Concluding Remarks

In this work, we have explored in depth many types of radioactive contamination that are present in the Counting Test Facility of Borexino, and may also appear to a lesser extent in the full-scale experiment. As we noted, the CTF is not sufficiently sensitive to say definitively that the scintillator it uses is pure enough for Borexino. Nevertheless, study of the CTF backgrounds is invaluable in its own right, as much for discovering and testing new techniques of background measurement as for setting radiopurity limits on individual isotopes.

Some of the techniques described in this work have been specific to the CTF—methods to deal with a two index of refraction system and with timing channel coverage of two PMTs during reconstruction of event positions, for instance. Even in this case, some lessons may be learned. Many times the tradeoff between cost and ease of detector construction versus the resulting complexity of data analysis, though it may seem better to favor the former at first, will yield data that are prohibitively difficult to analyze well. This restricts what can be discovered by the detector. Fortunately, most of these issues will not be present in the full-scale Borexino experiment.

Other techniques, mostly those at a higher level of analysis, are applicable to all scintillation-based detectors. This is true, for instance, of the analysis of the position reconstruction accuracy performed in Chapter 5. More importantly, it is the case for the techniques of particle identification described in Chapter 8. Many of these make it possible to remove background noise from the data sample individually, rather than using a statistical subtraction (which always worsens statistical errors in the final results). Perhaps the most important new technique developed in this work will prove to be the likelihood-based method for tagging radon daughter events, in particular the β decay of the isotope ^{214}Pb which would be difficult to distinguish otherwise.

Future improvements of the method may also be extended to isotopes in the thorium decay chain. In particular, the isotopes ^{212}Pb and ^{208}Tl could conceivably be tagged through this technique, significantly reducing background in the ^{7}Be and ^{8}B neutrino energy domains, respectively. Given the 11-hour half-life of ^{212}Pb, tagging thorium daughter isotopes will also make it possible to detect scintillator convection with much better sensitivity than observations of the radon daughters (separated by on the order of one hour) can provide. It is hoped that such methods may be put to good use in Borexino when it comes online, as well as in later neutrino, dark matter, and neutrinoless double β decay experiments.

Relatively small-scale detectors such as the CTF may in the future act as radiopurity testing facilities, capable of measuring the radioactivity levels of materials to be used in larger experiments at unprecedented sensitivities. The CTF itself, in fact, performed the first measurement ever made of ^{14}C in a petroleum derivative [149]—and this isotope makes by far the *greatest* contribution to the event rate measured in the facility! The ultimate sensitivity of a CTF-like detector to ^{14}C, if a hypothetical organic scintillator with a much lower level of the isotope could be found, would be on the order of one event/day in the central ton of the detector, for a mass fraction of about 10^{-22} g (four atoms!) of ^{14}C per gram of carbon. Sensitivities to uranium and thorium in a 5-kg sample, assuming secular equilibrium, are on the order of one part per trillion, on par with that of inductive coupled plasma mass spectroscopy. The sensitivity could be increased further with a larger sample or a longer counting period. Already there are ideas in the air to construct a $\sim$1 ton liquid xenon scintillation detector to be used as a materials testing facility. Due to the increased scintillation yield of Xe with respect to organic liquids, energy and position resolutions are much improved, and its sensitivity could be even better.

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