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The NMR system of the Hall A polarized Helium 3 target

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Abstract

We present in this technical note a detailed description of the NMR system of the Hall A polarized Helium 3 target, used for the E94-010 experiment.

Contents

1 NMR for Polarimetry

This section describes briefly the principles of Nuclear Magnetic Resonance applied to polarization measurements.

The polarization of polarized Helium 3 targets is measured using the adiabatic fast passage (AFP) nuclear magnetic resonance (NMR) technique, widely described in [1]. This technique has been used successfully in the past at SLAC during the deep inelastic scattering experiments E142 and E154, [2], [3], [4].

The AFP NMR technique consists in creating a rotating effective field able to flip the spins of the the polarized Helium 3 nuclei. The effective field is created using two magnetic fields :

- a large static holding field of magnitude H close to 30 G defining the quantization axis z
- a small oscillating RF field of magnitude $2H_1$ close to 100 mG perpendicular to the static field, oscillating with a frequency f of 91 kHz, close to the Larmor frequency $\gamma H/(2\pi)$ of the spins in the holding field. γ is the gyromagnetic ratio of the Helium 3 nuclei.

Refer to Figure 1 at the end of this document.

The holding field H is swept linearly at a constant speed of 1.2 Gs^{-1} below the resonance $2\pi f/\gamma$ to a value above the resonance. The ramping speed must be :

- adiabatic, that is slow enough so that the Helium spins remain aligned with the effective holding field during the sweep. Then the rate of change of the effective field must be much less than the Larmor frequency of the spins.
- a fast passage, so that the nuclei do not dephase when they pass through the resonance. Then the rate of change of the effective field must be faster than the spin relaxation rate at the resonance, where the effective field is minimum.

At the resonance, the magnetization of the polarized Helium 3 sample is rotating at 91 kHz around the quantization axis. Thus the spins can induce an oscillating flux through a pair of pick-up coils mounted orthogonally to the Helmholtz coils creating the main holding field and orthogonally to the RF coils. The induced voltage is proportional the the Helium 3 sample polarization. The proportionality constant is calibrated by measuring the well known polarization of a water sample in thermal equilibrium and also by the electron paramagnetic resonance (EPR) technique, which consists in measuring the shift of the Zeeman transitions of the Rubidium atoms in the target pumping chamber, due to the presence of polarized Helium 3 nuclei.

It is convenient to use the so-called rotating frame to describe the time evolution of the sample magnetization as a function of time. This frame is rotating at 91 kHz with the applied RF field around the z quantization axis. In the rotating frame, the effective field sensed by the Helium 3 nuclei is :

$$\vec{H}_{eff} = (H - H_0)\hat{z} + H_1\hat{x}' \tag{1}$$

where the resonance field value is : $H_0 = 2\pi f/\gamma$. The counter-rotating component of $\vec{H}_1$ does not affect the spins, as long as the RF field strength is small enough to neglect the Bloch-Siegert frequency shift. Then, the voltage induced in the pick-up coils is proportional to the transverse component of the Helium 3 nuclei magnetization. Its time evolution is described using :

$$S(t) = M\frac{\left(\vec{H}_eff\right)_\perp}{\left|\vec{H}_eff\right|} = M\frac{H_1}{\sqrt{(H(t) - H_0) + H_1^2}} \tag{2}$$

where $H(t) = H_0 + \alpha t$, α is the speed of the ramp (G.s^{-1}) and the resonance occurs at $t = 0$.

2 The NMR Setup

2.1 The coils

The NMR Polarimetry requires the use of several coil pairs :

- one pair of large Helmholtz coils
- one pair of smaller Helmholtz coils
- one pair of RF coils
- one pair of pick-up coils

The two pairs of Helmholtz coils allow us to create a holding field pointing in any direction. One set has a smaller diameter than the other. The two sets are orthogonal to each other and oriented at 19 degrees from the beam line, so that the coils themselves are not seen by the spectrometers. The angle convention we use in this manual is represented on Figure 2. Every coil in mounted in series with the other one. We have introduced an amperemeter in series between the two coils of each pair to monitor the current flowing through them. The target cell is placed right at the geometrical center of the two sets when the polarization measurement is performed.

The RF coils are also mounted together in series and horizontal. Their connection is shown on Figure 7. The target cell is also located at their geometrical center when measuring the polarization. A small toroid is wrapped around one of the incoming wire so that the RF current at 91 kHz flowing through them can be monitored online.

Finally, one pair of pick-up coils, connected in series using a preamplifier, is used to detect the induced voltage, when the target cell is placed between them during the NMR sweep.

The Helmholtz coils and the RF coils have been designed by the Walker Scientific Company. The pick-up coils have been locally designed and wrapped by hand. Figure 3 shows the main characteristics of the Helmholtz and RF coils.

2.2 The electronics

Most of the electronics is controlled by a Macintosh personal computer (see Figure 11, as will be explained later.

2.2.1 The KEPCO power supplies

The KEPCO power supplies produce a DC current in the Helmholtz coils. Their front panel can be seen on Figure 13. We have two power supplies, named KEPCO 3 (for the large coils) and KEPCO 4 (for the smaller coils). They can be used in two working modes :

- a Voltage Mode, where the output voltage of the power supply is stabilized in time
- a Current Mode, where the delivered current is stabilized in time

The ideal working mode would be the Current Mode, where the current remains stable in time, so that the Helmholtz field remains perfectly the same during the experiment. Unfortunately, the feedback control of the current stability produces a high frequency noise along the cables going to the coils, which destroys completely the NMR signal. Even the use of additional unpolarized capacitors did not improve. For that reason, the KEPCO power supplies are used in the Voltage Mode, where no such noise has been observed. The Voltage Mode is the one that allowed us to get the most beautiful NMR signals. The KEPCO power supplies can be driven through their GPIB interface as listeners only. However, to reduce transmission delays between the Macintosh and the power supply, we decided not to use the GPIB control of the power supplies. Instead, the KEPCO output voltage or current can be controlled by applying a DC voltage on their front panel. This DC voltage can be produced directly by using a function generator. For that reason, each KEPCO power supply is connected to a function generator, named FG Large or FG Small, depending on the set of coils they control.

Inputs

- power cord

- two wires (red and black) coming from the function generator driving the corresponding KEPCO and connected to the front panel Voltage Mode inputs (red and black). Warning, for KEPCO 4 (small coils), the front panel Voltage Mode inputs (red and black) have been reversed ! They should be as they are on KEPCO 3 ! A sticker indicates the right colours on the front panel.

Outputs

- OUT and COM cables for the main output of the current toward the coils
- SOUT and SCOM cables for the sensing circuit toward the coils (a 1 A fuse is connected to each sensing wire in the hall at the point were they are attached to the coils)
- two polarized 1 μF capacitors as shown on Figure 4 used by the sensing system in presence of a heavy load, as suggested by the company

Reference : Bipolar Operational Power Supply - KEPCO - Model BOP 36-12D

2.2.2 The function generators driving the KEPCO power supplies

We use two function generators to control the KEPCO power supplies. These function generators are entirely controlled by GPIB, in two modes :

- a **Waveform Mode**, where the function generators keep in memory the shape of the AFP ramp ; no external control is necessary to perform the sweep, except the external trigger.
- an **Offset Mode**, where the function generators deliver a DC voltage step by step, used to rotate the main holding field. For this mode, the value of the output voltage has to be specified at each step by the computer through their GPIB bus.

Refer to Figure 15.

Inputs

- power cord
- GPIB cord from the Macintosh

Outputs

- BNC to the corresponding KEPCO power supply, via the Field Rotation Box and Field Feedback Box (for EPR only)
- BNC trigger output to tho other function generator driving the other power supply and to the lock-in amplifier

Reference : Synthesized Function Generator - Stanford Research System - DS345

2.2.3 The RF power amplifier

The RF power amplifier generates the RF power sent to the RF coils. It simply receives the excitation from a dedicated function generator and sends it toward the pick-up coils. Refer to Figure 16.

Inputs

- power cord
- BNC output of the excitation function generator via an attenuator

Output : BNC to the RF coils

Reference : Broadband Power Amplifier - ENI - 2100 L

2.2.4 The VHF attenuator

The VHF attenuator simply reduces the input voltage applied to the RF power amplifier. The standard gain chosen for E94010 is 20 dB. Refer to Figure 18.

Inputs

- power cord
- BNC output from the excitation function generator, with a 5 dB attenuator cap

Output : BNC to the RF power amplifier

Reference : VHF attenuator - Hewlett Packard - Model 355D

2.2.5 The RF excitation function generator

The RF excitation of the power amplifier is produced by a dedicated function generator delivering a sine wave at 91 kHz with an amplitude of 2.4 Vrms to the power amplifier via the VHF attenuator. It is controlled by the Macintosh through its GPIB bus and sends a reference signal to the lock-in amplifier. Refer to Figure 17.

Inputs

- power cord
- GPIB cord from the Macintosh

Outputs

- BNC to the attenuator (and to the power amplifier)
- BNC to the lock-in amplifier for the RF reference at 91 kHz

Reference : Synthesized Function/Sweep Generator - Hewlett Packard - HP 3324A

2.2.6 The RF capacitor box

A box containing capacitors in series with the RF coils has been designed by Temple University to increase the RF power delivered to the coils, especially usefull with the long cables running from the power amplifier in the counting house to the RF coils in the hall. The default value of the unpolarized capacitor used is 38 nF, as selected by the knob. The values of the available capacitors are given in Table 1. See Figure 17.

