SHINE®

FROM MEDICAL ISOTOPES TO RECYCLING

Why Chrysalis Is a Demonstration Plant for Solving the Nuclear Fuel/ Waste Problem

BY **GREG PIEFER,** FOUNDER & CEO



EXECUTIVE SUMMARY

SHINE's Chrysalis facility in Janesville, Wisconsin is home to the world's first fusion-driven medical isotope production system. Licensed by the Nuclear Regulatory Commission under 10 CFR Part 50 and nearing completion, Chrysalis uses a fusion neutron source driving a subcritical fissile target to produce life-saving medical isotopes.

Chrysalis is also, in practical terms, a demonstration plant for spent nuclear fuel recycling. The two businesses, isotope production and recycling, share the same core unit operations and similar chemistry. The regulatory framework is identical, down to the same section of the NRC code and the same group of reviewers. And the execution capabilities SHINE built to deliver Chrysalis—in-house construction management, commercial-grade dedication, and vertically integrated manufacturing—are precisely what will determine which recycling facility projects succeed and which don't.

This makes Chrysalis more than a medical isotope facility. It's a first-of-a-kind operational foundation for SHINE's future recycling business. When executives from Orano—the company that operates all of France's recycling infrastructure—toured Chrysalis, their reaction was immediate recognition. They saw their own business.

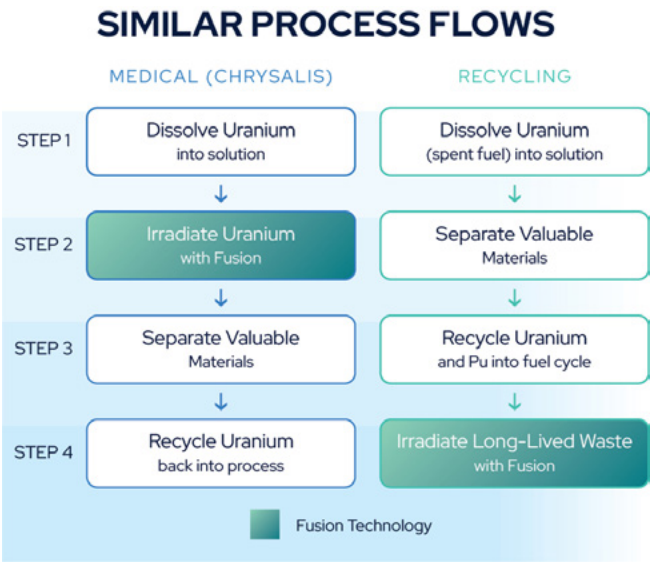
TECHNICAL & REGULATORY PARALLELS

— THE SAME FOUR OPERATIONS, RESEQUENCED

Though they serve different markets, spent nuclear fuel recycling and medical isotope production share the same four core unit operations. The difference is sequencing.

In Chrysalis, SHINE starts with fresh uranium and dissolves it into a sulfate or nitrate solution. That solution is then irradiated by a fusion neutron source, creating valuable fission products—principally molybdenum-99, which is used in over 40 million medical diagnostic procedures annually worldwide. After irradiation, SHINE separates the valuable isotopes from the uranium stream. Finally, the uranium solution is recycled back into the process for another irradiation cycle.

Spent fuel recycling follows the same four operations in a different order. Spent fuel—uranium oxide from a commercial power reactor—is first dissolved into solution. Because the fuel was previously irradiated in a reactor, the solution is already loaded with valuable materials and long-lived transuranic waste. The valuable materials are separated out. The uranium and plutonium are recycled back into the nuclear fuel cycle. And in SHINE's approach, the remaining long-lived transuranic waste is then irradiated with fusion neutrons in a subcritical assembly, transmuting it into shorter-lived isotopes that are dramatically easier to manage.



Both processes begin with dissolving uranium using similar chemistry. Both involve chemical separations. Both recycle uranium. Both use fusion-driven irradiation of a subcritical target.

