ENRICHED BORIC ACID
FOR PRESSURIZED WATER REACTORS

Nuclear Power Plant “Grafenrheinfeld” in Germany

EAGLE PICHER
TECHNOLOGIES, LLC

Eagle-Picher and Enriched Boron: Over 40 years of experience

For more than 40 years, Eagle-Picher has been involved with enriched boron products and the separation of boron isotopes.

Today, the Boron Department of Eagle-Picher Technologies operates a current generation facility for the separation of boron isotopes and the production of enriched boron products. This facility, located in Quapaw, OK, USA is the largest in the world. Enriching (or altering) the ratio of ^{10}Boron to ^{11}Boron is performed using a very efficient proprietary process.

In naturally occurring boron compounds, only 19.8% of the boron is ^{10}B isotope. Eagle-Picher's boron enrichment process has removed this natural limitation. ^{10}B enrichments from 1 to 99 At. % are available in a wide variety of compounds. ^{10}B has a very high thermal neutron capture cross section (over 3,800 barnes compared to ^{11}B's 0.005 barnes). In addition, when ^{10}B captures a thermal neutron, it does not produce any long-lived radioactive daughter products. As a result, enriched boron has found wide application in the nuclear industry.

Enriched Boric Acid

One important compound produced by Eagle-Picher is high purity enriched boric acid (EBA). Boric acid is added to primary coolant solutions used in Pressurized Water Reactors (PWRs). The isotope ^{10}B acts as a chemical shim in the cooling circuit, controlling the rate of the nuclear reaction. Chemical shims provide long-term gradual control of the reactor, while control rods provide short-term control during startup, shutdown, or under unusual conditions. Enriched boric acid allows the reactor operator to achieve a higher level of long-term control than is generally possible with natural boric acid.

Long-term control is also provided through the use of burnable poisons incorporated into or on the fuel itself. Gadolinium oxide, zirconium diboride, and erbium boride are examples of materials added to nuclear fuel to provide decreasing absorption of neutrons, thereby controlling the intensity of the nuclear reaction. For PWRs, total long-term control comes from the combination of the chemical shim and burnable absorber systems.

Table I presents the characteristics of Eagle-Picher's enriched boric acid product, including the maximum allowable impurities. This data represents the product selected by most reactor operators. Other configurations are available through special manufacturing conditions. As represented by the low levels of impurities, Eagle-Picher's processes provide purification benefits in addition to isotopic enrichment. The purity of the material described in Table I exceeds that of other commercially available grades.

Enriched boric acid offers the PWR operator a unique opportunity. For example, if the natural boric acid is replaced with 60% ^{10}Boron enriched boric acid, the boric acid concentration can be reduced by a factor of three (3) with no change in the ability of the solution to absorb neutrons. The ^{10}Boron content of the solution is the same, yet all of the constituents of the solution are reduced; lithium concentration, impurities contained in coolant additives, etc, are reduced by a factor of three. Enriched boric acid offers a simple solution to a wide variety of problems.

Table I

Characteristic	Specification Value	Unit of Measure
H_2O Insoluble Material	10	ppm maximum
Cl	0.26	ppm maximum
SO_4	0.12	ppm maximum
PO_4	0.1	ppm maximum
Heavy Metals (as Pb)	1.0	ppm maximum
Fe	2.0	ppm maximum
Ca	1.0	ppm maximum
AS	0.5	ppm maximum
Na	3.0	ppm maximum
F	0.3	ppm maximum
Equivalent Boric Acid	99.95	Wt. % minimum

Over the past few years, Eagle-Picher has provided enriched boric acid to European PWR plants. These plants have converted from natural boric acid to partially enriched boric acid during scheduled shut down periods without any modifications to the

Benefits From Enriched Boric Acid Use

Benefits due to increased ^{10}Boron Concentration

- Increased Reactor Power
- Allows use of fuel with high ^{235}U enrichment
- Allows increased use of MOX fuels
- Allows increase in burn up and cycle length
- **Reduction of spent fuel quantity per cycle**
  Therefore, backend costs for spent fuel treatment, waste management, and intermediate and final storage are reduced. This represents a **very important cost savings.**

Benefits due to decreased boric acid concentration

- Reduced concentration of boric acid in pools
- Lower risk of boric acid precipitation and crystallization
- Decreased coolant acidity and results in lower lithium concentrations
- Doesn't require modification of tank and pipe volumes
- Reduced requirements for trace heating
- Reduced requirements for fresh water and demineralized water

facilities. For most power plants, final enrichment in the borated solutions is about 30% ^{10}Boron.