Input : BNC cable from the output of the power amplifier

Output : BNC to the RF coils

Reference : designed on purpose by Temple University

2.2.7 The low-noise preamplifier

A preamplifier is used to connect in series both pick-up coils down in the hall and to amplify the induced voltage (only when measuring the water thermal polarization with a water cell). No filtering is applied for E94010. Refer to Figure 26.

Inputs

- power cord
- BNC from pick-up coil A
- BNC from pick-up coil B

Output : BNC to the lock-in amplifier in the Counting House (A+B signal)

Reference : Low-Noise preamplifier - Stanford Research Systems - Model SR560

2.2.8 The lock-in amplifier

The lock-in amplifier is used to measure the induced voltage in the pick-up coils. It extracts the Fourier component of the signal at 91 kHz, as set by the RF excitation function generator and does not amplify the signal. The induced voltage values are stored in the lock-in buffer during the AFP sweep, which is read by the Macintosh at the end of the sweep. Namely, the induced voltage appears in two channels (X and Y), one of which contains only the actual induced voltage and the other containing only noise. The phase of the lock-in amplifier can be set manually in order to reject all the noise in one of those two channels. See figure 19.

Inputs

- power cord
- GPIB cord from/to the Macintosh
- BNC from the preamplifier connected to the pick-up coils
- BNC from the external RF reference from the RF excitation function generator
- BNC trigger input from the DS 345 function generators to start the buffer acquisition

Reference : RF Lock-in Amplifier - Stanford Research Systems - SR844

2.2.9 The field rotation box

The Field Rotation Box (refer to Figure 14) contains two electronic circuits, each being inserted between the DS345 function generator and the corresponding KEPCO power supply. As will be explained later, this electronic circuit is used to get rid of voltage glitches appearing when the function generators are used in the Offset Mode to rotate the main holding field. Each circuit has been designed by the Fast Electronics Group at Jefferson Lab [5]. These circuits need to be driven by a third function generator producing simultaneously on both circuits a square burst during which they hold the voltage applied to the KEPCO power supplies.

Inputs

- power cord
- BNC from the corresponding DS345 function generator
- BNC from the Wavetek rotation function generator

Output : BNC to the corresponding KEPCO

2.2.10 The rotation function generator

The Wavetek function generator is connected to both electronic circuits contained in the Field Rotation Box. It produces a TTL signal of 10 V and of variable length (as will be specified later) when requested by the Macintosh. That TTL signal is sent to the electronic circuits, so they can determine when they need to hold their input voltage, to mask the glitches produced by the DS345 function generators. Refer to Figure 15.

Inputs

- power cord
- GPIB from the Macintosh

Output : BNC to both electronic circuits contained in the field rotation box

Reference : 50 MHz Function and Pulse Function Generator - Wavetek - Model 80

2.2.11 The DAQ interface

In case of a major failure in the system of our function generators driving the KEPCO power supplies, we have equipped our Macintosh with a DAQ card which output can be directly connected to the front panel of the KEPCO power supplies. Dedicated LabVIEW programs have been written for the AFP sweep and the field rotation using the DAQ card but have not been used for the experiment.

Outputs

- BNC to KEPCO 3 front panel
- BNC to KEPCO 4 front panel

Reference : National Instruments - Macintosh NB-AO-6 internal card (with BNC interface designed at JLab)

2.2.12 The RF current monitor

The RF current monitor is a small toroid built by the Pearson Company and inserted around one of the wires going to the RF coils. The induced voltage monitored online by a video camera looking at the screen of a portable oscilloscope in the Hall A is proportional to the RF current flowing through the wire : 1 V corresponds to 1 A.

Output : BNC to the oscilloscope

Reference : RF current monitor - Pearson

2.2.13 The multimeters

Two multimeters are used to monitor online the current flowing through the main Helmholtz coils. They are in the hall and have been inserted in series in between the two coils of each set and are read through their GPIB bus via the GPIB-ENET interface, which allows us to transfer their reading through the network. Refer to Figure 27.

Inputs

- power cord
- GPIB cable from/to GPIB-ENET interface
- one wire coming from one coil

Output : one wire going to the other coil

Reference : Dual Display Multimeter - Fluke - Model 45 with IEEE Kit (GPIB Bus)

2.2.14 The Hall A gaussmeter

A Hall probe provided by J. Lerose (refer to Figure 28) has been used to calibrate each set of Helmholtz coil down in the hall. The relation between the DC voltage applied by the function generator connected to the corresponding KEPCO has been swept from -8 V to 8 V and the created field has been measured using the Hall probe, placed at the geometrical center of the studied pair of Helmholtz pair coils. The Hall probe was read through a GPIB-ENET interface connected to the Ethernet.

Inputs

- power cord
- Hall probe

Output : GPIB cable to GPIB-ENET interface

Reference : Gaussmeter - Lake Shore - Model 450

2.2.15 The GPIB-ENET interface

The GPIB-ENET interface allows us to read any device with a GPIB bus through the standard network. All the GPIB addresses in the LabVIEW Vis of devices connected to the GPIB-ENET interface will start with **1:**. If instead the devices are connected to the Macintosh through standard GPIB cables, their address starts with **0:**. Refer to Figure 29.

Inputs

- power cord
- GPIB cord from multimeters

Output : BNC to ethernet and 50 Ω cap, through a dedicated transceiver provided by the Jefferson Lab computer center : Allied Telesis, Centre Com MX10, type IEEE 802.3 microtransceiver, 10 Base 2 (MAU).

Reference : National Instruments - GPIB-ENET Interface

2.3 Cabling

All references to BNC cables stand for RG58 cables.

- the coaxial cables running from the preamplifier in the hall to the lock-in upstairs in the counting house, going from the power amplifier in the counting house to the RF coils downstairs, and from the RF excitation function generator upstairs to the small loop downstairs (for Q curve studies) are RG213 cables with a length of 250 feet approximately. They are connected to a panel in the middle room upstairs in rack CH01B03 and under the beam line downstairs using end series plugs with a BNC (RG58) adaptor, as shown on Figure 9.
- the 4 OUTput/COMmon cables going from the KEPCO power supplies upstairs to the Helmholtz coils downstairs are 4 standard gauge 2 strained cables of 250 feet.
- the 4 SOUTput/SCOMmon sensing cables going from the KEPCO power supplies upstairs to the Helmholtz coils downstairs are Belden 2C18 cables. Same length again.

A drawing summarizing the cabling of the NMR system is shown on Figure 10.

3 The NMR System Control

The NMR target setup is entirely controlled by a Macintosh personal computer.

3.1 The Macintosh personal computer

The Macintosh personal computer is a Power PC 8100/80AV using Mac OS system software 7.5.3 revision 2 and is located in the counting House, as shown on Figure 6. It allows us to control entirely the polarization measurement procedure, using both the NMR and the EPR techniques. The Macintosh communicates with the electronics exclusively through the General Purpose Interface Bus (GPIB), using virtual instruments (Vi) written with the LabView version 4.1 software. The devices are driven through a NuBus-GPIB card (National Instruments NB-GPIB/TNT), through a NuBus-DAQ card (National Instruments NB-AO-6) or through an Ethernet GPIB-ENET interface (National Instruments) which allows you to drive any device through the standard JLab ethernet network. The Macintosh configuration is described at the end of this document and the GPIB address of each device is also given (refer to Table 4). The Macintosh has a memory of 96 Mb, and uses two hard disks (HD1 with 500 Mb and HD2+HD3 with a total of 1.2 Gb), one of which is split in two units of 600 Mb each (HD2 and HD3). The LabView programs used for the NMR and the EPR systems are stored in the partition HD3 and the NMR and EPR Data are saved on HD2. HD1 contains the Macintosh operating system and all the application programs. Refer to Figure 11.

3.2 Standard virtual instruments

We describe here each Vi every E94010 target operator will have to use during the E94010 running period.

You must first turn on the Macintosh computer. After a shut down, use the key combination **Control+Apple+Left arrow** (on the top right hand side of the keyboard) to restart the computer.

3.2.1 The NMR Master panel

You first need to run the NMR Master panel. The NMR Master panel is a self running panel ; it allows you to call dedicated Vis for specific tasks, for example : do an NMR measurement, measure the Q factor of the pick-up circuit, etc... To run the panel, go to the Apple menu with the mouse, towards the upper left corner of the Macintosh screen and click on the **NMR Master** shortcut. For information, the shortcut itself is stored in the **HD1:System Folder:Apple Menu Items**. The Vi is named **NMR Master** and is stored in the folder :**HD3:NMR:Common:LabVIEW Panels**. After a while, LabVIEW starts and the NMR Master panel appears. We present below each component (also called sub-Vis). To start a specific sub-Vi, simply click on the corresponding **GO** button in the **NMR Master** panel. To quit the NMR Master panel, click on the **EXIT** button. Finally, if you want to quit LabVIEW itself, use the key combination **Apple+Q**.

Vi Description

The **NMR Master** Vi is located in the **HD3:NMR:Common:LabVIEW Panels** folder and is named **NMR Master**. The Vi is looping until you press one of the **GO** buttons corresponding to a specific Vi, or closes if you press the **EXIT** button. It opens and runs automatically the Vi you have called by ressing its **GO** button and is continuously looping. Refer to Figure 30.

3.2.2 Record NMR Settings panel

Before any NMR measurement, you must fill out the NMR Settings panel. The display will be printed automatically when you press the **PRINT** button. The print out should always be kept in the target NMR binder. Please, do not forget to enter the name of the target operator in the blue Target Operator window, and the LAST RUN NUMBER in the data taking. Make also sure the target name is the right one. This sheet allows us to keep track of each important setting of the target setup :

- Controls rack: located close to the counting house whiteboard (Figure 20)
- NMR rack: located on the right side of the Macintosh (Figure 12)
- Lock-in amplifier: located on the top of the NMR rack (Figure 19)

- Lasers Monitor: the small TV monitor below the alarm panel (Figure 24)
- Lasers and RTDs X terminal: below the spectrometer magnets NMR oscilloscopes, on the counting house control desk on the right hand side of the NMR rack ; it is named HAC (Figure 25)

We explain here how to fill each window on the panel.

