

Benchtop NMR spectroscopy for industry

Quality Control of raw materials in the chemical industry

Introduction – benchtop and high field NMR spectroscopy

NMR spectroscopy is an analytical technique familiar to most chemists working in industry and academia, and is a vital part of today's chemistry, biochemistry, food and pharmaceuticals research. NMR enables fast identification of most organic substances by determining their chemical structure and can often quantify the amount of a specific substance in samples. Benchtop NMR spectrometers use permanent magnets instead of the cryogen cooled superconducting magnets used in high field NMR. They are consequently much smaller, easier to maintain and cheaper to run and can take over routine work previously carried out using high field NMR instruments or complementary analytical techniques (e.g. FTIR, NIR, GC-MS and some chromatography techniques). Instruments can be placed in a laboratory or test facility and can also be moved on a trolley to different factory locations. This now makes benchtop NMR spectroscopy an ideal technique for quality control of raw materials, for in line process monitoring and end product Quality Assurance (QA).



Screening Applications of Benchtop NMR

Most analytical work on benchtop NMR spectrometers uses just the proton (^1H) spectrum, but benchtop instruments are perfectly capable of obtaining spectra from other NMR-sensitive nuclei including carbon (^{13}C), fluorine (^{19}F), phosphorus (^{31}P), lithium (^7Li), boron (^{11}B), silicon (^{29}Si), and many others. The Oxford Instruments X-Pulse instrument offers a broadband option where a large range of NMR-sensitive nuclei can be accessed on a single instrument. Benchtop NMR spectrometers typically work best for identifying molecules or compounds with molecular weights around 600 Daltons or less. In this range, the peaks in the spectra can be quantified by lower dispersion benchtop systems.

A common application for benchtop NMR is fast screening of samples to confirm molecular structure after a chemical synthesis. This provides a QA tool, to check the quality and identity of incoming raw materials. They can additionally check large numbers of samples quickly to see whether the expected peaks are present in the spectrum before passing the samples on to high field systems for more detailed analysis. This saves a considerable time for the chemists doing the syntheses and makes sure that the expensive high field instruments are used in the most efficient way.

We highlight below case study examples of QA screening from chemical suppliers to the (1) plastics and construction, (2) fluoropolymers and (3) lithium battery industries.

Raw materials checking (1) – fibreglass sizing compounds.

In this example, a company making fibreglass was concerned about the quality of incoming chemicals used for glass fibre sizing. They used an Oxford Instruments X-Pulse instrument to test three different samples, each provided by two suppliers.

