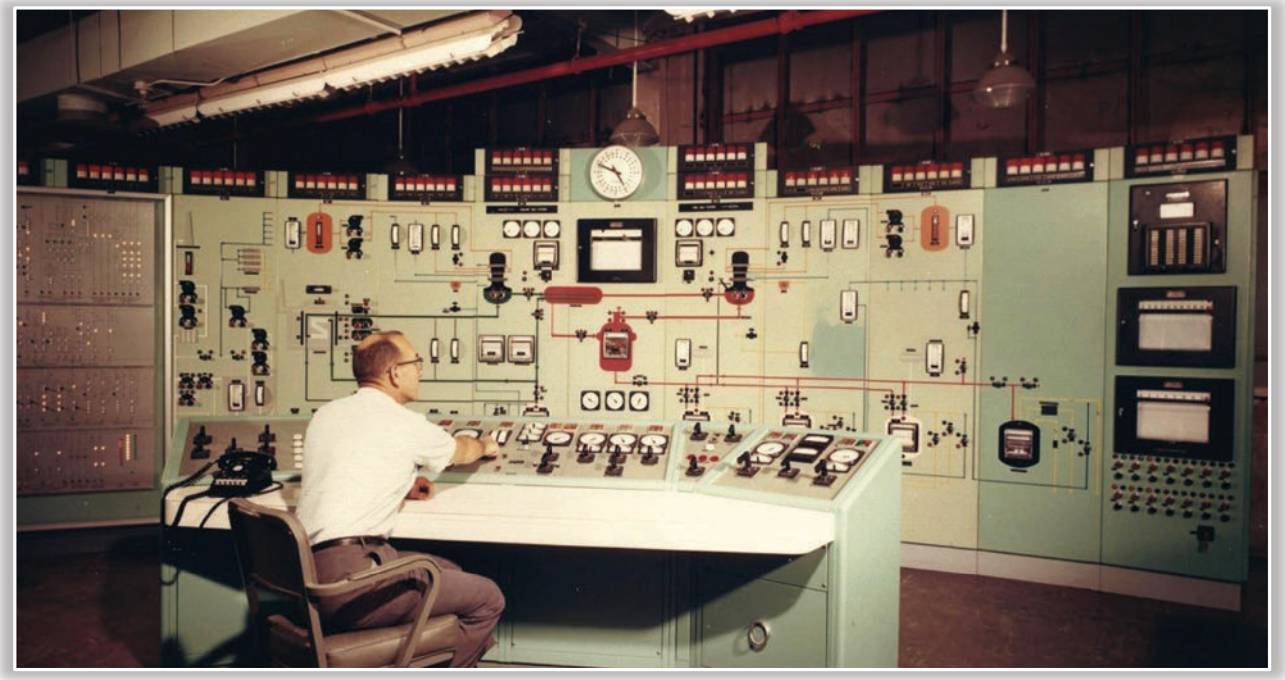


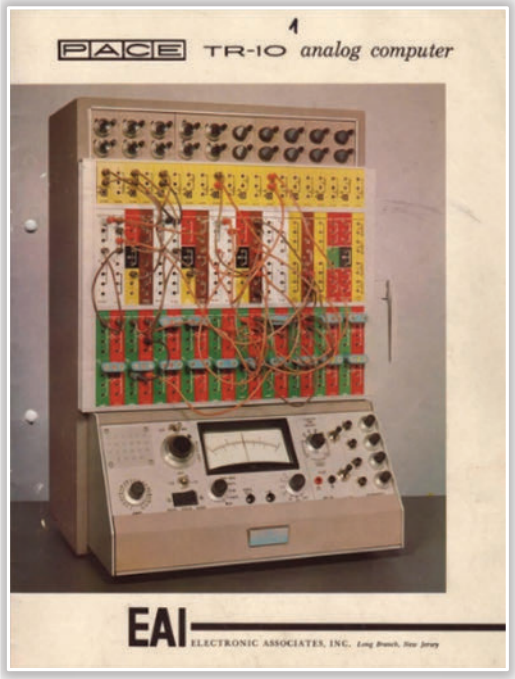
Frequency response testing, MSRE at 7.5 MW: Good under-standing and confirmation of the process dynamics

PRBS test excitement

- Dark and stormy night
- PRBS at-power testing running smoothly
- Rod "jogger" sticks in "withdrawn" position
- Power level rises, exceeds "maximum" (highest ever!)
- Power decreases (to normal) on its own
- Experimenters (Tom Kerlin and Syd) record event, go home
- Next day: "No need to file an incident report"
  - [Thanks, Dick Engel]

World's cheapest reactor training simulator for pre-operation operator training





MSRE control panel was powered by two TR-10 analog computers

MSRE: Insights for current MSR development

Contributors to success

- Project entirely at ORNL (not split between sister labs)
- Inspirational leadership and management (and limited bureaucracy)
- Close collaboration between disciplines (teamwork)
- Exceptional nuclear-chemical and innovative maintenance engineers
- Operation and experiments confirmed predictions very well
- Consistent (and adequate) funding (while it lasted)
- Everyone working on it ENJOYED it!

Problems

- Unexpected corrosion problems (later resolved)
- Funding cut for future MSR "breeder" designs (AEC shift to liquid metal fast breeder)
- Insufficient funding for "mothballing" led to major cleanup cost … later

Alvin Weinberg

With Glenn Seaborg

MSRE strip chart

His table

Dick Engel with Glenn

Renaissance man as well as scientist and Lab director:
Pianist, tennis player, and a terror at Division Information Meetings

Alvin Weinberg on tackling complex problems

“

In basic research the strength of laboratories like ORNL lies in the interdisciplinary composition of their staffs. Over and over again it has been demonstrated that the whole can be greater than the sum of its parts, that good people from diverse fields working together can make major scientific discoveries that are denied geniuses working in isolation.

Coherence is perhaps even more important in carrying out applied research. Many of the large jobs we are now undertaking at ORNL—the breeder reactor, civil defense, desalination, and the agro-industrial complex as an instrument for development of the world's hungry nations—these involve numerous technologies and viewpoints, some from the natural sciences, some from the social sciences, some even from the arena of public affairs.

The key to successful attacks on these complex questions is the existence of coherent teams working aggressively and with enthusiasm.

”

ORNL Review, Vol. 1, No. 1, 1967

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Thanks for your attention!