- **Controls rack** : the **Heater** settings are read on the oven heater controller chassis (refer to Figure 21) : oven air flow (arbitrary unit), oven temperature (read the green display only, which gives the actual temperature in the oven, in degrees Celsius) and heater temperature (in degrees Celsius). The **Target Position** is given by the red digital display called Aux Target Readout, on the target motion controller (arbitrary unit); refer to Figure 22. It tells us which target is in the beam : reference cell (glass cell with variable gas pressure), no cell, BeO target, polarized target (in beam) and position where the polarized target is between the pick-up coils. This is the position where the target has to stand if you want to measure the polarization of the target by NMR. This is why before any NMR measurement, you must call MCC (7047) and tell them you are about to move the target to its polarization measurement position. Once they agree, move the target to the pick-up coils position. After the measurement, move the target back into the beam position and call MCC back. Use the Cell selector to describe the position of the target on the panel. The two Helium 4 **Cooling Jets** flows (1 and 2, arbitrary unit) are displayed on the bottom red box, on the left of the **Reference Cell** pressure gauge (in psia) ; refer to Figure 23.
- **Lock-In amplifier** (above NMR rack, see Figure 19) : due to its location in a quiet corner of the counting house, the settings are pretty hard to check. However, they may be crucial to the analysis of the helium NMR signals. The default settings indicated by the Vi are the ones you should read on the lock-in. They will never be changed during the experiment (except the lock-in phase), unless needed for specific reasons (water calibration, ...). They are : the lock-in time constant (10 ms), the wide reserve for the signal input (low), the input impedance (50 Ω), the sensitivity (30 mV), the close reserve mode (low), display 1 (X channel), offset 1 (off), display 2 (Y channel), offset 2 (off), the reference source (external), the reference impedance (50 Ω) and the phase (to be set, in degrees). We have indicated in parenthesis their E94010 settings. The most important one is the phase of the lock-in, which changes every time the Helium 3 cell is replaced : it needs to be adjusted by hand by the NMR expert to put all the NMR signal in only one channel (X or Y). Each setting (except the phase and the offsets) is indicated by a small green led on the front panel of the lock-in, as shown on Figure 19. The phase can be read on the very right hand side red digital display (the third one : for instance, -64.00 deg). Make sure to note carefully its value in the phase window of the Vi. The Offset 1 and Offset 2 selectors should are set to off by default, if no yellow 'XY Offs' display appears just below the first two red displays (1 and 2).

- **NMR rack** : it contains the two KEPCO power suplies : **KEPCO 3 and KEPCO 4** which drive the main Helholtz coils (refer to Figure 13). KEPCO 3 drives the large set, and KEPCO 4 the small set. They should both be set to Voltage mode (use the two Mode K3 and Mode K4 selectors on the Vi to specify) and the red switches located close to the black knobs should always be set to off. Write down the value of the voltage and the value of the current, displayed on the digital display on the front panel of each KEPCO. Those values tell you if the field orientation is parallel or perpendicular. Use the corresponding selector, to check parallel or perpendicular. The **Rotation Box** is located in the rack, just below the Field Feedback Box. Refer to Figure 14. **It should always be turned on !** If not, the KEPCO power supplies will not deliver any current ! The **RF Current monitor** is a small toroid through which flows the RF current, located in the hall. Its output is displayed by an oscilloscope viewed on the TV monitor, above the RF power amplifier (refer to figure 16). When you fill out the form, there is no RF current in the RF coils. The current will appear when you start the AFP sweep, using the NMR Measurement panel. **Therefore, you will have to write down by hand on the print out sheet the value displayed on the oscilloscope when you run the NMR Measurement Vi**. The **Preamplifier** array displays the settings of the preamplifier located near the pick-up coils in the hall. The settings displayed on the Vi have been set by the NMR expert and should not be changed. For the E94010 helium data taking, they are : high pass (none), coupling (AC), roll off (none), source (A-B), low pass (none), invert (off), output (50 Ω, on the BNC output), gain mode (low noise), gain (1), power (line). Refer to Figure 26. Finally, the **RF Capacitor Box** allows you to specify the value of the serial capacitor introduced in the RF circuit to increase the RF current delivered to the coils. For E94010, it has been set to 38 nF and should not be changed. Refer to Figure 17.

- Lasers and RTDs X terminal : on the HAC X terminal screen (refer to Figure 25), in the **Lasers** display area, you can read the current and the temperature of each laser (4 longitudinal lasers and 3 transverse lasers). Enter on the Vi how many lasers are running (if a laser is running, its current is not zero). In the longitudinal configuration, the longitudinal lasers should be running and the transverse lasers should be off. In the transverse configuration, the longitudinal lasers should be off and the transverse lasers should be running. In the **Temperatures** display area, you can read the temperatures given by the 7 RTDs mounted on the Helium target (RTD 1 to RTD 7). Write down their approximate value on the Vi, from the RTD HAC X-terminal.

When you have filled out the Vi, simply press the **PRINT** button to run it. Several messages will pop up :

- check if there is enough paper in the Macintosh printer (look at the purple needle on the bottom of the printer's paper tray)

- print the RTD Temperatures screen displayed on HAC and check quickly that the proper lasers are working fine, as can be seen on the Lasers display on HAC

- remind you that you will have to write down by hand the peak-to-peak RF voltage value displayed on the RF CURRENT TV monitor when you perform the NMR sweep

Vi Description

The **Record NMR Settings** Vi is located in the **HD3:NMR:Common:LabVIEW Panels** folder and is named **NMR Settings**. The Vi is looping until you press the **GO** button. It displays the date and time of the record and then prints automatically the panel you have filled out, as you may see it on the screen. It will close by itself. Refer to Figure 31.

3.2.3 NMR Measurement panel

This panel should be called after running the NMR Settings panel and after having moved the Helium 3 target to the pick-up coils (MCC had to be warned and no beam should hit the target). The holding field has to be set in the parallel or antiparallel configuration to do a NMR polarization measurement. The Vi performs the AFP spin sweep of the polarized Helium 3 sample through the resonance. The default settings of the Vi are the following :

- For the holding field ramp : minimum field : 25 G, maximum field : 32 G, speed : 1.2 Gs^{-1}
- RF Voltage applied to the power amplifier : 2.4 Vrms
- RF Frequency : 91 kHz

They cannot be changed. To launch the sweep, simply click on the **GO** button. Several messages will pop-up :

- check that you have moved the polarized Helium 3 target to the pick-up coils
- check that the holding field is in the longitudinal configuration
- check that the longitudinal lasers are on
- check that the green LED on the lower right hand side of the RF EXCITATION HP3324A function generator is on (otherwise, no RF output will be delivered)
- as soon as the RF power turns on (the power amplifier needle deviates), write down on the NMR Settings printout the peak-to-peak value of the RF voltage displayed on the RF CURRENT TV monitor

The Vi then starts automatically the AFP sweep and displays after the measurement the X and Y readouts of the lock-in, stored in the lock-in buffer. The lock-in phase should have been set such that the signal is maximum in one channel, and minimum in the other one, as shown on Figure 32. The UP signal is displayed in red, the DOWN one in blue, as a function of the holding field value. The shift between the up and down value reveals a delay in the coil response and could artificially be corrected in the Vi. The relative delay between the two coils is perfectly stable in time and is estimated to be 0.50 ± 0.01 s. The X and Y data as a function of the holding field are automatically saved in the folder **HD2:NMR Data:Helium**, and are stamped with the date and time of the measurement ; the file name starts with a x for the X channel and with a y for the Y channel. The file name for each channel is indicated in the Data File window. The Vi also displays automatically the lock-in phase in the Lock-in window. When the sweep is completed (as displayed by the Stage window), print the screen using the key combination **Apple+P**. A menu will pop-up and confirm to print on the Mac printer by pressing **Ok**. After that, you may press the **EXIT** button to close the Vi.

Vi Description

The **NMR Measurement** Vi is located in the **HD3:NMR:Helium:LabVIEW:Sub VIs** folder and is named **NMR Helium XY FG-V**. The Vi is looping until you press the **GO** button. If first asks the RF Excitation FG to deliver a sine wave at 91 kHz with an amplitude of 2.4 Vrms. The lock-in is then asked to display its phase, channels 1 and 2 are respectively set to X and Y, the sensitivity goes to 30 mV rms, the offset feature of both channels is turned on and set to auto mode, to subtract any DC offset. The phase of the lock-in is then displayed on the Vi. Date and time of the measurement are displayed. The lock-in buffer transfer is set to GPIB mode, its buffer is cleared, the sampling rate set to 64 Hz, compatible with a time constant fixed at 10 ms. The buffer is set to loop mode and to trigger start. The Macintosh sends then a trigger to the SRS Function Generators driving the KEPCO power supplies. The lock-in also receives the trigger and starts automatically to store the pick-up coils data in its buffer. After that, the Vi is simply waiting for the ramp to be achieved, going from 25 G to 32 G and back to 25 G, at a speed of 1.2 Gs^{-1}. The Vi then stops the buffer acquisition, and reads the buffer content in ASCII mode for the X channel, converts the data in a convenient format, displays them on the screen and save them. It does the same for the Y channel. The data reading, conversion, splitting (between the up and down ramps) procedures are really specific to the SRS lock-in amplifier and rather complicated. To get more information, simply ask for the LabVIEW programs and for the devices manuals. The offset feature of both channels is then turned off and the RF voltage delivered by the RF Excitation function generator is set back to its minimum value of 0.4 mV rms (the frequency is still kept at 91 kHz, so that the lock-in remains locked). The stage window is regularly updated to inform about the whole process. To quit, press the **EXIT** button to close the Vi.

