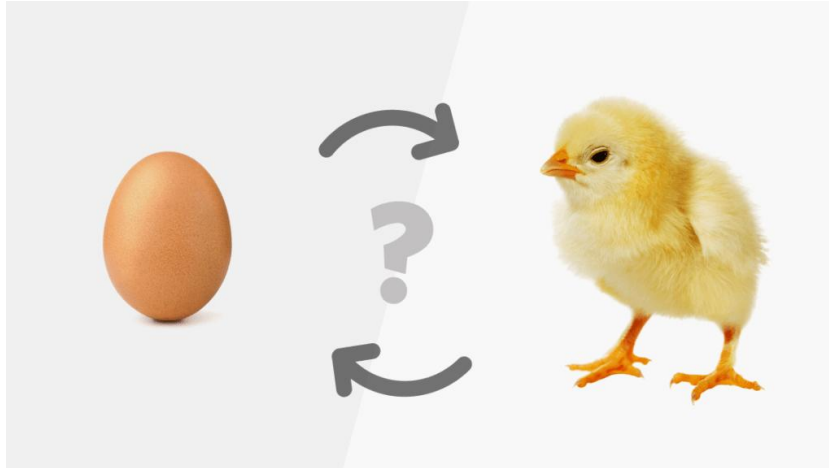


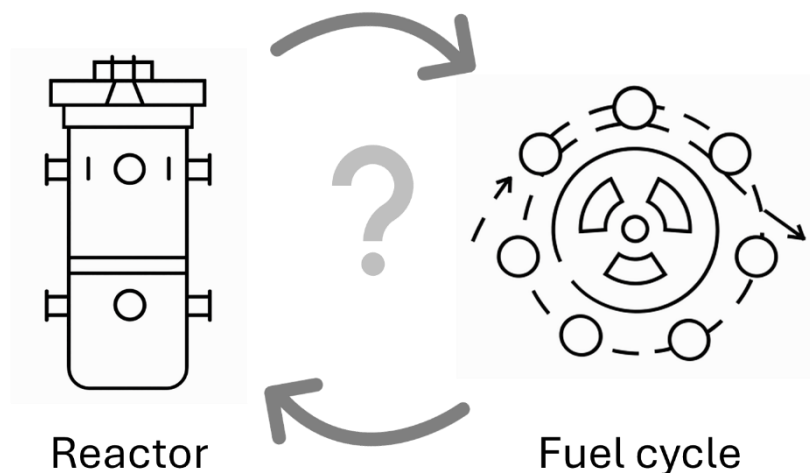
## Two Schools

If we want to design a poultry reproductive system, should we start with the chicken? Or with the egg?



In this [eternal paradox](#), the two are interdependent. We have to view the whole as a single, **coupled** chicken–egg system to resolve the paradox.

In the early 1940s many scientists in the United States were working on the [Manhattan Project](#). With the design and construction of the first nuclear bombs well underway, they turned their attention to systems for the production of energy from nuclear chain reactions - and they encountered a paradox. In such systems the fuel cycle influences the reactor design, and the reactor influences the fuel cycle design.



In a 1997 lecture, [Alvin Weinberg](#) recalled this period of exploration:

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*“There were two people at the metallurgical laboratory [the Manhattan Project], [Harold Urey](#), the isotope chemist, and [Eugene Wigner](#), the*

*designer of Hanford, both Nobel Prize winners who always argued that we ought to investigate whether chain reactors, engineering devices that produced energy from the chain reaction, ought to be basically mechanical engineering devices or chemical engineering devices. And Wigner and Urey insisted that we ought to be looking at chemical devices—that means devices in which the fuel elements were replaced by liquids.”*

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#### “THE PROTO-HISTORY OF THE MOLTEN SALT SYSTEM”

ALVIN M. WEINBERG, FORMER DIRECTOR OF OAK RIDGE NATIONAL LABORATORY, FEBRUARY 28, 1997



Harold Urey



Eugene Wigner

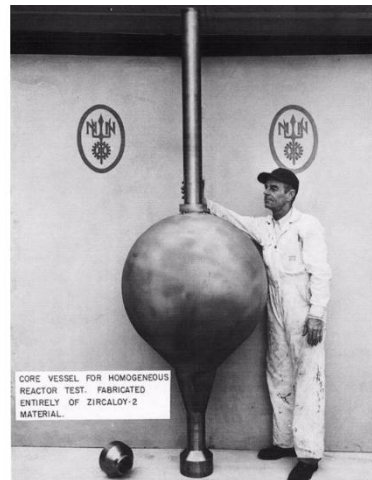
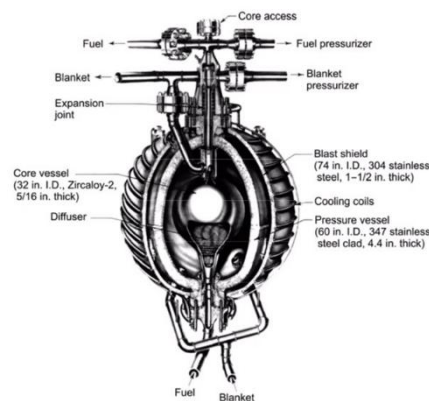
As early as 1944, Urey and Wigner had identified one of the most complex paradoxes in nuclear system design. Should the reactor be designed first, with the fuel cycle adapted accordingly - or should the fuel cycle be designed first, with the reactor built to match? In the coupled reactor-fuel cycle system, which **way of thinking** would produce the simplest overall system?