Positive effects from the use of enriched boric acid are twofold.

1. The concentration of ^{10}Boron in the reactor circuits is generally increased.
2. The global concentration of boric acid is decreased.

The use of EBA as a chemical shim promotes advancement of reactor fuel management (see Figure 2). This new management approach includes very important cost savings. Also, thanks to enriched boric acid, water chemistry may be operated constantly at pH 7.4 for the whole cycle (See Figure I).

This change in water chemistry allows:

1. Reduction of precipitation by impurities and therefore less activation of ferritic nickel decreasing dose rates in the power plant.
2. Minimization of lithium content and therefore, reduction of the corrosion effect on zircalloy
3. Reduction of stress corrosion cracking of the steam generator tubes.

The use of enriched boric acid creates a less corrosive environment, reduces dose rates, and increases the lifetime of the power plant.

Enriched boric acid also allows reactor operators to reduce the number of burnable absorber rods in the core. The cumulative advantages indicate that use of enriched boric acid makes new solutions available for power plant operators. For these reasons, enriched boric acid has been chosen for use in the newly designed EPR (European Pressurized Water Reactor).

Figure 1

Source :Siemens Presentation

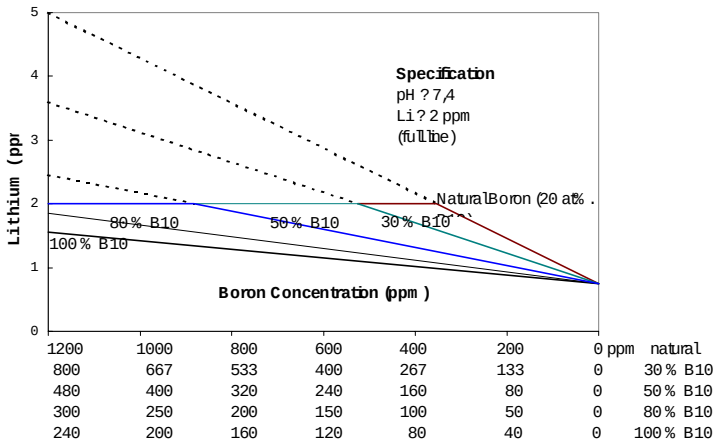
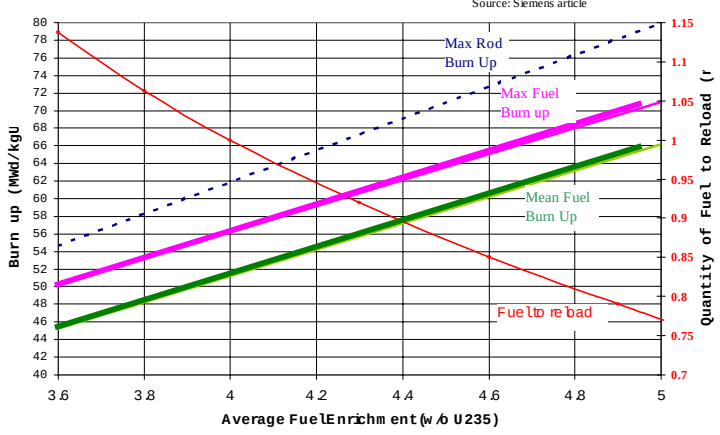


Figure 2

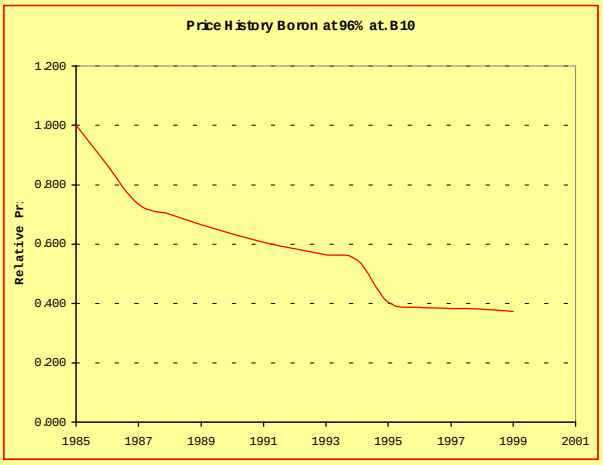
Source: Siemens article



Eagle-Picher Technologies, LLC is committed to serving the enriched boron needs of the nuclear industry. We continually refine and improve our processes to provide high quality products at the lowest possible cost. Through innovation and process improvement, we have been able to reduce the price of our most common products by a factor of 2.5 since 1985. This trend is almost unparalleled in the industry. When adjusted to include cost growth due to inflation, our products reflect an even greater value for our customers.