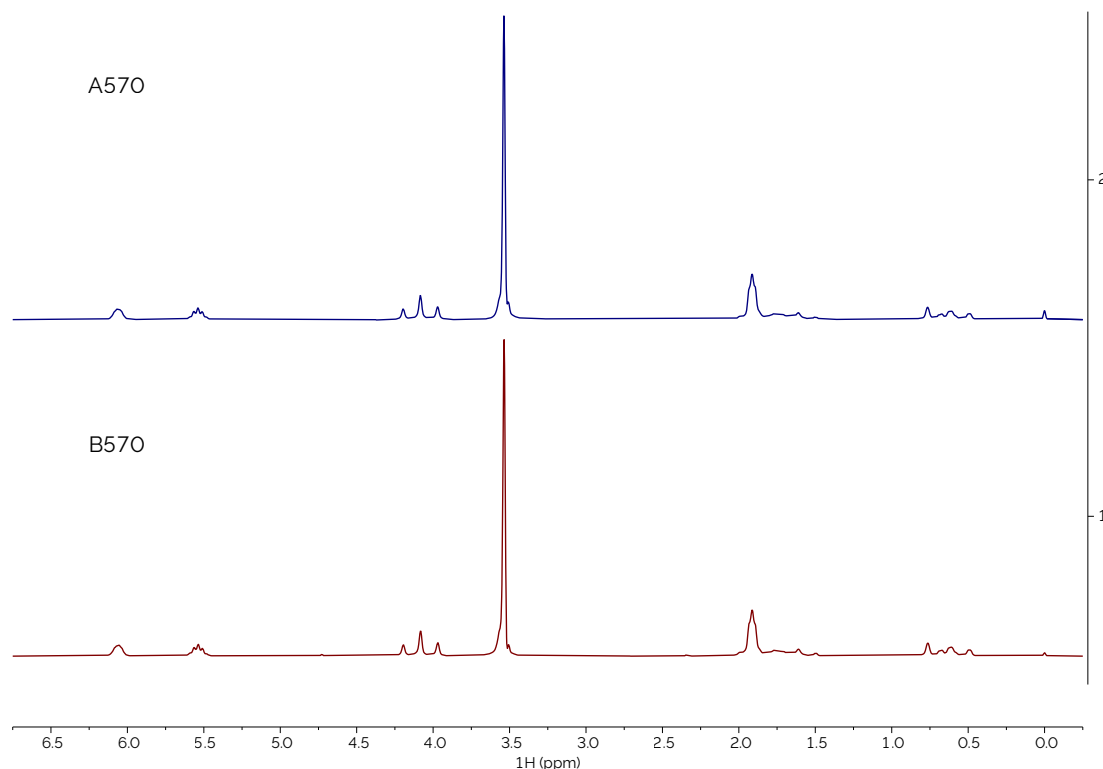


Figure 1 - Comparison of spectra of sample type 570, from suppliers A and B

The user compared samples from the two suppliers that were supposed to be the same material. First, sample type 570 (Figure 1, above). Clearly the two spectra are identical, proving that the materials from Supplier A and Supplier B are the same.

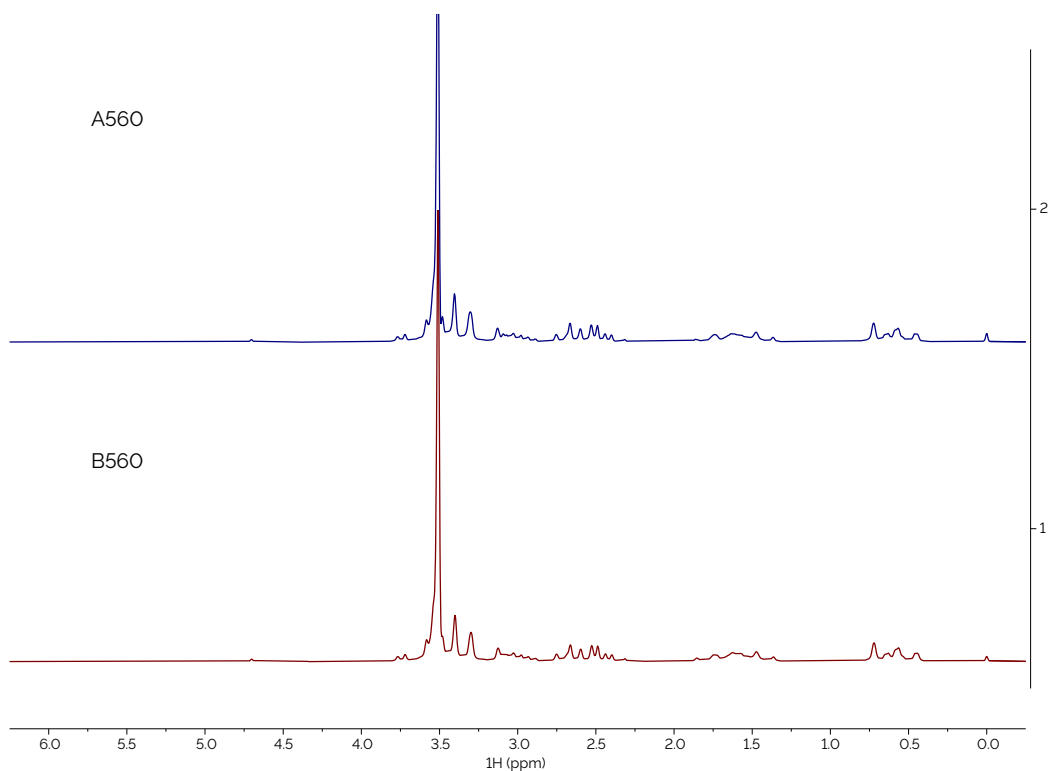


Figure 2 - Comparison of spectra of sample type 560, from suppliers A and B

We see the same with spectra from sample type 560, as in Figure 2 (above). Again, the two spectra are identical, proving that the materials from Supplier A and Supplier B are the same chemical.