A chemistry-centred approach offered many advantages. A liquid fuel would be easier to prepare upstream of the reactor and easier to reprocess downstream. Inside the reactor, the liquid could simultaneously serve as fuel, coolant, and moderator, radically simplifying its architecture.

#### **But which liquid?**

Researchers at Oak Ridge National Laboratory launched the Homogeneous Reactor Experiment using uranium salts dissolved in water. At the time, this chemistry was well

understood thanks to the Manhattan Project, and the fact that water efficiently moderates neutrons made it possible to reach criticality using low-enriched uranium.

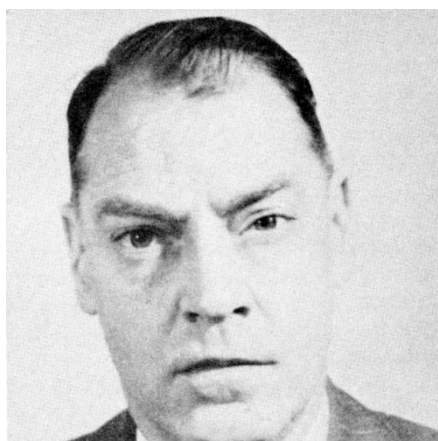


## Aqueous homogenous reactors

Early experiments showed that a liquid-fuelled reactor could indeed operate. But difficulties quickly emerged. Radiation caused the radiolysis of water, producing hydrogen and oxygen - a potentially explosive mixture. The hot solution was also highly corrosive, and keeping water liquid at high temperature meant high pressure operation.

Gradually, engineers realized that while the liquid fuel idea was promising, **water was not the right liquid.**

It was then that two Oak Ridge researchers, Raymond C. Briant and Edward S. Bettis, proposed an alternative: Dissolving uranium in molten salts. These liquids do not undergo radiolysis and can operate in a stable manner at high temperature and low pressure.



Ray Briant



Ed Bettis

And so began Oak Ridge's love affair with molten salts as fuels and coolants for reactors - and the rest is history.

A paper published by Weinberg in 1957, citing Briant as a posthumous co-author, compares the two approaches:

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*“Two very different schools of reactor design have emerged since the first reactors were built.*

*One approach, exemplified by solid fuel reactors, holds that a reactor is basically a mechanical plant; the ultimate rationalization is to be sought in simplifying the heat transfer machinery.*

*The other approach, exemplified by liquid fuel reactors, holds that a reactor is basically a chemical plant; the ultimate rationalization is to be sought in simplifying the handling and reprocessing of fuel.*

*At the Oak Ridge National Laboratory we have chosen to explore the second approach to reactor development.”*

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R.C. BRIANT & ALVIN WEINBERG, “[MOLTEN FLUORIDES AS POWER REACTOR FUELS](#)”, NUC. SCI. ENG., 2, 797–803 (1957).

Yet despite its potential, the chemistry-centred approach using liquid fuel has always struggled to prevail. Civilian nuclear power is largely the story of a school of thought centred on reactors and solid fuels.

This way of thinking is a direct legacy of the technology’s military origins. The Manhattan Project had an essentially unlimited budget and one clear objective: Produce plutonium for weapons. The priority was therefore to master the chain reaction and to build reactors capable of generating sufficient neutron flux. Fuel cycle matters such as recycling, materials management or resource optimization could be dealt with later.

When civilian nuclear power emerged after the war, this technical culture naturally persisted. It also reflected the state of knowledge at the time. Between the 1940s and 1960s neutron physics advanced rapidly, while the chemistry of irradiated fuels and the behaviour of fission products remained far more uncertain. Designing reactors with established and familiar solid fuels appeared to be the most pragmatic approach.

Industrial and political dynamics then reinforced this path. The international standardization around light water reactors ultimately structured the entire industrial ecosystem around this logic.

And yet nuclear energy is still [in its infancy](#). To fulfil its full potential in addressing the technological, societal, and environmental challenges of the 21st century - to become an

obvious choice across [all the vectors](#) of the fiercely competitive energy markets - we will need the simplifications made possible by the liquid fuels envisioned by Urey and Wigner, and the molten salt reactor solution invented by Briant and Bettis.

Ultimately, the future of nuclear energy technologies may come down to a single school of thought: an uncompromising and relentless pursuit of **simplicity**.

