

Slide 1 - Sir John Laurie Bt, Progrès Nucléaire

Good afternoon, and thank you for inviting me to speak at today's workshop.

My name is Sir John Laurie. I am an Industrial Architect and President of the French association Progrès Nucléaire.

I have been involved with molten salt reactors since 2012.

I'd like to make it clear at the outset that I'm speaking to you today as an advocate of the technology.

My purpose is not to suggest that every Molten Salt Reactor concept is safe, mature, or economically viable. They are not.

My purpose is to explain why I think molten salt reactors deserve to be considered as a distinct family of nuclear technologies, and why their safety case may require us to think somewhat differently from the way we think about conventional solid-fuel reactors.

Slide 2 - Promoting Molten Salt Reactors

Progrès Nucléaire is a French, independent and non-partisan association.

Our values are scientific, pragmatic, eco-modernist and independent.

That means that we try to base our arguments on scientific reasoning, to compare solutions objectively, and to look at nuclear energy as one of the tools available to improve human prosperity while protecting the climate and the natural environment.

Our missions include increasing awareness of molten salt reactor technology, encouraging investment in the technology, and creating a community in which the different stakeholders can exchange information.

I also write a personal blog called Fission Liquide, where I have explored many of the ideas that I will present today.

I mention this because I want to distinguish clearly between advocacy and regulatory assessment.

I am here to propose questions and ways of thinking.

The assessment of whether a particular reactor design satisfies the required safety objectives remains, of course, the role of the competent authorities.

So I hope you will listen to this presentation partly as a challenge: not a challenge to regulatory standards, but perhaps a challenge to some of the assumptions that we have inherited from the technologies with which we are most familiar.

Slide 3 - Introduction

The presentation will be in four parts.

First, what is an MSR, and why is there renewed interest in the technology?

Second, a short history, to understand where MSRs came from and where we are today.

Third, classification, including MSR Taxonomy and different industrial variants

And finally, I will finish with a few key messages about design and safety.

Slide 4 - What is a Molten Salt Reactor?

So what is a molten salt reactor? The Generation IV International Forum states that:

“Molten salt reactors are a class of nuclear fission reactors where molten salts serve as the reactor fuel, coolant, and/or moderator.”

The IAEA definition talks about reactors “in which molten salt has a prominent role in the core”

The important word here is “class”

This is not one single reactor, but rather a family of reactor designs. And as we’ll see later it’s a rather large and growing family.

Some MSR’s have liquid fuel. Some use molten salt only as coolant. Some use graphite moderation. Others are fast-spectrum systems with no moderator. Some use fluoride salts, while others use chloride salts.

So when we say “MSR safety”, we should be careful.

We are not discussing a single set of hazards, or a single safety architecture.

In fact, two designs can both be called MSR’s while having very different neutron physics, chemistry, materials, fuel-cycle arrangements and accident sequences.

For regulators, this diversity is important because it means that the regulatory conversation should, progressively, move away from the generic category “MSR” towards the characteristics of the particular design.

Slide 5 - A Three-legged Stool

So why has there been so much interest recently in molten salt reactors?

Well, nuclear energy has a problem. Even though it has an extraordinary value proposition, as a high power, low carbon, dispatchable source of energy, the nuclear industry has evolved from a military culture, which has not prepared it well for exposure to highly competitive national and international energy markets.

In my 14 years of molten salt reactor advocacy, I have heard beliefs such as:

“Nuclear is special – it’s not like other industries”

“Cost is not really an issue”, or

“Safety has no price”

But all industries have to balance value, cost and time, rather like the 3 legged stool that I’m showing here. Many promising nuclear energy projects have been cancelled because public or private investors could see no clear balanced path to getting their money back.

And we badly need those projects to succeed, because of the very considerable hazards of the fossil fuel alternatives. The most dangerous nuclear power plant is the one that doesn’t get built.

Nuclear energy systems come with inherent hazards, to humans and the environment. Achieving a level of safety that is proportionate to those hazards is an absolute prerequisite to any nuclear energy project. But it’s important to recognize that safety does not add value, only cost and time.

Slide 6 - To simplify, eliminate hazards!

Traditional nuclear safety engineering is **extremely** sophisticated at reducing risk.

We identify initiating events, analyse accident sequences, add prevention and mitigation, and demonstrate that residual risks are acceptably low.