3.2.4 Extract Polarization panel

This Vi should be used just after the AFP sweep. It doesn't need any particular tuning. Just run it by clicking on the **GO** button. You will first be asked if you want to create an R file, from previously saved X and Y data. R is simply $R = \sqrt{X^2 + Y^2}$. Just choose "No" unless you really want to fit R. Another window opens to ask you to choose your data file. Simply go to the folder **HD2:NMR Data:Helium** and choose the file corresponding to your last measurement and having the largest amplitude (channel X or channel Y). The name of your data file will be displayed in the Vi Data File window for confirmation. Then the Vi will start to fit the UP and DOWN signals. The result of the fit should appear after a few minutes. The Vi will give you the value of the polarization, using both calibration methods : the NMR Water calibration and the EPR calibration. The fitting function is the square root of a Lorentzian with a linear background and has five free parameters : width w (in G), background slope s (in mV/G), resonance field H_{res}(in G), peak height h (in mV) and background constant c (in mV), according to the formula :

$$signal(H) = \frac{h}{\sqrt{1 + \frac{(H-H_{res})^2}{w^2}}} + sH + c \tag{3}$$

The width of the resonance curve at $h/\sqrt{2}$ is $2H_1$, and w is the estimated value of H_1.

The error matrices and the reduced χ^2 are also displayed for each fit. Once again, print the display when you get the polarization values, using the **Apple+P** combination. Press the **EXIT** button to quit. You can also press again the **GO** button if you want to change the range of the fit (Min Field UP, Max Field UP, idem for DOWN) set by default to 25 G and 32 G. You may also specify your own guessed values of the inital fitting parameters in the grey arrays ; if so, do not forget to switch the two yellow buttons to the UP initial coefficients and DOWN initial coefficients positions. You may have to change these initial coefficients if the fit(s) you get are wrong. Just get an estimation of their value from the plot of the signal. To quit, press the **EXIT** button to close the Vi.

Vi Description

The **Extract Polarization** Vi is located in the **HD3:NMR:Helium:LabVIEW:Sub VIs** folder and is named **NMR Helium Fit**. The Vi is looping until you press the **GO** button. It first displays the date and time of the fit and allows you to open a data file, contening the holding field values and the readouts of the lock-in for the up and down ramps. Once the data file is opened, the data are split to reconstruct both up and down ramps. Each ramp is then individually fitted using the Levenberg Marquardt algorithm to determine the least squares set of coefficients that best fit the set of input data points. The best fit is then displayed for both ramps. The value of the polarization is calculated from the EPR calibration constant and from the Water NMR calibration constant, which default values are set by the NMR expert in the small blue windows on the very right hand side of the Vi and named **EPR Constant** and **H2O Constant**. Refer to Figure 33.

3.2.5 Read Saved NMR Data panel

This Vi should be used if you simply need to check the content of a saved NMR data file. Simply press the **GO** button to run the Vi ; a window will pop-up asking you to choose a data file. We remind you that the NMR data files are located in the folder : **HD2:NMR Data:Helium**. The name of your data file will be displayed in the Data File window for confirmation. When done, you can print the window using the **Apple+P** key combination and quit the Vi by pressing the **EXIT** button.

Vi Description

The **Read Saved NMR Data** Vi is located in the **HD3:NMR:Common:LabVIEW Panels** folder and is named **NMR Read Saved Data**. The Vi is looping until you press the **GO** button. It opens the file you ask for, splits the up and down data and just displays them on the graph. Refer to Figure 34.

3.2.6 Spin up & Lifetime panel

This Vi allows you to fit spin up or spin down data. Spin up data are used to predict the saturation value of the target polarization, and spin down data allow us to extract the lifetime of the cell. First, switch the red button to Spin up to fit spin up data or to Lifetime to fit spin down data. Then, simply enter the Time values (in minutes) in the first left hand side array named 'Time' and the corresponding Amplitude (in mV) or Polarization (in %) values in the 'Amplitude' array. Use the red Unit selector to specify the unit of your data. Then press **GO** to run the Vi. Your data points and the result of the fit will be displayed together, and you will get an estimation of the maximum polarization the target can reach (Spin up window) or an estimation of the cell lifetime (Lifetime window). The reduced χ^2 and the error matrices are also displayed for information. To quit, press the **EXIT** button to close the Vi.

Vi Description

The **Spin up & Lifetime** panel Vi is located in the **HD3:NMR:Common:LabVIEW Panels** folder and is named **NMR Lifetime**. The Vi is looping until you press the **GO** button. It then fits the data you have entered using the Levenberg Marquardt algorithm and the following fit expression :

- For an estimation of the cell lifetime L, the data are fit with the shape :

$$ae^{-x/L} \tag{4}$$

- For an estimation of the cell saturation polarization P_0, the data are fit with the shape :

$$P_0\left(1 - e^{-(x-b)/c}\right) \tag{5}$$

where a, b and c are fit parameters and where x is the time (in min). Refer to Figure 35.

3.2.7 Spin Up/Down Curve panel

This Vi should be used if you want to study the spin-up/down curve of the target over a few hours. It performs several AFP sweeps using the NMR Measurement Vi, their total number being specified by the control button 'Total number of sweeps' regularly spaced in time, as specified by the 'Delay between ramps (min)' control (in minutes). When you press **GO**, it will display the evolution in time of the height of the R UP and DOWN lock-in signals. We remind you that the target must remain between the pick-up coils if you decide to run that Vi. All the messages have been by-passed so that the Vi can run by itself. Once done, you may print it with **Apple+P** and quit by pressing **EXIT**. The spin-up curves are saved in the folder **HD2:NMR Data:Spin_up**.

Vi Description

The **Spin Up/Down Curve** Vi is located in the **HD3:NMR:Helium:LabVIEW:Sub VIs** folder and is named **NMR Helium XY FG-V SPINUP**. The Vi is looping until you press the **GO** button. It uses the same procedure as the NMR Measurement Vi. Every single sweep is saved in the folder **HD2:NMR Data:Spin_up** with its name starting with **single sweep** and the curve displaying the height of the up and down signal as a function of time is saved in the same folder and its name starts with **curve**. The Vi can be stopped at anytime (except during the sweeps). All the data are saved and also is the last curve. Refer to Figure 36.

3.2.8 Holding Field Rotation panel

The field rotation panel should be used to switch from the longitudinal (transverse) to the transverse (longitudinal) configuration. Refering to the angle convention, 0 deg points downstream and 270 deg points at 90 deg from 0 deg on the electron arm side. Refer to Figure 2. Before running the Vi, you need to select the rotation you need to perform : rotation from Longitudinal to Transverse : choose **Go from 0 to 270 deg** or **Go from 0 to 90 deg**, rotation from Transverse to Parallel : choose **Return to 0 from 270 deg** or **Return to 0 from 90 deg**. You may also go to the antiparallel configuration by choosing **Go from 0 to 180 deg** and return to the parallel configuration from the antiparallel one with **Return to 0 from 180 deg**. When you have made your choice, simply press the **GO** button to launch the Vi. You will be asked to check that the rotation function generator (Wavetek, with the sticker FG R) is not on Standby mode (yellow steady led **OFF**). If it is on Standby mode, simply press the horizontal arrow keys on the right to go to the square burst shape (the fourth from the left). Then the Vi starts. The process is slow and can take up to 15 minutes. You will be able to follow the field rotation on the virtual compass. When done, simply click on the **EXIT** button to quit.

WARNING !

- the lasers must always be **OFF** when you rotate the field. Several messages will remind you to turn the lasers off

- if you want to measure the polarization of the target by NMR, go to the parallel or antiparallel configuration

Vi Description

The **Spin up & Lifetime** panel Vi is located in the **HD3:NMR:Common:LabVIEW Panels** folder and is named **NMR Field Rotation Box**. Refer to Figure 37. The Vi is looping until you press the **GO** button. The function generators used to drive the KEPCO power supplies have two working modes :

- the Waveform Mode, where they can perform the AFP sweep of the holding field
- the Offset Mode, where they can rotate the holding field

To perform the rotation, the function generators driving the two KEPCO power supplies have to be set to the Offset Mode. Usually, they are used in the so-called **Waveform Mode**, where they keep in memory the shape of the time evolution of their output voltage they send to the KEPCO when you perform an AFP sweep. The shape is a simple triangle, going from an applied voltage corresponding to 25 G to an applied voltage corresponding to 32 G, and immediately back to 25 G. When the Macintosh sends a trigger command to these function generators, they simply start the sweep. At any instant in the Waveforme Mode, their voltage output is calculated from the **Amplitude** and the **Offset** of the waveform, in particular in the steady state when they are not ramping. To rotate the field, it is necessary to switch to an **Offset Mode** from the **Waveform Mode**, where the output voltage does only depend on one parameter : the offset output voltage, so that it can be multiplied by the cosine or the sine of the rotation angle (depending on the concerned Helholtz coils set). For that reason, when you switch from the longitudinal configuration to the transverse configuration (from the transverse configuration to the longitudinal configuration), the function generators are set from the Waveform Mode to the Offset Mode before the rotation (are set from the Offset Mode to the Waveform Mode after the rotation). The change from Waveform Mode to Offset Mode is performed by adjusting the Amplitude and Offset values so that the output voltage remains constant, until the Amplitude is close to zero. The change from Offset Mode to Waveform Mode is performed by downloading the Waveform to the function generators by dedicated Vis (called Helium Initialization Vis), which will be described later. The SRS function generators are perfectly working in the Waveform mode, where they can deliver a smooth voltage ramp to the KEPCO power supplies. Unfortunately, they produce some glitches in the Offset Mode when their output voltage reaches fixed values : 2.5 V, 1.25 V, 6.25 V, ... down to 0 V. This malfunction is due to the use of specific internal relays by SRS. During the rotation, the output voltage of each function generator is swept by small steps of 0.02 V to rotate the field adiabatically and can not be performed if we are not able to get rid of these glitches. To get rid of them, we got the idea to build an electronic circuit able to hold the voltage applied to the KEPCO power supplies at each steps. The circuit was built by the Fast Electronics Group at Jefferson Lab [5]. The circuit needs to be driven by a third function generator, producing a square TTL burst every time the offset value of the function generator driving each KEPCO is changed, as shown on Figure 5. The voltage applied to the Kepco is maintained to its value during the burst.

