A **breeder reactor** is a nuclear reactor that generates new fissile material at a greater rate than it consumes such material. These reactors were initially (1940s and 1960s) considered appealing due to their superior fuel economy; a normal reactor is able to consume less than 1% of the natural uranium that begins the fuel cycle, whereas a breeder can utilize a much greater percentage of the initial fissionable material, and with re-processing, can use almost all of the initial fissionable material. Breeders can be designed to utilize thorium, which is more abundant than uranium. Currently, there is renewed interest in breeders because they would consume less natural uranium (less than 3% compared to conventional light-water reactors), and generate less waste, for equal amounts of energy, [1] by converting non-fissile isotopes of uranium into nuclear fuel.

Production of fissile material in a reactor occurs by neutron irradiation of fertile material, particularly uranium-238 and thorium-232. In a breeder reactor, these materials are deliberately provided, either in the fuel or in a **breeder blanket** surrounding the core, or most commonly in both. Production of fissile material takes place to some extent in the fuel of all current commercial nuclear power reactors. Towards the end of its life, a uranium (not MOX, just uranium) PWR fuel element is producing more power from the fissioning of plutonium than from the remaining uranium-235. Historically, in order to be called a ***breeder,*** a reactor must be specifically designed to create more fissile material than it consumes.

One measure of a reactor's performance is the "breeding ratio" (the average number of fissile atoms created per fission event). Historically, attention has focused upon reactors with low breeding ratios (at or slightly above a breakeven value of 1.0), so that they produce only slightly more fissile material than they consume. Such designs range from a breeding ratio of 1.01 for the Shippingport Reactor [2] [3] running on thorium fuel and cooled by conventional light water to the Russian BN-350 liquid-metal-cooled reactor with a breeding ratio of over 1.2. [4] Theoretical models of breeders with liquid sodium coolant flowing through tubes inside fuel elements ("tube-in-shell" construction) show breeding ratios with an upper limit of 1.8 are possible. [5]

Breeding ratio

In normal operation, most large commercial reactors experience some degree of fuel breeding. It is customary to refer only to machines optimized for this trait as true breeders, but industry trends are pushing breeding ratios steadily higher, thus blurring the distinction. [6]

Breeding vs burnup

All commercial light water reactors breed fuel, but they have breeding ratios that are very low (though still significant) compared to machines

traditionally considered "breeders." In recent years, the commercial power industry has been emphasizing high-
burnup
fuels, which are typically enriched to higher percentages of U-235 than standard reactor fuels so that they last longer in the reactor core. As burnup increases, a higher percentage of the total power produced in a reactor is due to the fuel bred inside the reactor.

At a burnup of 30 gigawatt-days per metric ton of uranium (GWd/MTU), about thirty percent of the total energy released comes from bred plutonium. At 40 GWd/MTU, that percentage increases to about forty percent. This corresponds to a breeding ratio for these reactors of about 0.4 to 0.5. That is to say, about half of the fissile fuel in these reactors is bred there.
[
7
]
Correspondingly, this effect extends the cycle life for such fuels to sometimes nearly twice what it would be otherwise.
MOX fuel
has a smaller breeding effect than U-235 fuel and is thus more challenging and slightly less economic to use due to a quicker drop off in reactivity through cycle life.

This is of interest largely because next-generation reactors such as the
European Pressurized Reactor
,
AP1000
and
ESBWR

are designed to achieve very high burnup. This directly translates to higher breeding ratios. Current commercial power reactors have achieved breeding ratios of roughly 0.55, and next-generation designs like the AP1000 and EPR should have breeding ratios of 0.7 to 0.8, meaning that they produce 70 to 80 percent as much fuel as they consume, improving their fuel economy by roughly 15 percent compared to current high-burnup reactors.

Breeding of fissile fuel is a common feature in reactors, but in commercial reactors not optimized for this feature it is referred to as "enhanced burnup". Up to a third of all electricity produced in the current US reactor fleet comes from bred fuel, and the industry is working steadily to increase that percentage as time goes on.

Types of breeder reactors

Two types of traditional breeder reactor have been proposed:

- **fast breeder reactor** or FBR. The superior neutron economy of a fast neutron reactor makes it possible to build a reactor that, after its initial fuel charge of plutonium, requires only natural (or even depleted) uranium feedstock as input to its fuel cycle. This fuel cycle has been termed the plutonium economy.

- **thermal breeder reactor** . The excellent neutron capture characteristics of fissile uranium-233 make it possible to build a moderated reactor that, after its initial fuel charge of enriched uranium , plutonium or MOX , requires only thorium as input to its fuel cycle. Thorium-232 produces uranium-233 after neutron capture and beta decay .

In addition to this, there is some interest in so-called "reduced moderation reactors", [8] which are derived from conventional reactors and use conventional fuels and coolants, but are designed to be reasonably efficient as breeders. Such designs typically achieve breeding ratios of 0.7 to 1.01 or even higher.