We have become extremely good at making complex nuclear systems safe by adding layers of protection, redundancy, diversity, procedures and controls.

But that approach adds complexity – and complexity can itself be dangerous. In the context of the French EPR2 program, operators and regulators have been working together recently to identify and reduce complexity wherever possible.

Rules are indispensable in hazardous industries — but an increasing number of rules can eventually come at the expense of overall understanding.

Complexity can increase the risk of human error.

It can cause people to lose sight of the underlying purpose of a requirement.

And it can reduce their ability to analyse a situation and act effectively when the situation does not correspond exactly to a predefined procedure.

Simplicity is important. A nuclear energy system is never going to be “simple”. But wherever there are opportunities to make it simpler, those opportunities should be actively pursued by everyone involved in nuclear safety.

But there is another route. The hierarchy of controls shows us that **eliminating hazards is, by far**, the most effective way of making a system safer.

If the architecture of the reactor eliminates or substantially reduces an intrinsic hazard, then the corresponding accident sequences can disappear or become much less severe.

In other words: First simplify the physical problem by designing the hazard out, **then** protect against what remains.

Slide 7 - Hazard Pruning

This is what I call hazard pruning.

The conventional approach can be imagined as a large and growing fault tree.

Over 80 years of experience from historical designs has added failure modes, initiating events and protection requirements – more and more branches, twigs and leaves, until we end up with a very large and complicated fault tree.

What molten salt reactors bring are opportunities to prune off entire branches.

For example, if a system does not require a large inventory of high-pressure water around the fuel, one entire family of high-pressure loss-of-coolant hazards is changed.

If the fuel is liquid, the fuel does not have to remain inside thousands of individual fuel rods.

That changes the relationship between fuel, coolant and decay-heat removal.

If the physical properties of the fuel provide strong negative temperature feedback, some reactivity-control functions may be achieved through physics rather than through active equipment.

And if the fuel is already a circulating liquid, heat transport is integrated into the fuel system itself.

So while these are not automatic safety claims, and it's perfectly possible to design an unsafe molten salt reactor, there are genuine opportunities to simplify reactor designs. And that is why people like me are excited by the potential of molten salt reactors.

Slide 8 - The nuclear energy system design paradox

I'll now move on to talk about the history of molten salt reactors.

And it's a story which started with a "which comes first" paradox, a bit like the chicken and the egg.

In the early 1940s many scientists in the United States were working on the Manhattan Project, known at the time as the "metallurgical laboratory". 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 the 20th century Alvin Weinberg directed MSR developments at Oak Ridge National Laboratory in Tennessee. In a 1997 lecture, he said:

"There were two people at the metallurgical laboratory, 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."

Slide 9 - 1944 - Liquid fuel concept

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?

Slide 10 - 1952 – Homogeneous Reactor Experiment

Researchers at Oak Ridge National Laboratory launched the Homogeneous Reactor Experiment using uranium salts dissolved in water. They understood the chemistry pretty well thanks to the Manhattan Project; and the fact that water efficiently moderates neutrons made it possible to reach criticality using low-enriched uranium.

It started up in 1952 and showed that a liquid-fuelled reactor could indeed operate. But they quickly ran into difficulties. 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, they realized that while the liquid fuel idea was promising, water was not the right liquid.

Slide 11 - 1950 - Let's use Molten Salts

But by that time two Oak Ridge researchers, Raymond C. Briant and Edward S. Bettis, had already proposed an alternative: Dissolving uranium in molten salts, which are liquids that don't undergo radiolysis and can operate in a stable manner at high temperature and low pressure.

And so began Oak Ridge's love affair with molten salts as fuels and coolants for reactors.

In a 1957 paper, Alvin Weinberg wrote:

"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."

Slide 12 - 1954 – Aircraft Reactor Experiment

Ray Briant was responsible for the aircraft reactor program, and he chose to use molten salt fuel for the aircraft reactor experiment, which ran successfully for 4 days in November 1954 and proved the molten salt concept.

Slide 13 - 1965-1969 – Molten Salt Reactor Experiment (MSRE, 7MWt)

Even after the aircraft reactor program was cancelled (it was a pretty bad idea to power a bomber with a nuclear reactor), Oak Ridge managed to get funding for a second prototype, and they built the Molten Salt Reactor Experiment, which ran successfully for over 4 years and achieved all of its objectives. So at this point the Oak Ridge people were pretty fired up because they realised that the MSR had enormous potential as a relatively simple, elegant design with appealing synergies for the interface with upstream and downstream fuel cycle processes, as well as a high degree of intrinsic safety.