Eagle-Picher Technologies has committed the time, capital, and technology necessary to insure a continuing supply of enriched boric acid for the next 40 years and beyond. Our stability is evidenced by the length of our existence (our company began in 1843), by our tenure in the enriched boron business (40 years), and by our commitment to the future.

The quality of our products is an equal part of our commitment to the nuclear power industry. Our quality system is registered to ISO-9001, and also meets the requirements of 10CFR 50, Appendix B, and other domestic industry standards. For American applications, we are familiar with "Safety Related" programs, and deliver products to covered facilities frequently.



Listing of European Power Plants Converted to Eagle-Picher Enriched Boric Acid

Power Plant	Capacity	Power Plant	Capacity
Grafenrheinfeld	1345 MW	Grohnde	1430 MW
Gösgen	1020 MW	Isar 2	1440 MW
Philippsburg 2	1424 MW	Emsland	1363 MW
Brokdorf	1440 MW		

Other Enriched Boron Products Available from Eagle-Picher Technologies, LLC

Eagle-Picher manufactures the following products for nuclear power applications:

Enriched Sodium Pentaborate
Enriched ^{10}Boron additive to Standby Liquid Control Systems at BWR facilities

Enriched Boron Carbide
Enriched powder and components for shielding and reflecting applications. Available enriched in either ^{10}B or ^{11}B isotope. Typical applications are: control rod pellets and powders, neutron shielding, neutron reflectors.

Borated Aluminum
Enriched ^{10}Boron material for shielding and criticality control applications such as spent nuclear fuel storage and transportation.

Enriched Iron Boride (ferroboron)
Enriched ^{10}Boron additive for borated stainless steel. Borated stainless steel applications include criticality control duty in storage pools and casks.

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ENRICHED BORIC ACID

GENERAL CHARACTERISTICS

The Boron Department specializes in isotopic boron products for specific applications. Our manufacturing systems give us the flexibility to customize isotopic composition to meet customer requirements. Enriched boric acid is one of the basics of our product line, and is a precurser for most of our other boron containing chemicals. Enriched in either isotope to very high levels, our boric acid exceeds accepted standards of the nuclear industry throughout the world. In all chemical reactions, our enriched products behave exactly as their natural counterparts.

In a thermal neutron environment, enriched boron compounds have opposing neutron capture cross sections making ^{10}Boron an extremely good neutron absorber while ^{11}Boron is excellent neutron reflector.

Eagle-Picher manufactures a standard grade of enriched boric acid to satisfy most nuclear applications. For those applications where standard product characteristics are not suitable or where alternative purity is acceptable, custom materials are also available. Product data is available for standard products as well as customized products. There is no standard product for ^{11}B enriched boric acid.

Typical Physical Characteristics

	Enriched ^{10}Boron	Enriched ^{11}Boron	Natural Boron
Form	White Crystals	White Crystals	
Enrichment	To 99+% Atomic	To 99+% Atomic	
Molecular Weight	61.045 @ 99% ^{10}B	62.021 @ 99% ^{11}B	
Thermal Neutron Cross Section (Barns)	3837	0.005	
Density			1.52 grams/cm^3
Heat of Formation			-262.16 kcal/mole
Vapor Pressure @ 109° C			0.62 mm Hg
Vapor Pressure @ 180 ° C			15.00 mm Hg
Decomposes @			185 ° C
Solubility in Methanol @ 25° C			173.9 g /L

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^{10}B ENRICHED BORIC ACID
PRODUCT SPECIFICATION

Standard Material

Characteristic		Specification Limit	
Enrichment	96	wt % ^{10}B	Minimum
Equivalent Boric Acid	99.95	wt.%	Minimum
Impurities:			
Arsenic	0.5	ppm	Maximum
Calcium	1	ppm	Maximum
Chlorine	0.26	ppm	Maximum
Fluorine	0.3	ppm	Maximum
Heavy Metals (as Pb)	1	ppm	Maximum
Iron	2	ppm	Maximum
Phosphates	0.1	ppm	Maximum
Sodium	3	ppm	Maximum
Sulfates	0.12	ppm	Maximum
Water Insolubles	10	ppm	Maximum

- Packaging: 40 kg per fiber drum, protected by vapor barrier bag.
- Certificate of Analysis provided with each shipment.
- For complete details, refer to Eagle-Picher specification HBO3-S96-001
- Specific enrichments, purities, and particle sizes are available to meet special requirements.

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