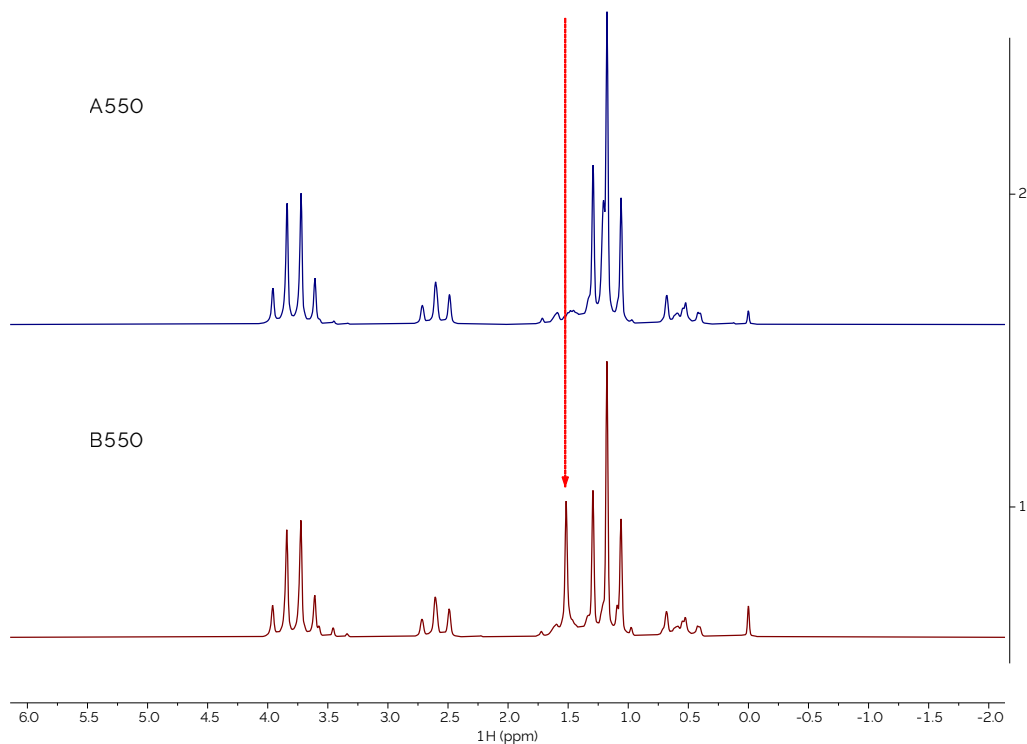


Figure 3 - Comparison of spectra of sample type 550, from suppliers A and B

However, when we compare the spectra from sample type 550 (Figure 3, above) we can immediately see that the spectra are NOT the same, proving that the material from one of the suppliers is not the correct material.

Raw materials checking (2) – fluorinated chemical feedstocks.

In this example, a chemical manufacturer received a feedstock chemical from two different suppliers and found that one of them worked in their reaction but the other didn't, costing the company a significant amount in both time and money. They wanted to know if the cause of if this was due to degradation, contamination, or another factor.

The feedstock chemical was 2,3-Dichloro-1,1,1-trifluoropropane, a relatively simple molecule that generates a surprisingly complex ^1H NMR spectrum given that it has only three hydrogen atoms. We first looked at the ^1H spectrum of a reference sample of this material and compared that to the spectrum of the "failed" material. Figure 4 shows the two spectra.

