Further, the instrument can "raster" the observed surface with argon ions, blasting off the top few layers of atoms like a machine gun. This then allows subsequent analyses of the underlying layers. Through repeated cycles of this process, comparative analyses of one layer after another can be made. This reveals the depth of impurity segregation on the intergranular surfaces and portrays a good picture of surface chemistry and its effects on bulk material properties.

In 1979, Japanese researchers reported a remarkable discovery. They found that the addition of small amounts of boron to nickel aluminide increased its ductility. Following this lead, researchers at Oak Ridge National Laboratory, using Exploratory R&D funds, determined that this phenomenon only worked under a highly specific condition. This was when the total number of aluminum atoms, compared to the total number of nickel atoms, was just slightly less than that dictated by its natural or stoichiometric ratio. In nickel aluminide (Ni_3Al), the natural atom ratio of nickel to aluminum is 3 to 1, or in other terms, 75 to 25 atom percents.

In 1982, Basic Energy Sciences researchers applied their earlier gained knowledge about grain boundaries, intergranular surfaces, and impurity migration to the problem of understanding what was going on. Once again, a key element of their research involved the capabilities of Auger electron spectroscopy.

In a report published in 1985, Basic Energy Sciences researchers presented their findings and offered an explanation of the ductility phenomenon. Under conditions where the relative abundance of aluminum, compared to nickel, was slightly less than the natural ratio in pure Ni_3Al, say 24 atom percent rather than 25, boron atoms migrated in droves to the grain boundaries. They accumulated there in the top two or three atom layers of the surface. They concentrated themselves in numbers far outweighing, by 60 times or more, their bulk proportion of, say, 0.1 percent.

Under these circumstances, boron acts as an electron donor in the lattice structure. This is believed to add to the electron bonding potentials of nickel atoms between the intergranular surfaces. This makes the surfaces adhesive, lending ductility to the polycrystalline bulk material.

Other impurities, by contrast, such as sulfur or phosphorous, were found to migrate strongly to open cavities and voids, and to a much lesser degree to the grain boundaries. This was fortunate, because these elements act as electron captors, believed to diminish the bonding strength between the intergranular surfaces, encouraging fracture and adding to embrittlement.

Specifically, Basic Energy Sciences researchers showed that the solubility limit of boron in Ni_3Al was about 0.3 weight percent; that ductility of Ni_3Al increased dramatically from near zero to over 50 percent elongation with the addition of boron up to about 0.1 weight percent; that boron migration to the grain boundaries was highly dependent on the existence of slight deficiencies in the relative abundances of aluminum atoms compared to nickel; that grain boundary boron segregation strongly affected grain boundary cohesion and related atomic arrangements, which affected ductility; and that distribution of other impurities remained unaffected by the existence of slight variances in alloy stoichiometry (relative atom abundances).

All of this led to a much clearer understanding of the boron-ductility phenomena which, in turn, led to more broadly-based research on other members of the family of ordered intermetallic alloys. It also provided much needed specificity to guide theoretical work on the role of atomic arrangements and electron structures in metal-to-metal bonding at grain boundaries. Finally, it encouraged engineers to pursue practical applications by lending predictability to various metallurgical procedures.

The discovery of the boron-ductility effect, accompanied by this detailed understanding, was pivotal in the development of a whole new field of research. It precipitated much follow-on and continuing research by both Government and industry on nickel aluminide. As one measure of industry's interest, over a half a million dollars in research money was provided by private companies to the Oak Ridge National Laboratory in 1985 to investigate related production and processing methods. The research earned an IR-100 Award from *Research & Development* magazine (formerly *Industrial Research*), and the alloy is now subject to extensive patent and licensing activity by industrial firms throughout the United States.