Brief Summary of the Invention

This summary of the invention provides a broad overview of the invention, its application, and uses, and is not intended to limit the scope of the present invention, which will be apparent from the detailed description when read in conjunction with the drawings.

It would be an advancement in the state of the art to develop a nuclear fuel for use in various types of nuclear reactors. Therefore, embodiments of a nuclear fuel element for use in various types of nuclear reactors are disclosed.

According to a first aspect or in one embodiment, a nuclear fuel element is provided. The nuclear fuel element may comprise a plurality of solid nuclear fuel particles. Each of the plurality of solid nuclear fuel particles may comprise a nuclear material, and wherein the plurality of solid nuclear fuel particles comprises one or more of tristructural-isotropic (TRISO) particles. The nuclear fuel element may comprise a non-solid matrix. The plurality of solid nuclear fuel particles may be intermixed in the non-solid matrix. The non-solid matrix may be substantially stagnant relative to the plurality of nuclear fuel particles. The non-solid matrix may comprise a material selected from the group consisting of a liquid metal, a liquid metal alloy, and a liquid salt.

In some embodiments, the non-solid matrix is selected from the group consisting of a liquid metal and a liquid metal alloy.

In some embodiments, the non-solid matrix is selected from the group consisting of tin, lead, sodium, aluminum, bismuth, zinc, magnesium, calcium, cerium, rubidium, zirconium, beryllium, potassium, yttrium, strontium, barium, and alloys thereof.

In some embodiments, the non-solid matrix comprises a metalloid. In some embodiments, the non-solid matrix further comprises an element selected from the group consisting of silicon and germanium.

In some embodiments, the non-solid matrix is selected from the group consisting of tin, tin-aluminum alloy, tin-aluminum-gallium alloy, tin-zinc-aluminum alloy, tin-magnesium alloy, tin-aluminum-magnesium alloy, and tin-magnesium-zinc alloy.

In some embodiments, a composition percent of tin in the non-solid matrix is more than 80 percent tin by mass fraction. In some embodiments, a composition percent of tin in the non-solid matrix is more than 90 percent tin by mass fraction.

In some embodiments, the non-solid matrix is selected from the group consisting of lead, lead-bismuth-tin alloy, and lead-magnesium alloy.

In some embodiments, the non-solid matrix is selected from the group consisting of sodium-lead alloy, sodium-lead-bismuth alloy, and sodium-bismuth alloy.

In some embodiments, the non-solid matrix is selected from the group consisting of lead-bismuth alloy and lead-bismuth eutectic.

In some embodiments, the non-solid matrix is liquid sodium.

In some embodiments, the non-solid matrix is liquid gallium.

In some embodiments, the non-solid matrix comprises an alloy selected from the group consisting of an alloy of tin, aluminum, and gallium; an alloy of tin, aluminum, lead, and bismuth; an alloy of lead and magnesium; an alloy of aluminum and magnesium; an alloy of magnesium and zinc; an alloy of bismuth and sodium; and an alloy of lead and sodium.

In some embodiments, the non-solid matrix comprises an alloy selected from the group consisting of an alloy of lead and lithium; an alloy of tin and lithium; and an alloy of lead, bismuth, and lithium.

In some embodiments, the non-solid matrix comprises liquid salt.

In other embodiments, the non-solid matrix further comprises a material selected from the group consisting of water, sulfur, a supercritical fluid, organic liquid, and inorganic liquid.

In some embodiments, the plurality of solid nuclear fuel particles comprises tristructural-isotropic (TRISO) particles. The non-solid matrix may be selected from the group consisting of tin-aluminum alloy, tin-aluminum-gallium alloy, lead-bismuth alloy, and lead.

In some embodiments, at least one of the plurality of solid nuclear fuel particles comprises one or more materials selected from the group consisting of a ceramic material, a metallic material, a carbon material, and a cermet material.

In some embodiments, at least one of the plurality of solid nuclear fuel particles comprises actinide fuel kernels.

In some embodiments, at least one of the plurality of solid nuclear fuel particles comprises a fuel kernel selected from the group consisting of a UN kernel, a UO_2 kernel, a UC kernel, a UCO kernel.

In some embodiments, the nuclear material is selected from the group consisting of a fissionable material, a transmutation material, and a fertile material.

In some embodiments, the plurality of solid nuclear fuel particles comprises fissionable material selected from the group consisting of uranium, thorium, and plutonium.

In other embodiments, the plurality of solid nuclear fuel particles comprises transmutation or fertile materials selected from the group consisting of thulium, thallium, gadolinium, silver, strontium, holmium, and lithium.

In some embodiments, each of the plurality of solid nuclear fuel particles has a volume smaller than 0.5 cm^3 and larger than 6×10^{-7} cm^3.

In some embodiments, each of the plurality of solid nuclear fuel particles has a volume smaller than 1.5×10^{-2} cm^3 and larger than 6×10^{-7} cm^3.

In some embodiments, the non-solid matrix is approximately a same density as the plurality of solid nuclear fuel particles.

In some embodiments, the non-solid matrix is less dense than the plurality of solid nuclear fuel particles.

In some other embodiments, the non-solid matrix is more dense than the plurality of solid nuclear fuel particles.

In some embodiments, the nuclear fuel element creates energy in a nuclear reactor selected from the group consisting of a fast spectrum fission reactor, a thermal spectrum fission reactor, an epithermal spectrum fission reactor, and a fission-fusion hybrid reactor.

In some embodiments, the nuclear fuel element creates energy in a nuclear reactor cooled by a coolant selected from the group consisting of a liquid metal coolant, liquid salt coolant, gas coolant, a water coolant, and heat pipes.

A nuclear fuel core for use in various nuclear fuel reactors is also provided. In some embodiments, a nuclear fuel core comprises a plurality of solid nuclear fuel particles, where each of the plurality of solid nuclear fuel particles comprises a nuclear material; a non-solid matrix, where the plurality of solid nuclear fuel particles is intermixed in the non-solid matrix, the non-solid matrix is substantially stagnant relative to the plurality of nuclear fuel particles, and the non-solid matrix comprises a material selected from the group consisting of a liquid metal, a liquid metal alloy, and a liquid salt; and a plurality of coolant tubes penetrating the non-solid matrix, where each of the plurality of coolant tubes contains a flowing coolant.

According to a second aspect, a nuclear reactor is also provided. In some embodiments, the nuclear reactor comprises a power generation loop, and a reactor. In some embodiments, the reactor comprises a nuclear fuel element and a coolant. In some embodiments, the nuclear fuel element comprises a plurality of solid nuclear fuel particles, where each of the plurality of solid nuclear fuel particles comprises a nuclear material, and wherein the plurality of solid nuclear fuel particles comprises one or more of tristructural-isotropic (TRISO) particles, bistructural-isotropic (BISO) particles, quadristructural-isotropic (QUADRISO) particles, or any other composite particle that is a spherical, layered fuel particle comprising carbon, ceramic, and any actinide; and a non-solid matrix. In some embodiments, the plurality of solid nuclear fuel particles is intermixed in the non-solid matrix. In some embodiments, the non-solid matrix is substantially stagnant relative to the plurality of solid nuclear fuel particles. In some embodiments, the non-solid matrix comprises a material selected from the group consisting of a liquid metal, a liquid metal alloy, and a liquid salt.