Reprocessing

Use of a breeder reactor assumes nuclear reprocessing of the breeder blanket at least, without which the concept is meaningless. In practice, all proposed breeder reactor programs involve reprocessing of the fuel elements as well. This is important due to nuclear weapons proliferation concerns, as any nation conducting reprocessing using the traditional aqueous-based

PUREX family of reprocessing techniques could potentially divert plutonium towards weapons building. In practice, commercial plutonium from reactors with significant burnup would require sophisticated weapon designs, but the possibility must be considered. To address this concern, modified aqueous reprocessing systems, which add extra reagents, forcing minor actinide "impurities" such as curium and neptunium to commingle with the plutonium, have been proposed. Such impurities matter little in a fast spectrum reactor, but make weaponizing the plutonium extraordinarily difficult, such that even very sophisticated weapon designs are likely to fail to fire properly. Such systems as the TRUEX and SANEX are meant to address this.

Even more comprehensive are systems such as the Integral Fast Reactor (IFR) pyroprocessing system, which uses pools of molten cadmium and electrorefiners to reprocess metallic fuel directly on-site at the reactor. [9] Such systems not only commingle all the minor actinides with both uranium and plutonium, they are compact and self-contained, so that no plutonium-containing material ever needs to be transported away from the site of the breeder reactor. Breeder reactors incorporating such technology would most likely be designed with breeding ratios very close to 1.00, so that after an initial loading of enriched uranium and/or plutonium fuel, the reactor would then be refueled only with small deliveries of natural uranium metal. A quantity of natural uranium metal equivalent to a block about the size of a milk crate delivered once per month would be all the fuel such a 1 gigawatt reactor would need. [10] Such self-contained breeders are currently envisioned as the final self-contained and self-supporting ultimate goal of nuclear reactor designers.

The Fast Breeder Reactor

Main article: Fast Breeder Reactor

EBR-I, 1951) to over 1000 MWe. As of 2006, the technology is not economically competitive to thermal reactor technology; but India, Japan, China, Korea and Russia are all committing substantial research funds to further development of Fast Breeder reactors, anticipating that rising uranium prices will change this in the long term. Looking further ahead, three of the proposed generation IV reactor types are FBRs:

- **Gas-Cooled Fast Reactor** (GFR) cooled by helium .
- **Sodium-Cooled Fast Reactor** (SFR) based on the existing Liquid Metal FBR (LMFBR) and Integral Fast Reactor designs.
- **Lead-Cooled Fast Reactor** (LFR) based on Soviet naval propulsion units.

As well as their thermal breeder program, India is also developing FBR technology, using both uranium and thorium feedstocks.

The Thermal Breeder Reactor

The Liquid Fluoride Reactor was also developed as a thermal breeder. Liquid-fluoride reactors have many attractive features, such as deep inherent safety (due to their strong negative temperature coefficient of reactivity and their ability to drain their liquid fuel into a passively-cooled and non-critical configuration) and ease of operation. They are particularly attractive as thermal breeders because they can isolate protactinium-233 (the intermediate breeding product of thorium) from neutron flux and allow it to decay to uranium-233, which can then be returned to the reactor. Typical solid-fueled reactors are not capable of accomplishing this step and thus

U-234 is formed upon further neutron irradiation.The Advanced Heavy Water Reactor is one of the few proposed large-scale uses of thorium. As of 2006 only India is developing this technology. Indian interest is motivated by their substantial thorium reserves; almost a third of the world's thorium reserves are in India, which in contrast has less than 1% of the world's uranium. Their stated intention is to use both fast and thermal breeder reactors to supply both their own fuel and a surplus for non-breeding thermal power reactors. Total worldwide resources of thorium are roughly three times those of uranium, so in the extreme long term this technology may become of more general interest.

Traveling Wave Reactor

Main article: Traveling wave reactor

A theoretical type of self-contained breeder reactor called a traveling wave reactor is proposed in a patent by Intellectual Ventures. If it were to be built, it would be fueled by natural uranium, depleted uranium or thorium and would be able to operate for many years without needing any refueling. [11]

Notable Breeder Reactors

- Experimental Breeder Reactor I (U.S., decommissioned 1964, world's first electricity-producing nuclear power plant)

- BN-600 (Russia, end of life 2010) [12] [13]
- Clinch River Breeder Reactor (U.S., construction abandoned in 1982 because the US halted its spent-fuel reprocessing program and thus made breeders pointless) [14]

- Monju (Japan, being brought online again after a serious sodium leak and fire in 1995) [15]
- Superphénix (France, closed 1998) [16]
- Phénix (France, operational since 1974, stopped its grid electricity production as of March 2009, prior to decommissioning) [17] [18] [19]

Taken from wikipedia (http://en.wikipedia.org/wiki/Breeder_reactor)