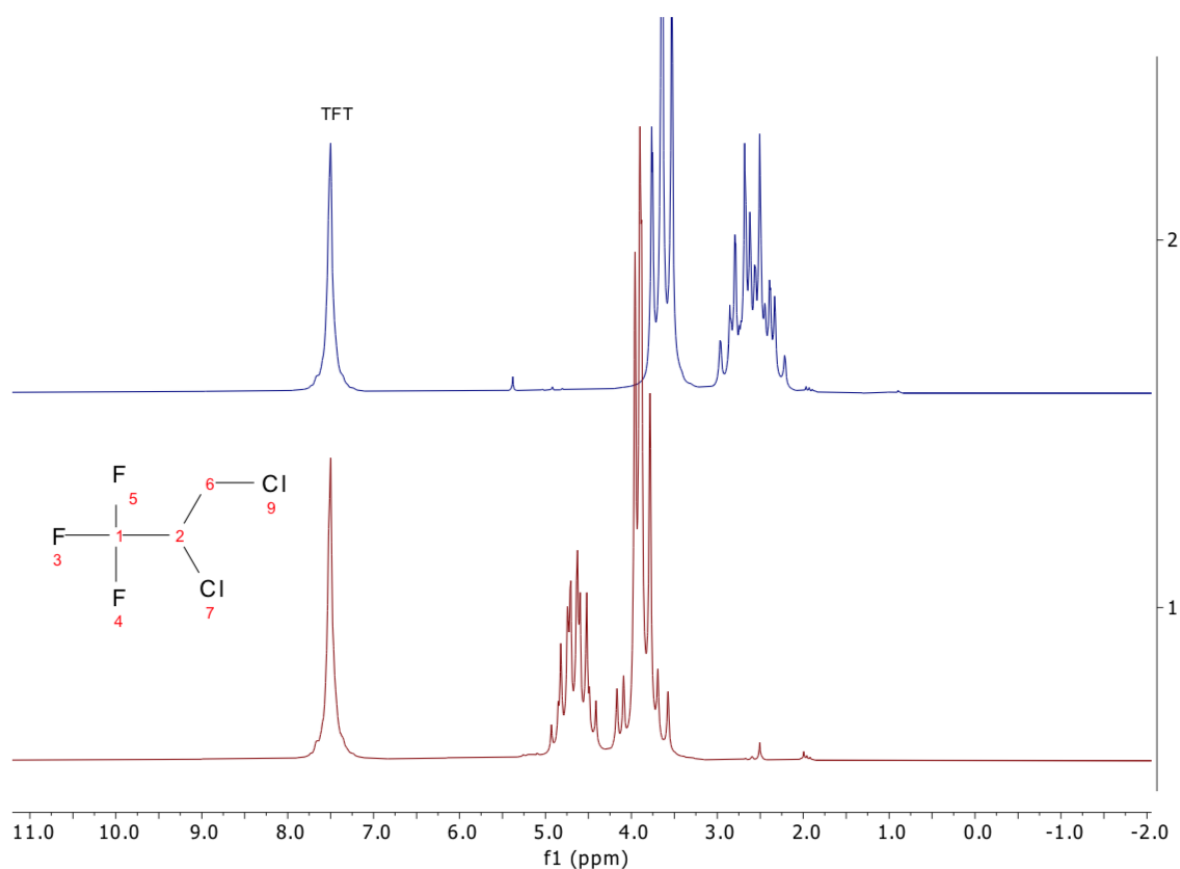


Figure 4 - ^1H 1D NMR spectra of 2,3-Dichloro-1,1,1-trifluoropropane (bottom, red) and the unknown sample (top, blue).

It is clear that there are big differences between the two spectra, so we can tell immediately that the reason for the failure of the reaction is that this supplier's feedstock is chemically different from what was claimed.

To confirm this conclusion, we then looked at the ^{19}F spectra which is extremely straightforward to interpret and again saw very large differences between them, as shown in Figure 5.

By looking also at the ^{13}C spectra (not shown here) we were able to identify that the “failed” material was in fact 3-Chloro-1,1,1-trifluoropropane and not 2,3-Dichloro-1,1,1-trifluoropropane and was mislabelled. Because the full structural determination is not necessary to screen a compound, either the ^1H or the ^{19}F spectra alone can provide the yes/no QA answer. Both can be acquired in approximately 1 minute enabling a fast and, when needed, high throughput checking process.