And Weinberg in particular realised that as reactors got more and more powerful, that intrinsic safety was going to become really important for the economic viability of nuclear energy. And so he went to the Atomic Energy Commission to drum up support, and money, for more development work.

Slide 14 - 1972 - Chet Holifield fires Alvin Weinberg

But the AEC was under political pressure to reduce the number of reactor programs – to make technology choices.

The molten salt reactor didn't have the maturity, the budget or the political support of other technologies such as the pressurised water reactor or the liquid metal fast breeder reactor. And Weinberg kept banging on to the AEC about safety, which at that time was the least of their concerns.

Until in 1972 senator Chet Holifield eventually blurted out:

"Alvin, if you are concerned about the safety of reactors, then I think it may be time for you to leave nuclear energy."

And that was the turning point. Weinberg was fired as director of ORNL, the MSR program was cancelled and the team dispersed. And the technology was quietly brushed under the carpet for decades.

Slide 15 - 2009 – Kirk Sorensen publishes ORNL literature

And the next thing that happened was that this guy read one of Weinberg's books, called "fluid fuelled reactors".

He was working for NASA on how to supply energy to a colony on the moon, and he was amazed that no one knew about molten salt reactors.

So he went to Oak Ridge, found all the ORNL literature, scanned it to PDF files and published them on his blog.

Now thanks to the internet the whole world had access to that scientific and engineering literature, and interesting things started to happen.

In the 2010s about a dozen organisations were launched with the aim of bringing MSR technologies to market.

Slide 16 - 2023- Thorium Molten Salt Reactor - Liquid Fueled (TMSR-LF1, 2MWt)

And the most successful of these has been the Chinese Thorium Molten Salt Reactor program, because it quickly received significant political and financial support. A team of hundreds of scientists and engineers designed and built a 2MW prototype reactor in the Gobi desert, working closely with the Chinese nuclear safety authority, and it achieved criticality in October 2023.

Slide 17 - MSR Taxonomy

That brings me on to the classification of all these recent MSR developments. Some very good work was done on this by Aslak Stubsgaard who is the Chief Technical Officer of Copenhagen Atomics. And that was taken up by Jiri Krepel at the Paul Scherrer Institute in Switzerland and became the basis of the MSR taxonomy included in the IAEA report on the status of molten salt reactor technology in 2023. The taxonomy identifies 4 classes of MSR: Graphite-based, Homogeneous, Heterogeneous and Other, as well as the type of salt used (Fluorides or Chlorides) and the neutron spectrum (thermal or fast).

Slide 18 - MSR Taxonomy – Spectrum & Salts

And so if we look at the neutron spectrum and the salts, you can see that most of the current initiatives use either a thermal spectrum with fluoride salts, or a fast spectrum with chloride salts.

I'd like to point out that these organisations are at very different levels of development.

The Chinese have already built a reactor and have said they will build a second one, but we haven't seen any evidence of that yet.

The American companies are now enjoying strong bipartisan political support for new nuclear projects but are struggling to raise enough cash to make meaningful progress towards a first of a kind reactor.

And the European companies are struggling for survival in a context of limited political and financial support. I have included the two Moltex concepts here because they are novel architectures which have an interesting place in the taxonomy, but in fact Moltex went bust in 2025.

Slide 19 - MSR Taxonomy - Classes

Here are the same organisations organised according to the different classes identified in the taxonomy. You can see that the two companies that are with us today are in different classes. Stellaria's concept is a homogeneous MSR whereas Thorizon's is a heterogeneous MSR. Other well-advanced organisations such as the Chinese TMSR program and Kairos Power use a graphite moderator in their design.

Slide 20 - MSR Industrial Variants

Aside from the scientific classification in the taxonomy I have proposed here for the first time an industrial classification.

This could be applied to any advanced reactor design, not just MSRs.

The factors that have a major influence on the design are:

The size, or the power rating of the system – nuclear projects have been essentially categorised as: Enormous (same as current designs), Small or Micro – that's above 1000MW, hundreds of megawatts or tens of megawatts.