The fusion side is also fundamentally similar, though scale expansion will be needed to go from medicine to waste. In both facilities, fusion neutrons enter a near-critical system, are multiplied through fission, and produce the desired nuclear transformation. The reactivity control challenges and the regulatory

safety case are nearly identical. All this gives SHINE the experience needed for recycling, and we've demonstrated the ability to scale fusion over multiple product lines already.

— SAME REGULATORY FRAMEWORK, SAME REVIEWERS

Both Chrysalis and spent fuel recycling facilities are regulated under 10 CFR Part 50. The Research and Test Reactor group that approved Chrysalis' operating license application would also review and approve a recycling facility application. Those reviewers already understand SHINE's design philosophy, safety case methodology, and engineering approach. They have found the architecture of a fusion-driven subcritical system licensable. A recycling facility extends that approved architecture rather than requiring the NRC to build new analytical frameworks from scratch.

Regulatory review is not purely a technical process—it is also shaped by relationships and institutional knowledge. The nuclear industry's history is filled with projects that consumed years and billions of dollars creating new regulatory pathways. SHINE has already done that work. That investment carries forward directly into every subsequent facility.

WHAT CHRYSALIS HAS ALREADY DEMONSTRATED

Chrysalis is not yet in daily operation. But the milestones achieved to date represent technical and regulatory firsts that no other organization in the world can match—and that are directly applicable to recycling.

NRC construction permit (2016).
SHINE received its NRC construction permit in 2016. No other company has received an NRC construction permit for a comparable facility in US history.

First new-technology operating license application approved under 10 CFR Part 50 (2023).
The NRC completed its review of SHINE's operating license application in 2023—the first time ever that a new technology completed this process under Part 50 with the NRC. This required demonstrating the full safety case for a fusion-driven subcritical system, including reactivity control, radiation protection, chemical processing safety, and waste management.

> *These milestones place SHINE more than a decade ahead of any potential recycling competitor."*

World-record steady-state fusion neutron output.
SHINE has demonstrated sustained DT fusion neutron production at 5×10^{13} neutrons per second—a world record for steady-state fusion output and the scale required for Chrysalis operations. This shows that we are world leaders in the scaling and commercialization of cutting edge fusion technology.

Demonstrated uranium recycle.
Through a partnership with Argonne National Laboratory, SHINE has demonstrated the reuse of irradiated uranium—validating the recycling loop that is central to both isotope production and spent fuel recycling.

Facility construction is 75% complete.
The Chrysalis facility—including hot cells, chemical processing systems, ventilation, shielding, and fusion irradiation systems—is nearing completion, with operations expected in the next two years.

These milestones place SHINE more than a decade ahead of any potential recycling competitor. No other organization combines an NRC-approved fusion-driven subcritical architecture, demonstrated chemical processing capabilities, a proven nuclear construction track record, and a formal partnership with the world's most experienced recycling operator. Others may describe a similar vision, but SHINE has spent the past decade building the institutional and technical foundation to execute it.

A DIFFERENT MODEL FOR NUCLEAR EXECUTION

The nuclear industry has faced cost and schedule challenges for identifiable structural reasons that SHINE has deliberately worked to avoid. These execution capabilities are as critical to the recycling opportunity as the technical parallels with Chrysalis.

— THE COST-PLUS PROBLEM

Much of the nuclear industry operates on cost-plus contracting, where engineering firms are paid their costs plus a fee calculated as a percentage of those costs. Higher costs mean higher fees. Over decades, this incentive structure has produced an industry culture that accepts—and can reinforce—high cost and long schedules.

The most instructive example is the Mixed Oxide Fuel Fabrication Facility (MFFF) at the Savannah River Site in South Carolina. Originally estimated at under $2 billion with a three-year construction timeline, the MOX facility consumed approximately $8 billion over more than a decade, never reached 50% completion, and was cancelled in 2018. Revised estimates projected it would not be completed until 2048 at a cost exceeding $17 billion. The project was cancelled before processing any plutonium.