To return from the Offset Mode to the Waveform Mode (at 0 deg or 180 deg), the function is reprogrammed by a specific Vi (Helium initialization Vi) so that it can sweep the holding field. During the programming, many glitches are produced and sent to the KEPCO power supplies. Once again, the electronic circuit is used to hold the voltage applied to the KEPCOs constant during the programming.

We indicate below the calibrated procedure followed by the Vi to mask the glitches with the square burst :

- During the rotation, the sequence is :
  - set the Offset value on the function generators driving the KEPCO power supplies
  - wait 800 ms
  - send the trigger command to the function generator connected to the 'latch' circuit
  - wait 360 ms
  - set the Offset value on the function generators driving the KEPCO power supplies
  - etc...

  The amplitude of the square burts is 10 V and has a length of 400 ms.

- During the Waveform Downloading, the sequence is :
  - wait 1 s
  - send the trigger command to the function generator connected to the 'latch' circuit
  - wait 700 ms

  The amplitude of the square burts is 10 V and has a length of 1 s.

The above values have been optimized for the Macintosh and take into account all the delay introduced by the Macintosh computer itself when the NMR Master panel is self running. The mask effect of the glitch with the square burst can be easily observed with an oscilloscope.

In the Waveform Mode, the output voltage delivered by the function generator, without any impedance adaptation is given by :

- if the waveform has been defined with a positive maximum (2 in our case),

$$Output = 2Offset - Amplitude \tag{6}$$

- if the waveform has been defined with a negative maximum (-2 in our case),

$$Output = 2Offset + Amplitude \tag{7}$$

Arbitrary units are used to define the waveform in a vector (x,y) mode. The data have to be sent as multi-byte binary data and the binary data is followed by a checksum to ensure data integrity. The procedure used to program the waveform is not trivial and can be found in the Vi itself.

- The unit of the time axis (x) is determined by the sampling frequency $FSMP$ of the waveform :

  $$FSMP = \frac{v}{\Delta B} \tag{8}$$

  where v =1.2 Gs^{-1} is the holding field ramping speed and $\Delta B = 7$ G is the field range, from 25 G to 32 G. In other words, 100 units on the x axis correspond to a time length d given by :

  $$d = \frac{\Delta B}{v} \tag{9}$$

- The y axis unit is completely arbitrary. Only the $Amplitude$ and the $Offset$ of the waveform fix the output voltage of the function generator. Refer to Tables 2 and 3.

  - the Amplitude is given by :

    $$Amplitude = \frac{\Delta V}{2} \tag{10}$$

    where ΔV is the voltage range applied to the KEPCO power supply corresponding to a sweep from 25 G to 32 G.

  - the Offset is given by :

    $$Output = 2Offset \pm Amplitude \tag{11}$$

  In the Offset Mode, the output voltage is simply given by :

  $$Output = 2Offset \tag{12}$$

  without any impedance adaptation. That feature allows us to control the KEPCO power supplies using the function generators over a wider range of currents.

3.2.9 Q Curve Pick-up Coils panel

This Vi allows you to check the response of the pick-up coils circuit using a small excitation loop, glued on the side of the RF coils mounting. When you run the Vi by pressing the **GO** button, you will be asked to disconnect the RF coils cable coming out of the RF excitation function generator (Hewlett Packard HP3324A) and to connect the Q curve cable, going to the small loop, down in the hall. Then the Vi will sweep the excitation frequency and the lock-in will read the pick-up coils response. The sweep process is slow and may take as much as 20 minutes. The frequency is displayed in the Frequency window, in kHz. When done, the resonance curve will appear on the screen and will be saved in the directory : **HD2:NMR Data:Q Curves**. When done, **do not forget to switch the cables back !** You may print the window using the key combination **Apple+P** and quit using the **EXIT** button. Refer to Figure 38.

WARNING : it is not recommended to perform a Q curve measurement when the target has a high polarization. It could result in polarization loss. Usually, Q curve studies are performed every time the Helium cell is replaced or before and after every water calibration.

Vi Description

The **Pick-up Coils Q Curve** panel Vi is located in the **HD3:NMR:Common:LabVIEW Panels** folder and is named **NMR Q Curve**. The Vi is looping until you press the **GO** button. The RF frequency of the sine wave is then set to 60 kHz and to an amplitude of 3.5 Vrms. The Vi asks the lock-in to display automatically the reference frequency on the very right hand side display. The sensitivity of the lock-in is set to 1 Vrms. The frequency is then swept from 60 kHz to 300 kHz, by steps of 0.5 kHz. At each step, the Vi reads the rms value of 50 lock-in measurements in the R channel. After the sweep, the frequency is switched back to 91 kHz and the amplitude to its minimum value of 0.4 mVrms.

3.2.10 Current Monitoring panel

The Current Monitoring Vi is used to check the values of the current circulating in the Helmholtz coils. For now, only the large coils current can be monitored. An amperemeter is connected to the large coils in the hall and is read by a GPIB-ENET box. If you run the Vi by pressing the **GO** button, the GPIB-ENET box will transmit 10 measurements of the current through the network. You may change the number of values read using the 'Number of measurements' control. You may indicate in the KEPCO 3 or 4 Display window the value of the current you read on the KEPCO display (right hand side digital display). Then the Vi calculates the relative error between the actual measured current and the current displayed on the KEPCO panel. When done, the measurements will be saved in the directory : **HD2:NMR Data:Current**. You may print the window using the key combination **Apple+P** and quit using the **EXIT** button.

Vi Description

The **Current Monitoring** panel Vi is located in the **HD3:NMR:Common:LabVIEW Panels** folder and is named **NMR Monitor Current**. Refer to Figure 39. The Vi is looping until you press the **GO** button. The Vi reads 10 times both amperemeters through the GPIB-ENET interface, displays the measurements and calculates the relative differences.

3.2.11 Emergency Shut Down panel

The Emergency Shut Down Vi should be used only in case of extreme emergency. By pressing the **GO** button, you will turn off the RF excitation field, and kill the main holding field. It should be used only to turn off the current in the main Helmholtz coils and in the RF coils, when intervention on the coils is required. The target operator should be aware that the polarization of the target may be dramatically damaged if this Vi is used. Press the **EXIT** button if you decide not to run that Vi at the very last minute.

Vi Description

The **Emergency Shut Down** panel Vi is located in the **HD3:NMR:Common:LabVIEW Panels** folder and is named **NMR Emergency**. Refer to Figure 40. The Vi sets the Amplitude and the Offset of the function generators driving the KEPCO power supplies to zero (so the KEPCO applied voltage goes to zero). The amplitude of the RF excitation function generator is set to its minimum value of 0.4 mVrms.

3.3 Specific virtual instruments

These instruments have to be used only by the target NMR xpert, and should not be used during the standard data taking.

3.3.1 Holding field calibration

The holding field calibration should be performed once before the experiment, to find the coefficients of the linear relation between the DC voltage applied to the front panel of the KEPCO power supply for a given set of coils, and the magnetic field measured downstairs in the hall. A specific Vi has been written to change step by step the applied voltage and to measure the magnetic field and the current flowing through the coils. This Vi is named **NMR Coil Calibration FG-V** and may be found in the **HD3:NMR:Common:LabVIEW Panels** directory. Refer to figure 41. In this Vi, you first select with a switch the set of coils you want to calibrate : the large Helmholtz coils or the smaller ones. You must have installed the Gaussmeter down in the hall : the probe must be placed at the geometrical center of the studied pair, and must be connected to the gaussmeter, connected itself to the GPIB-ENET interface. The multimeter of the studied set should also be connected to the GPIB-ENET interface. When you run the Vi, the function generator of the pair you wish to study will go to Offset Mode, the value of the offset (half the actual output value) being swept from the limits you specify on the Vi's panel. By default, the sweep will start at -4 V and go to 4 V. An adjustable delay of 2 s is available to wait. For the immediate current stabilization in the coils. for the specified voltage range, the steps will have an amplitude of 0.01 V and it may take 2h to calibrate one set of coil. The Vi simply changes the offset value of the function generator, waits the specified delay and read the Hall probe and the multimeter. At the end of the calibration procedure (not before !), the curves Field vs Voltage and Field vs Current should appear. You expect to get perfectly linear curves. Two other plots will show you the fitted relations between the Field, the Voltage and the Current. The value of the slope, the intercept and the mean squared error will be displayed by the fitting procedure. **The slope and intercept values for the curves Field vs Voltage for both KEPCO power supplies are input parameters in the initialization Vis**, as will be explained later.

