# Radioactive waste management: decarburization, recycling and reuse by additive manufacturing

*RINA Consulting - Centro Sviluppo Materiali S.p.A, in collaboration with ENEA Fusion and Technology for Nuclear Safety and Security Department (Frascati, Rome) gained significant know-how on the feasibility of recycling waste materials from decommissioned nuclear plants towards their reuse by additive manufacturing. Manufacturing components starting from recycled activated material originated by DEMO reactor, might be an important factor to support the environmental sustainability of fusion radioactive waste management.*
*These techniques could be transferred to the management of radioactive wastes generated in non-fusion sectors, including for example nuclear fission and other big science facilities.*

## Description of the technology

This technology focuses on recycling activated steels (EUROFER, AISI 316L(N)) from future DEMO fusion reactors. The materials are processed into metal powders and reused to produce new components through Additive Manufacturing (AM), mainly Selective Laser Melting (SLM), aiming to reduce the volume of radioactive waste.

The process starts with Vacuum Induction Melting (VIM) to create ingots replicating irradiated component compositions. A crucial step is decarburization to remove Carbon-14 ($^{14}C$), a key nuclide for low-level waste (LLW) disposal. Based on Vacuum Oxygen Decarburization (VOD), the process uses oxygen blown into molten steel at ~1700°C and 1–5 mbar, forming CO gas that is removed. Tests showed 99% decarburization efficiency for both steels, corresponding to a decontamination factor (DF) of 100. For EUROFER, a DF of ~1000 is theoretically needed to reach 1 ppm C; for AISI 316L(N), 10 ppm is sufficient. Resulting solid waste is ~3% of EUROFER mass and ~15% for AISI 316L(N).

Metal powders are then produced via Vacuum Induction Gas Atomisation (VIGA) and sieved to 15–65 µm, ideal for SLM. About 92% of the powders met AM quality standards. Preliminary SLM tests produced dense (99.5%) specimens without macro-defects.

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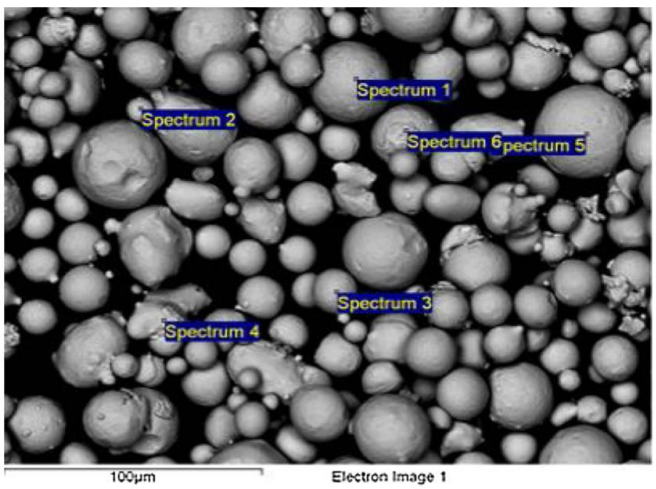
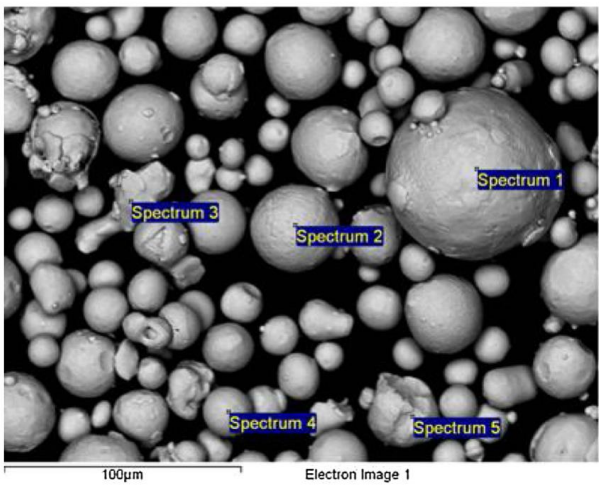
a)




b)




The project is led by ENEA and RINA-CSM, supported by EUROfusion, combining expertise in VIM, VOD, VIGA, AM, and materials testing. Experimental results confirm the feasibility of the full process chain, which supports remote-handling solutions in radioactive environments. Industry trends toward automation also align with adaptation to radiation-hardened conditions.

Challenges remain, especially in removing Ni, Mo, and Nb. Nb elimination requires harsh oxidation, causing up to 15% steel loss and significant radioactive slag. A better strategy is to control Nb during steel production. Further study is needed on the mechanical properties of recycled parts and on adapting systems for “rad-hard” use.

For $Li_4SiO_4$ pebble recycling, the goal is to reduce use of enriched 6Li and minimize waste. After irradiation, 26Al dominates, though impurities may arise. Recycling by melting used and new material together is proposed. Attempts to remove Al with $CaF_2$ and $SiO_2$ showed limited success, indicating challenges with managing resulting gases.

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## Innovation and advantages of the offer

This technology innovatively applies Vacuum Oxygen Decarburization—typically used in conventional metallurgy—to irradiated steels, achieving up to 99% carbon removal, a critical step for converting low-level radioactive waste into recyclable material. Unlike standard waste immobilization or long-term storage, it enables the reuse of activated metals via Additive Manufacturing, specifically SLM, with 92% powder yield meeting AM standards. The process minimizes final waste (3–15% of initial mass) and reduces reliance on enriched isotopes like $^{6}$Li. Economically, it lowers disposal and material costs, requires only moderate AM expertise, and aligns with automation trends for radioactive environments.

## Non-fusion Applications

This technology, originally developed for fusion, can also help manage radioactive and contaminated metals in other sectors. It can be used to recycle materials from nuclear fission reactors, especially during plant decommissioning. Big science facilities like particle accelerators, which also generate activated metals, could benefit too. In defense and space, it supports reuse of radiologically exposed parts from ships or satellites.

The method is also useful in industries dealing with toxic or complex metal waste, such as mining or petrochemicals. Recycled powders can be used in additive manufacturing to create new parts, reducing waste. The process is compatible with automation and radiation-hardened environments. Overall, it offers a sustainable solution for metal reuse beyond fusion.

## EUROfusion Heritage

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