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> *The Chrysalis facility was delivered at roughly 20% of the predicted cost of comparable fission-based isotope production facilities."*

What makes this especially relevant is that the MOX process—blending weapons-grade plutonium with uranium oxide to produce fuel—is in many respects simpler than what Chrysalis does. MOX fabrication does not involve hundreds of kilocuries of radioactivity, fusion systems, or real-time chemical separations. If the traditional execution model could not deliver a comparatively straightforward facility, the question for investors is straightforward: why would the next nuclear processing facility be any different?

— SHINE'S INTEGRATED EXECUTION MODEL

Owner-led EPC.
SHINE performs its own engineering, procurement, and construction management. An owner-led EPC team cares about the result because they will operate the facility for decades. A cost-plus contractor does not own the outcome, and their incentives do not reward timely, cost-effective completion—in fact they reward excessive cost and projects that never end.

Vertically integrated manufacturing.
For technically complex nuclear process equipment and advanced fusion systems, SHINE designs, engineers, and builds internally. This keeps critical-path technology under direct control.

Hacking the supply chain with commercial-grade dedication.
SHINE procures standard components from commercial vendors with modern manufacturing practices and validates them for nuclear service through an in-house dedication process. This replaces the traditional NQA-1 procurement model, which adds enormous cost and lead time without necessarily improving quality.

This has played out repeatedly in building Chrysalis. One example: SHINE hired a local commercial concrete company, LyCon, to supply all concrete for the facility. LyCon delivered 1,600 truckloads at a commercially reasonable rate with flawless execution—SHINE validated quality by sampling during pours, and every batch passed. This is one of many cases in which commercial vendors performed exactly as needed for nuclear service.

Conversely, SHINE hired an NQA-1 vendor to build a gravity-fed nuclear piping system for floor drains—no valves, just pipes. It took two years and arrived with

elbows welded the wrong way and slag-contaminated welds throughout. SHINE hired a commercial vendor to fix it, radiographing every weld for verification. The result was a shorter timeline, lower cost, and every weld met specification on the first attempt. This is one of many cases where the NQA-1 label added cost and lead time without guaranteeing quality.

These patterns are structural. The Chrysalis facility was delivered at roughly 20% of the predicted cost of comparable fission-based isotope production facilities, such as the €2.4 billion Pallas reactor in the Netherlands. SHINE expects to carry that cost advantage directly into recycling.

CONCLUSION

The question facing investors in spent fuel recycling is not whether the market is real—it's who can execute. Building a nuclear chemical processing facility with fusion-driven transmutation requires NRC licensing experience, demonstrated nuclear construction capability, and operational knowledge of the specific systems involved. SHINE has spent a decade acquiring all three through Chrysalis.

A recycling facility built on the Chrysalis template would use the same class of systems—fusion drivers, subcritical assemblies, hot cells, chemical processing equipment—at a comparable physical scale. SHINE's partnership with Orano targets a pilot plant processing 100 metric tons of spent fuel per year, with operations in the early 2030s. No other organization in the world has the combination of NRC-approved fusion architecture, demonstrated nuclear chemical processing, a proven cost-disruptive construction model, and a formal partnership with the world's most experienced recycling operator needed to deliver it.

SHINE expects to achieve a commercial recycling pilot in four to five years, building on the foundation Chrysalis has established. When it does, it will bring to the recycling market the same disruptive cost model that built Chrysalis at a fraction of the cost of comparable nuclear facilities—and the only fusion-driven transmutation capability in the world.



// AUTHOR BIO

Greg Piefer is the founder and CEO of SHINE Technologies, a company transforming nuclear fusion from scientific ambition into real-world impact. Under his leadership, SHINE has developed and deployed commercial, fusion-based systems across sectors including healthcare, advanced manufacturing, and national security—laying the groundwork for economically viable fusion energy. His vision extends to nuclear waste recycling and ultimately developing economically viable fusion energy.

Greg holds a PhD in nuclear engineering and BS degrees in physics and electrical and computer engineering from the University of Wisconsin–Madison.

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