The most recent coil calibration for E94010 gives us :

- KEPCO 3 : $B = \alpha_3 V + \beta_3$ where α_3 = -3.94 GV^{-1} and β_3=-0.29 G
- KEPCO 4 : $B = \alpha_4 V + \beta_4$ where α_4 = -4.26 GV^{-1} and β_4=-0.29 G

where V is the output voltage delivered by the function generator, measured without impedance adaptation. In the Offset Mode, V=2$Offset$. A simple compass was also used to check the direction of the holding field, with an angular resolution of 1 degree. The calibration data are not saved and the Vi's panel should be printed after a calibration.

3.3.2 RF field calibration

The RF Field Calibration vi allows you to study the dependance of the RF field measured using a simple loop placed horizontally at the geometrical center of the RF coils, when you sweep the RF voltage delivered by the RF excitation function generator upstairs in the counting house. This Vi is named **NMR H1 vs VRF** and may be found in the **HD3:NMR:Common:LabVIEW Panels** directory. Refer to Figure 42. Your small loop has to be connected to the lock-in input upstairs (using for example the BNC cable going from the pick-up coils preamplifier downstairs to the lock-in upstairs). When you run the Vi, the RF voltage is swept from 0.01 to 2.5 Vrms by steps of 0.01 Vrms. At each step, the Macintosh reads 20 times the output of the lock-in amplifier and calculate its rms value. A delay of 1 s is introduced by default between the voltage setting and the lock-in reading. When completed, the procedure shows you the linear relation between the RF field value (proportional to the lock-in output) and the amplitude of the RF voltage delivered by the RF excitation function generator. The slope, the intercept and the mean square error of the linear fit are displayed. This is not an absolute calibration. To get the absolute calibration, you simply need to measure the amplitude of the sine wave output of the loop down in the hall. Let's say you measure a peak-to-peak amplitude $V_{PeaktoPeak}$ with an oscilloscope and using your loop (in the same configuration as during the calibration procedure) ; then the induced voltage V in the loop is :

$$V = \frac{d\phi}{dt} \equiv \omega\phi \tag{13}$$

and the RF field H_1 is obtained from :

$$B = 2H_1 = \frac{V_{PeaktoPeak}}{4\pi f S} \tag{14}$$

where

$$S = n\pi D^2/4 \tag{15}$$

The loop contains n=24 turns, with a diameter of D=29 mm. For a running RF voltage of **2.4 Vrms** (default setting when performing the NMR measurement), we measure downstairs a peak-to-peak voltage of 227 mV. It corresponds to a RF field amplitude of H_1=**62 mG**. Once again, the data are not saved here and you may print the Vi panel if needed.

3.3.3 Helium waveform initialization at 0 deg

The Helium initialization at 0 deg Vi is located in the **HD3:NMR:Helium:LabVIEW Panels:Main Panels** folder and is named **NMR Helium Initialization 0**. See Figure 43. It programs the waveform in the function generators driving the KEPCO power supplies, used to perform the AFP sweep of the Helium spins. The waveform is a triangle waveform, starting from the minimum value of the holding field to its maximum value, both of which are specified in dedicated windows on the Vi panel. The holding is pointing **downstream**. **The default settings (minimum field, maximum field and speed) must be the same as the ones specified in the NMR Measurment Vi (in that Vi, they are hidden but may be accessed through the diagram of the Vi) ! So, if you decide to change them, do not forget also to change them in the NMR Measurement Vi**. The coil angle should not be changed. It is the actual value of the coil orientation in the hall. The speed of the sweep can also be adjusted. Note the four input parameters (slope and intercept for KEPCO 3, and slope and intercept for KEPCO 4) requested by the Vi. These parameters are obtained by calibrating each set of coil idependently. After having run this Vi, **you will get the values of the waveform Offset and Amplitude for both function generators. Thoses values are used by the Holding Field Rotation Vi and are set by default in the program. They are hidden on the front panel of the Holding Field Rotation Vi but may be switched back to visible in the diagram of the Vi**. You should never have to call and run the Helium initialization at 0 deg Vi, except after a cell replacement. The Vi produces huge glitches in the holding field that may damage the target polarization. However, it is used at the end of the Holding Field Rotation Vi when you rotate back to the 0 deg. configuration. In that case, the Field Rotation Box is used to protect the holding field so that the polarization of the target will not be damaged.

3.3.4 Helium waveform initialization at 180 deg

The Helium initialization at 0 deg Vi is located in the **HD3:NMR:Helium:LabVIEW Panels:Main Panels** folder and is named **NMR Helium Initialization 180**. Refer to Figure 44. It basically does the same as the previous Vi, but this time the holding field will always be pointing upstream. It is also called by the Holding Field Rotation Vi when you going to the longitudinal and antiparallel configuration, so that the AFP sweep for the NMR measurement can be also performed in the antiparallel configuration.

3.3.5 Water waveform initialization at 0 deg

This Vi is located in the **HD3:NMR:Water:LabVIEW Panels:Main Panels** folder and is named **NMR Water Initialization FG-V**. Refer to Figure 45. It programs the waveform specific to the NMR measurement of the water polarization. But here, the waveform contains this time a plateau at the maximum value of the field with a length of $\Delta B/v = 5.8$s. **The default settings (minimum field, maximum field and speed) must be the same as the ones specified in the NMR Water XY FG-V Vi (in that Vi, they are hidden but may be accessed through the diagram of the Vi) ! So, if you decide to change them, do not forget also to change them in the NMR Measurement Vi**.

3.3.6 Water panel

The NMR Water Vi is located in the **HD3:NMR:Water:LabVIEW Panels:SubVis** folder and is named **NMR Water XY FG-V**. See Figure 46. It does the same as the basic NMR Helium panel with some changes :

- takes into account the new shape of the water waveform
- can perform as many sweeps as you want and always displays the average
- can wait 5 min before starting a series of sweeps, so people can leave the target area

Due to the large number of sweeps, you can specify the name of the subdirectory in which the water data will be saved. Each sweep will be saved individually for both X and Y channels and also the average sweep at the end. You subdirectory will be created in the directory : **HD2:NMR Data:Water**. Typically, a water calibration requires some 500 sweeps, which can take a few hours. Be carefull to run the Water initialization at 0 deg Vi before starting your sweep and to make sure that the default settings (min. field, max. field and speed) are the same in both Vis.

3.3.7 Water waveform initialization for T_1 measurements

This Vi is located in the **HD3:NMR:Water:LabVIEW Panels:Main Panels** folder and is named **NMR Water Init T1 FG-V**. Refer to Figure 47. It does the same as the Water initialization at 0 deg Vi but now, the plateau has been suppressed. It is useful to be run for T_1 measurement puposes.

3.3.8 Water panel for T_1 measurements

This Vi is the same as the NMR Water Vi, but takes into account the fact that the plateau in the waveform has disappeared. It should be used only after having initialized the function generators with the Water initialization T_1 Vi, and once again, make sure that the default settings (min. field, max. field and speed) are the same in both Vis. The Vi is located in the **HD3:NMR:Water:LabVIEW Panels:SubVis** folder and is named **NMR Water T1 FG-V** . Also, a third display on the panel shows you the time evolution of the current in the large Helmholtz coils (80 current measurements performed during the sweep). Refer to Figure 48.

3.3.9 Read Q Curve Data panel

This Vi is used to read previously saved Q curve data, located in the folder :**HD2:NMR:Q Curves**. It allows you to select your data file and displays the Q curve. The name of your data file is displayed in the Data File window for information. The Vi is located in the **HD3:NMR:Common:LabVIEW Panels** folder and is named **NMR Read Q Curve Data**. Refer to Figure 49.

3.3.10 Important points

- **Optimal lock-in phase :** the optimal lock-in phase for NMR measurements with the Helium 3 target must be adjusted every time the cell is replaced. The phase has to be changed manually using the big knob on the right hand side of the lock-in amplifier. Make sure to return to manual mode on the lock-in panel, otherwise you won't be authorized to change the phase. To determine the value of the phase offset θ you need to add/subtract to the lock-in current phase, simply perform a NMR measurement with the standard panel, and calculate the angle θ (in degrees !) given by $\theta = Arctan(Y/X)$, where Y is the amplitude of the NMR signal displayed on the Y channel, and X is the amplitude of the NMR signal displayed on the X channel. When the phase is optimal, the signal should appear in the X channel, and the Y channel should only show noise, with a small amplitude signal fraction on the Y channel, as displayed on Figure 32.

- **Preamplifier settings :** the preamplifier gain must be changed by hand in the hall when you switch from the Helium 3 target to the Water target. In the Helium 3 target configuration, it is set to 1 and in the Water configuration, it is usually set to 200. When you perform a Q curve measurement, be sure to switch the gain back to 1 otherwise the lock-in amplifier will get overloaded. There is no GPIB control of the preamplifier, so be sure to check the gain setting before you close the hall and start to take data.

3.4 Macintosh Software Configuration

We describe below the settings of the Macintosh configuration panels, which can be reached through the Apple menu, in the section **Control Panels**.