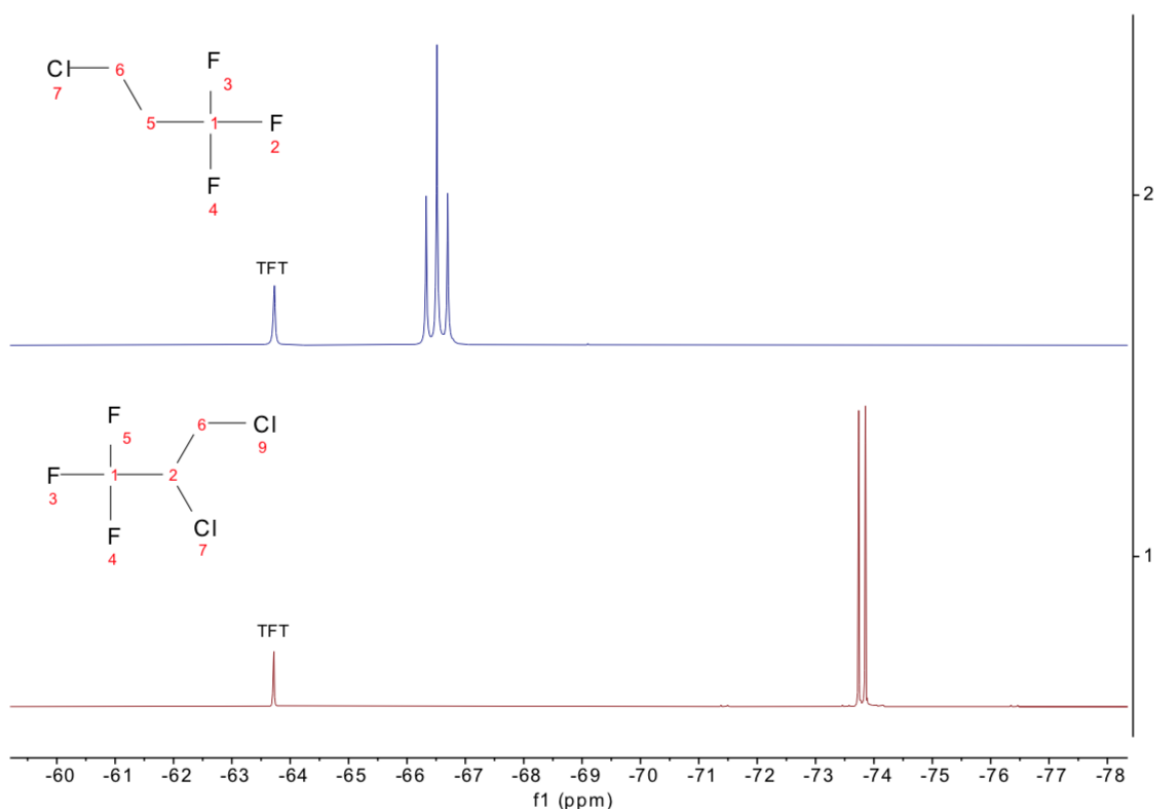


Figure 5 - ^{19}F 1D NMR spectra of 2,3-Dichloro-1,1,1-trifluoropropane (bottom, red) and the unknown sample (top, blue), now assigned as 3-Chloro-1,1,1-trifluoropropane.

Final product checking (1) – Electrolytes for Lithium ion batteries

In this case study, a chemical manufacturer had two different batches of their final product, a typical battery electrolyte of lithium hexafluorophosphate (LiPF_6) in a mixture of two carbonated solvents, ethyl methyl carbonate (EMC) and ethylene carbonate (EC). Although to the eye the two batches B1 and B2, looked identical it was found that batch B2 had very different performance characteristics to those expected when placed inside a battery cell. As with the previous examples, initially the ^1H spectra of the two compounds were collected. The spectra both show all the expected peaks for the ^1H nuclei in the two solvents as identified in figure 6. Visually, they appear identical. Again, as with the previous example

the next test was to measure the ^{19}F spectrum, in these samples this will specifically probe the Li-salt and will identify if the source of the performance difference can be found there. When comparing the spectra in figure 7, the difference is immediately apparent. In sample B2 the expected doublet from the PF is also accompanied by a second doublet. This doublet most likely corresponds to $\text{OPF}(\text{OH})$, a common breakdown product of LiPF_6 when exposed to water in the presence of carbonated solvents. This clearly identifies the cause of the performance difference between the two electrolytes.