Then we have the energy vector. How are we going to deliver the energy produced by the reactor. As electricity? Or directly as heat to displace fossil fuels from industrial processes or heating networks? Or are we going to use the reactor to produce energy carrying molecules such as Hydrogen, Ammonia or Methanol? Or perhaps some hybrid of 2 or all 3 vectors.

And then finally, how we deliver the reactor also makes a big difference to the design. If we want to manufacture the reactor components and deliver them to a power station by truck then their size will be limited by getting them under motorway bridges or through tunnels. But the power station can be pretty much anywhere. If we deliver by sea then we can manufacture much bigger components in shipyards, but we're then limited to coastal or estuary locations for siting the power station.

Slide 21 - Countries with MSR activities

MSR development is becoming increasingly international. There are programs and companies in Europe, North America, Asia and elsewhere.

For European regulators, that creates both an opportunity and a challenge, as the family of technologies emerges.

The opportunity is that European organisations do not have to reproduce every experiment independently. International cooperation can be especially valuable where experiments are expensive or where operating experience is still scarce.

The challenge is that we need mechanisms for sharing evidence, terminology, experimental data and safety understanding across jurisdictions. And this is where regulatory cooperation can potentially have a role beyond the individual licensing case.

Slide 22 - Atlas

One of the resources that I have built for Progrès Nucléaire, and that I keep up to date, is this Google maps atlas of MSR organisations. Each pin has the name, a logo and a website link. The red pins are companies, the blue ones are research institutes, then we have associations, the sites of actual or future reactors, and sites which are manufacturing system components - whether they be reactors or fuel. You can visit it using this presentation by clicking the image on this page.

Slide 23 - Simplicity is Difficult

So I think that one of the key messages is that simplicity is difficult.

To some extent, MSRs are currently stuck in a loop.

Regulators need evidence from operating data. Investors need regulatory confidence. And without investment, there is no reactor and therefore no operating data.

There is still much work to do to prove the safety of MSRs, but that doesn't mean these systems are unsafe. It just means that we don't know yet. So it's really important in those situations that regulators say "we don't know yet" and work with organisations to find pragmatic ways of providing evidence that satisfies safety requirements.

The question is then how much time and money is needed to provide that evidence? Who pays the entry ticket for each design? What is the balance between public and private financing? Who holds the intellectual property? These are very difficult questions.

But we need to answer those difficult questions, because the world desperately needs to make progress in low carbon energy systems.

Slide 24 - MSR Opportunities

Molten salt reactors give us unique opportunities to simplify nuclear energy systems, because of the way of thinking which allowed the concept to emerge in the 1940s. By taking a whole nuclear energy system approach – the reactor and the fuel cycle, Harold Urey and Eugene Wigner realised that the unique advantages of liquid fuels would be needed, for an industrially feasible and economically viable closed fuel cycle.

Real, disruptive innovation is about increasing value while simultaneously reducing cost and time. There is real potential to do this with molten salt reactors, and to develop a family of technologies which are optimized for different customer applications, with better coverage of energy markets due to their high temperature operation and the potential to penetrate non-electric markets whose needs are almost exclusively met today by burning fossil fuels.

For regulators, simpler nuclear energy systems mean smaller fault trees. You have to design MSRs carefully but if it's done right then designers and regulators working together should be able to clearly demonstrate a high degree of intrinsic safety.

Once a safety case has been written, that story has to be told to politicians, local authorities, citizens, media and civil society. For a safety authority, simplicity is not merely an engineering advantage. It can become a societal safety advantage — because a safety case that can be understood is easier to scrutinise, to explain and to trust. There are NGO members who increasingly need an honourable way out from their historical opposition to nuclear energy. A simpler, fundamentally different design could help them to change their minds.

So my request to European regulators is: Please recognize the enormous potential of molten salt designs to simplify nuclear safety. And please remain open-minded: They may be immature, but that doesn't mean they're unsafe.

Slide 25 - A new path

To close, I'd like to once again quote Alvin Weinberg, who said:

“The molten-salt technology is entirely different from the technology of any other reactor. To the inexperienced, the technology is daunting... Perhaps the moral to be drawn is that a technology that differs too much from an existing technology has not one hurdle to overcome—to demonstrate its feasibility—but another even greater one—to convince influential individuals and organizations who are intellectually and emotionally attached to a different technology that they should adopt the new path. »

Slide 26 - Fin

Thank you very much for your attention.

There were two other slides in my presentation, but they have been censored by the thought police so you are not allowed to see them.