3.4.1 "NB-Boards" Panel

Two slots of the NuBus board are used :

- Slot C : NB-AO-6 (for the DAQ card)
- Slot D : NB-GPIB/TNT (for the GPIB card)

3.4.2 "NI-DAQ" Panel

DEVICES

- device : 4
  name : NB-AO-6
  type : 114
  bus : Nubus
  socket : C
  address : 0xfcc00000
  DMA socket : 0
  RTSI bus : 0

- device : 5 name : NB-GPIB/TNT
  type : -1
  bus : Nubus
  socket : D
  address : 0xfdd00000
  DMA socket : 0
  RTSI bus : 0

  DEVICE CONFIGURATION

  Device #4

- NB-AO-6 I/O subsystem : DAC0
  Polarity : bipolar
  Vref : 10 V
  Mode : volta...
  Voltage display not available

  Device #5

- NB-GPIB/TNT

3.4.3 "NI-488 Config" Panel

NUBUS CONFIGURATION

- Auto Configure selected
- 9ABCDE where D is selected and a zero appears below
- Interface type : Nubus slots

- Bus/Device : gpib0
  Primary Address : 0
  Secondary Address : none
  Time out : 10 s
  Bus Timing : NAT4882 timing
  System Controller selected
  Assert REN ... selected
  Write END on Last Byte selected
  EOS byte : 0

- Bus/Device : gpib1
  Primary Address : 0
  Secondary Address : none
  Time out : 10 s
  IP Address : 129.57.188.55
  System Controller selected
  Assert REN ... selected
  Write END on Last Byte selected
  EOS byte : 0

ETHERNET CONFIGURATION

- 12345678 where 1 is selected and 1 appears below

- Interface type : Ethernet box products

- Bus/Device : gpib0
  Primary Address : 0
  Secondary Address : none
  Time out : 10 s
  Bus Timing : NAT4882 timing
  ENET Connections : 9
  System Controller selected
  Assert REN ... selected
  Write END on Last Byte selected
  EOS byte : 0

- Bus/Device : gpib1
  Primary Address : 0
  Secondary Address : none
  Time out : 10 s
  ENET Connections : 9
  IP Address : 129.57.188.55
  System Controller selected
  Assert REN ... selected

Write END on Last Byte selected
EOS byte : 0

Never forget to save the settings file (named GPIB Setup) in the following folders :

- HD1:System Folder
- HD1:NI-488.2
- HD1:NI-488.2:Ethernet

3.4.4 GPIB-ENET Controller

The box has to be connected to the JLab network, using either BNC (the case for E94010) or 10 base T plugs. Its IP address has to be assigned by the Computer Center and given to the box using the IP Assign utility. The current IP address is : **129.57.188.55** or MEZIANIGPIB. Its Hexadecimal address is : **00:80:2f:ff:19:5a**.

- The side box manual switches #5 and #6 should be set to the ON position
- The Power, Ready and Receive leds should be on and steady
- The Listen led could be flashing
- Make sure to use a 50Ω cap when connection the box to the standard network BNC plugs.

Use the Unix **ping 129.57.188.55** command to check that the box is alive.

3.4.5 "MacTCP" Panel

IP Address : 129.57.188.54

Click on **More** to get more information

- Obtain Address : manually
- IP Address : Class : B
  Address : 129.57.188.54
  Subnet Mask : 255.255.0.0
  Net : 16 - Subnet : 0 - Node : 16
  Net : 33081
  Subnet : 0
  Node : 48182

- Domaine Name Server Information : cebaf.gov 129.57.32.100 (default)
  jlab.org 129.57.32.101

- Routing Information : Gateway Address 129.57.188.1

3.4.6 "Network" Panel

LocalTalk Built In should appear within a gray square.

4 NMR Procedures with the polarized Helium 3 target

4.1 NMR polarization measurement

- If you are in laser perpendicular configuration, turn the 3 transverse lasers off, rotate the field to the parallel configuration and turn the 3 parallel lasers on

- Make sure the target is in the Helium 3 (beam) position

- Make sure you are in the parallel field configuration

- Run the NMR Record Settings panel. Make sure you get the print out

- Call MCC and tell them you are going to move the target down to the pick-up coils to measure its polarization. When the target is masked, move the target down to the pick-up coils

- Print the RTD screen

- Run the NMR Measurement panel and print it when completed

- Move the target back to its beam position

- Call MCC, tell them you have measured the polarization and that the target is back to its beam position. Be sure to follow the beam back procedure before sending the beam back to the target (beam position, raster on, current less than 15 μA, ...)

- Run the NMR Extract Polarization panel and print it

- Staple the plots together and store them in the target binder

4.2 Longitudinal to transverse holding field rotation

- Perform a NMR polarization measurement, as described before

- Make sure the target is in the Helium 3 position (beam)

- Turn OFF the 3 longitudinal lasers on HAC

- Run the NMR Holding field Rotation panel, selecting 'Go from 0 deg to 270 deg'.
- When the rotation is complete, turn ON the 3 transverse lasers

4.3 Transverse to longitudinal holding field rotation

- Make sure the target is in the Helium 3 position (beam)
- Turn OFF the 3 transverse lasers
- Run the NMR Holding field Rotation panel, selecting 'Return to 0 deg from 270 deg'.
- When the rotation is complete, turn ON the 3 longitudinal lasers
- Perform a NMR polarization measurement

4.4 Plots to print

For every NMR measurement, print :

- NMR Record settings panel (will be printed by the Vi)
- NMR Measurement panel (print it at the end of the sweep)
- NMR Extract Polarization panel (print it when completed)
- RTD temperatures screen (print it from HAC)

Staple the four plots together and store them in the target binder.

4.5 Warnings

- Never stop a running LabVIEW Vi
- Never put CW beam on the target without raster
- Every target operator must read and sigh the Target Operation Manual
- If the target ruptures, turn OFF the transverse lasers
- The lasers should be off before rotating the holding field
- The transverse lasers should only be on if the target is in the Helium 3 position
- Never move the target with transverse lasers on
- We indicate on Table 5 the voltage and current values for each KEPCO in the 0 deg. and 270 deg. configurations

4.6 New coil calibration

- Run the Coil Calibration Vi, for each pair of coils and write down the values of the slope and intercept. They should be close to the ones measured during E94010 and given above. Pay attention to the signs of the slope and of the offset, which should be the same as for E94010.
- Change the slope and intercept default value for each set of coils in the Helium and Water initialization Vis. Run these Vis to get the default values of the Offset and Amplitude for each set.
- Change the default $Offset$ and $Amplitude$ values for each set in the Holding Field Rotation panel.

References

[1] A. Abragam, "The principles of nuclear magnetism", Oxford University Press (1961)

[2] H. Middleton, "The spin structure of the neutron determined using a polarized He-3 target", Ph-D Thesis, Princeton University (1994)

[3] M. Romalis, "Laser polarized ^{3}He target used for a precision measurement of the neutron spin structure ", Ph-D Thesis, Princeton University Press (1997)

[4] T. Smith, "A precision measurement of the neutron spin structure functions using a polarized He-3 target", Ph-D Thesis, Michigan University (1998)

[5] J. Proffitt, "Analog latch circuit operation/specifications", Jefferson Lab Physics Fast Electronics Group (8/6/1998)

5 Tables and Pictures

Table 1: *Capacitor Box*

Selector position	Capacitor value (nF)
1	26
2	-
3	38
4	48
5	95
6	100
7	105
8	155
9	160
10	165
11	no

Table 2: *Amplitude and Offset of the waveform at 0 deg*

Waveform K3	(x=0,y=0) (100,-2) (200,0)
B_{max}	32 G
B_{min}	25 G
V_{maxK3}	$(B_{max}\cos(-19) - \beta_3)/\alpha_3$
V_{minK3}	$(B_{min}\cos(-19) - \beta_3)/\alpha_3$
Amplitude K3	$(V_{maxK3} - V_{minK3})/2$
Offset K3	$(V_{maxK3} + Amplitude)/2$
B_{max}	32 G
B_{min}	25 G
V_{maxK4}	$(B_{max}\sin(-19) - \beta_4)/\alpha_4$
V_{minK4}	$(B_{min}\sin(-19) - \beta_4)/\alpha_4$
Waveform K4	(x=0,y=0) (100,2) (200,0)
Amplitude K4	$(V_{maxK4} - V_{minK4})/2$
Offset K4	$(V_{minK4} + Amplitude)/2$

Table 3: *Amplitude and Offset of the waveform at 180 deg*

Waveform K3	(x=0,y=0) (100,2) (200,0)
B_{max}	32 G
B_{min}	25 G
V_{maxK3}	$(B_{max}\cos(-19) - \beta_3)/\alpha_3$
V_{minK3}	$(B_{min}\cos(-19) - \beta_3)/\alpha_3$
Amplitude K3	$(V_{maxK3} - V_{minK3})/2$
Offset K3	$-(V_{maxK3} + Amplitude)/2$
B_{max}	32 G
B_{min}	25 G
V_{maxK4}	$(B_{max}\sin(-19) - \beta_4)/\alpha_4$
V_{minK4}	$(B_{min}\sin(-19) - \beta_4)/\alpha_4$
Waveform K4	(x=0,y=0) (100,2) (200,0)
Amplitude K4	$(V_{maxK4} - V_{minK4})/2$
Offset K4	$-(V_{minK4} + Amplitude)/2$

Table 4: *List of GPIB addresses used in the LabVIEW Vis*

Device	GPIB Address
Function Generator SRS DS345 (drives KEPCO 3)	0:20
Function Generator SRS DS345 (drives KEPCO 4)	0:18
Function Generator Wavetek 80 (rotation)	0:17
Function Generator HP 3324A (RF excitation)	0:19
Lock-in SRS SR844 (lock-in amplifier)	0:8
Multimeter Fluke 45 (KEPCO 3)	1:5
Multimeter Fluke 45 (KEPCO 4)	1:6
Hall A Gaussmeter (Holding field calibration)	1:21

Table 5: *KEPCO settings*

Orientation	KEPCO 3 Voltage	KEPCO 3 Current	KEPCO 4 Voltage	KEPCO 4 Current
0 deg	31.0 V	6.86 A	-10.2 V	-2.23 A
270 deg	-8.5 V	-2.37 A	-24.9 V	-6.55 A

