There are two major options to handle spent nuclear fuel, name reprocessing and final storage. A theoretical alternative is "transmutation".

Once trough

The present approach to handling nuclear fuel in Sweden is "once-trough" and final deposition. This approach is highly realistic:

- Is based on existing and proven technology
- Is economically feasible.

There are several aspects which may be considered negative, however:

- The solution is wasteful regarding natural resources.
- Large amounts of nuclear waste needs to be stored in a safe way and manner for a very long time.

The Plutonium issue

One of the interesting aspects of nuclear reactors is that they actually can produce fuel. This does not violate the first or second principle of thermodynamics. We are not creating energy, just making existing energy accessible.

The way things work, only a small fraction - like 0.7% - of the uranium reserves can be used in nuclear reactors. The reason for this is that a small part of uranium, the ^{235}U isotope, can be employed to achieve self sustained chain reaction. Most of natral uranium is the isotope ^{238}U, which absorbs far to many neutrons without fission to be useful in a normal reactor. One interesting property of ^{238}U is that it can absorb a neutron and convert to

^{239}Pu which is a very good nuclear fuel. Could we build a nuclear reactor that produces at least one ^{239}Pu atom for each ^{235}U consumed would we not have an eternal source for energy, but a process that could produce something like 100 times the energy for each kg of uranium used than the normal fission process.

Reprocessing

One option for handling spent fuel is reprocessing. Reprocessing has a major benefit for fuel utilization at least in theory, as both uranium and plutonium can be reused. Natural uranium does only conatin about 0.7% of the isotope ^{235}U which is usable for energy production in light water reactors. The rest is mainly ^{238}U which cannot sustain nuclear chain reaction in normal reactor designs. When the reactor is in operation some of the ^{238}U atoms will be converted to ^{239}U by capturing a neutron. The ^{239}U atom will emit a beta particle (high energy electron) and convert to ^{239}Pu. This form of plutonimum is a good reactor fuel. So when we burn out ^{235}U we are building up ^{239}Pu the rate of ^{239}Pu produced to the ^{235}U is called breeding factor. If we achieve a breeding ratio larger than 1 we produce more fuel than we consume. This is not perpetum mobile, the price we pay is that we use up ^{238}U. The other price is that ^{239}Pu has some less desirable properties.

- It can be used to construct atomic bombs, although with some limitations.
- Although not highly active it's highly radiotoxic (poisonous)

By reprocessing fuel we can extract the plutonium and use it to replace ^{235}U, but there is a consideration that it could also be used to make bombs. Plutonium coming from light water reactors is not very attractive as weapons material, however, because it contains large amounts of heavy plutonium istopes that makes it hard to build a functional and effective weapon.

Breeders

On average a fission of a ^{235}U atom produces about 2.3 new neutrons, on the average. To sustain chain reaction exactly 1 neutron needs to be captured by a fissible atom and cause fission. Could we absorb one additional neutron in ^{238}U we could produce as much ^{239}plutomium as we consume ^{135}U. ^{239}Pu is fissible and can be used instead of ^{235}U. This is not a perpetum mobile because we actually use up all ^{238}U, but in a sense even better than a perpetum mobile because it actually works. The first nuclear power plant connected to the grid has been an experimental breeder.

France used to have a very ambitious breeder program, with the Super Phoenix as pinnacle, but Super Phoenix failed. It seems that Japan is going to have a serious go at a breeding cycle. Their plans call for 100% breeders well before the end of this century.

Transmutation

A new idea is transmutation. The idea is to convert the long lived actinides to short lived istopoes by intensive neutron bombadement using a spallation source. In a spallation source a target consisting heavy material like lead or quicksilber is irradiated with high energy protons having so high energy that they can pass the potential barrierr. The protons cause the target atoms to split producing a large number of neutrons. The neutrons will be captured in the actinides and convert them to nuclei having relatively short lifetime. To my understanding a such reactor would also produce much more power than it would consume.

Fusion, the ultimate solution

The final frontier is fusion, the way the sun and other bright stars are producing energy. The problem with fusion on earth is that we need very high temperature above 100 million Kelvins (about the same in Celsius ;-)

The cold war demonstrated the feasibilty of fusion in the form of the hydrogen bomb. Many years after the first hydrogen bomb, self sustained fusion was demonstrated in the JET (Joint Europen Torus) in England. The next step on the way of nuclear nirvana is ITER, which will demonstrate the feasibilty of fusion energy for energy production. Fusion has two advantages over fission:

- It produces less and less problematic radioactive materials.
- It is possible to base a fusion cycle on materials that are abundant.