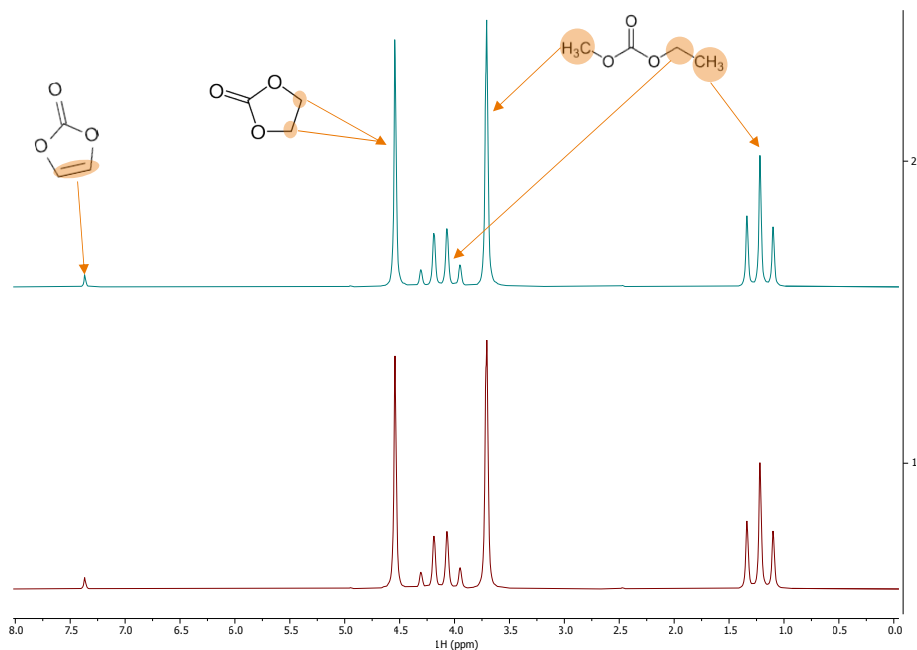


Figure 6 - ^1H Spectra of two different batches of LiPH_6 in EMC/EC

Conclusions

In the examples presented, similarities and differences in the “good” and “bad” spectra can be spotted with the naked eye, and without any knowledge of the chemical structure of the compounds. This enables “Go - No Go” test methods for incoming raw materials that can be formalised with spectral pattern matching to reference databases.

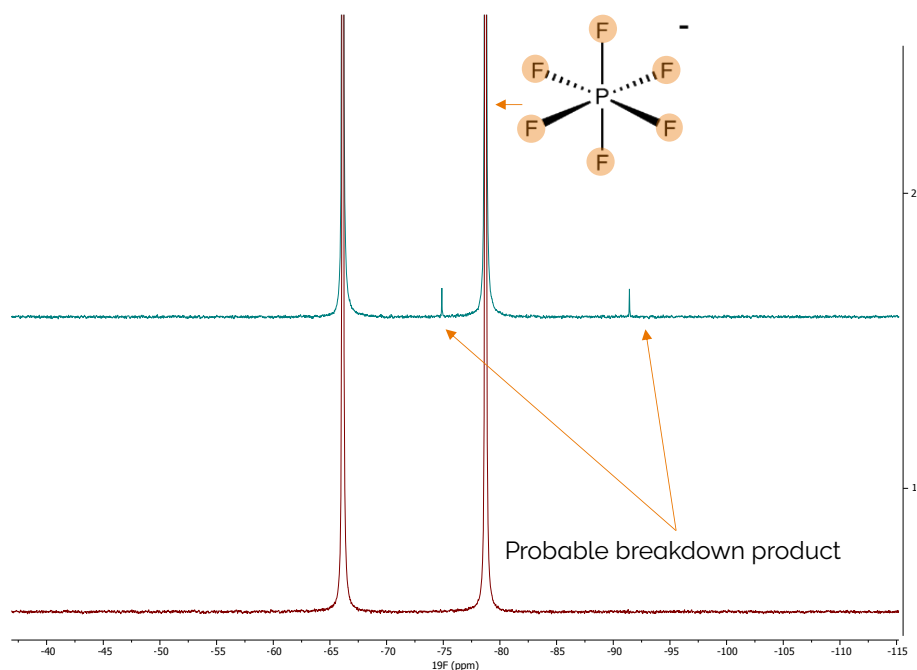


Figure 7 - ^{19}F Spectra of two different batches of LiPH_6 in EMC/EC, extra peaks in sample B2 clearly show the failed sample

For many QA/QC and raw materials screening applications, especially for low molecular weight molecules, modern benchtop NMR spectrometers now provide a faster, more convenient and low-cost solution. They can replace or complement analytical methods such as GCMS, FTIR and chromatography as well as more complex, expensive high field NMR instruments. Their speed and simplicity of use creates significant cost and time savings for both low volume and high throughput uses.



X-Pulse is a high-resolution benchtop NMR spectrometer. Using a high stability 60MHz (1.4T) permanent magnet X-Pulse enables users to collect NMR data without the need for liquid cryogens or specialist facilities. X-Pulse has been optimised with unique shimming technology to provide resolution of better than 0.35Hz. For convenience, X-Pulse uses standard 5mm NMR tubes requiring only 300µL of sample. X-Pulse is the first benchtop NMR system to have a broadband X-Nuclei channel allowing users to select the nucleus that is right for their own application including, carbon, phosphorous, lithium, boron, silicon and many more.

X-Pulse is controlled by the user friendly spinflow software interface. This software allows users to control every aspect of the instrument. For quality control applications like those described above specific experiments can be stored and run using a single mouse click to ensure repeatability and consistency between measurements.

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