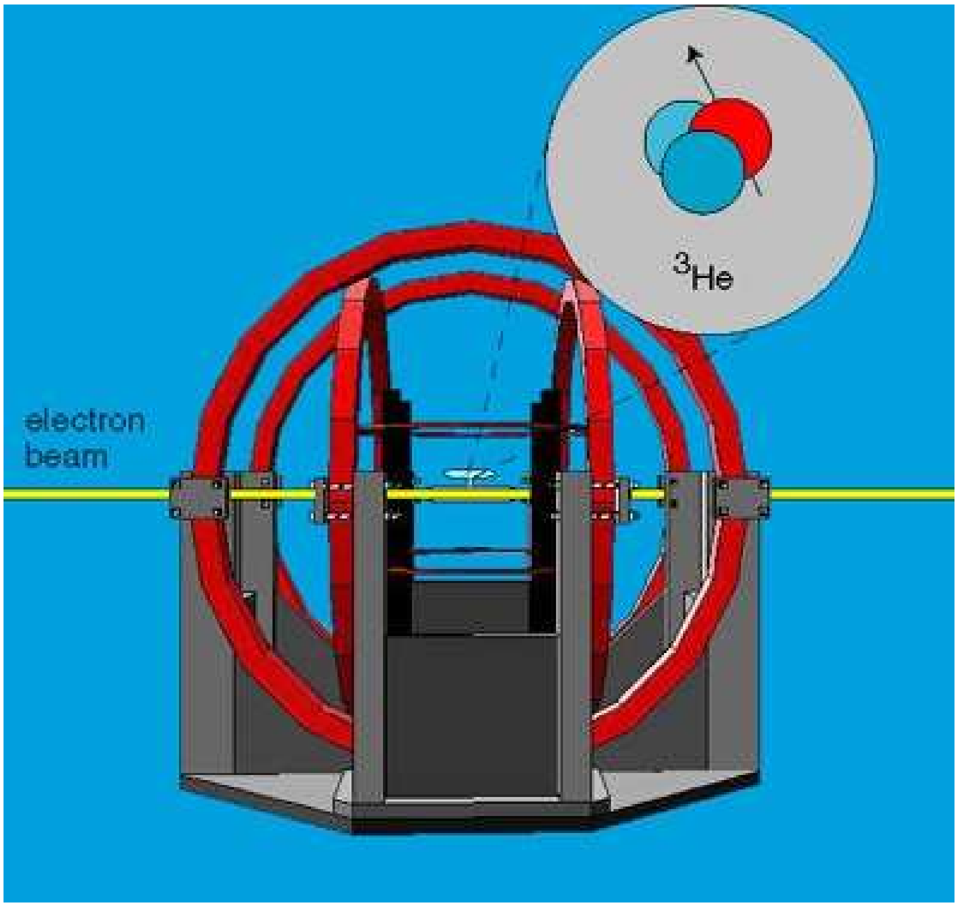

Figure 1: NMR setup : this drawing shows the two sets of Helmholtz coils creating the DC holding field H. The RF coils are located above and below the target and generate the RF field $2H_1$. The pick-up coils are aligned along the target chamber (hidden here). Courtesy of K. Slifer.

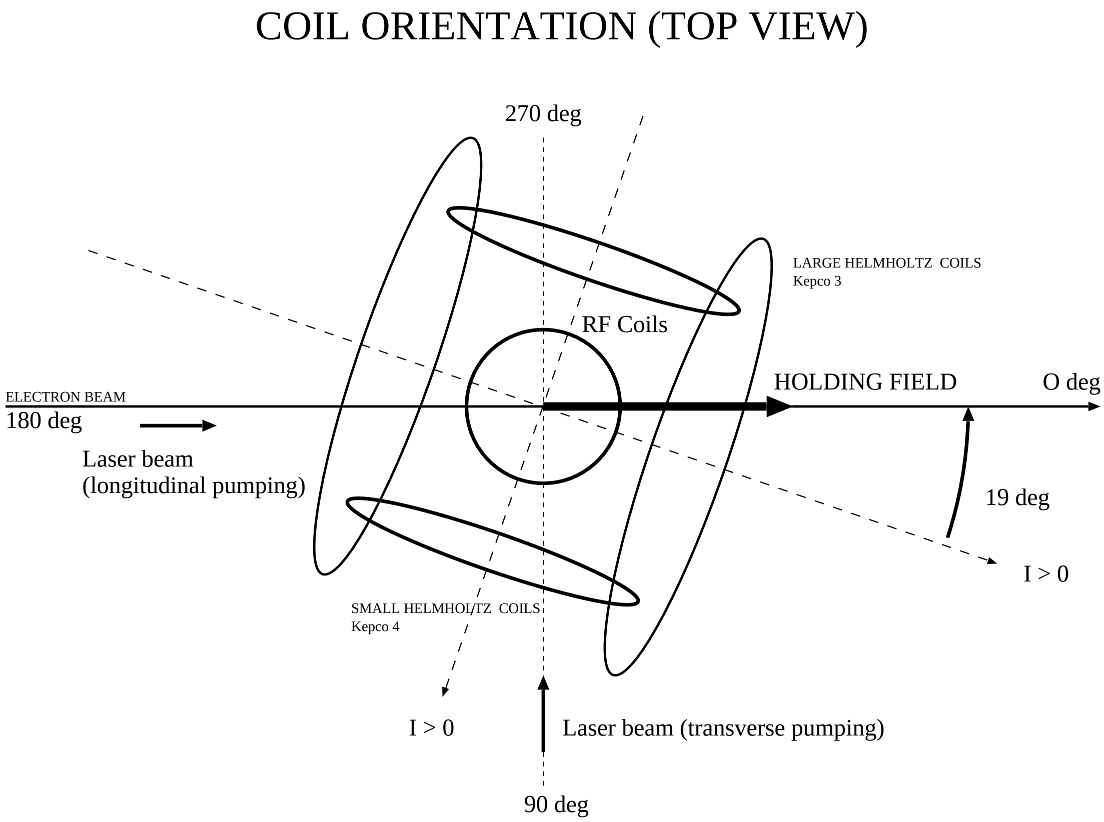

Figure 2: this drawing shows you the convention used for the holding field orientation. A 0° orientation corresponds to the holding field pointing downstream. A 270° orientation corresponds to the field pointing at 90° from the beam line, on the electron arm side. The target NMR polarization measurement can only be performed when the holding field is in the longitudinal parallel configuration (pointing downstream) or in the longitudinal antiparallel configuration (pointing upstream).

Model # 62-B411671

Serial # X51380

Specification	Axis #1	Axis #2	Axis #3
Area of Uniformity	2400 cm^3	2400 cm^3	2400 cm^3
Uniformity	< 1,0 %	< 1.0 %	< 1.0 %
Overall I.D.	56,5"	50,5"	31"
Overall O.D.	62"	54.75"	33,5"
Nominal Intercoil Spacing (face to face)	27"	24"	15.75
Resistance (per coil pair @70°F	3.02 Ω	3.05 Ω	1,38 Ω
Rated Operating Current	11,21 Amps	11.17 Amps	1,2 Amps
Central Field at Rated Operating Current	37 Oe	37.2 Oe	.106 Oe
Water Cooling (YES/NO)	No	No	No
Recommended Cooling Water Pressure	psi	psi	psi
Nominal Water Flow Rate at Recommended Pressure	gal/min	gal/min	gal/min
Recommended Water Temperature	°F	°F	°F
AC Operation (YES/NO)	NO	No	YES
Nominal Inductance	mH	mH	112 µH
Maximum Frequency	Hz	Hz	100 KHz
Rated Operating Current	ARMS	ARMS	1,2 ARMS
Voltage at Rated Operating Current and Maximum Frequency	VRMS	VRMS	VRMS

Figure 3: this chart shows you the specifications of : the large Helholtz coils (axis 1), the smaller Helmholtz coils (axis 2) and the RF coils (axis 3), given by the Walker Scientific Company.

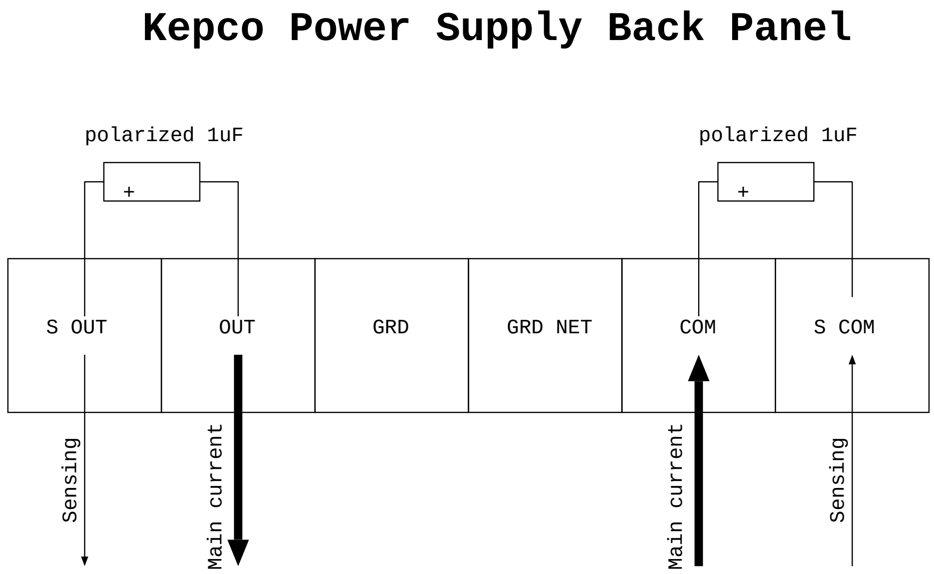

Figure 4: this drawing shows you how the Helmholtz coils are connected to the KEPCO power supplies back panel. The polarized $1\mu F$ capacitors are required for the sensing system when the cables are long.

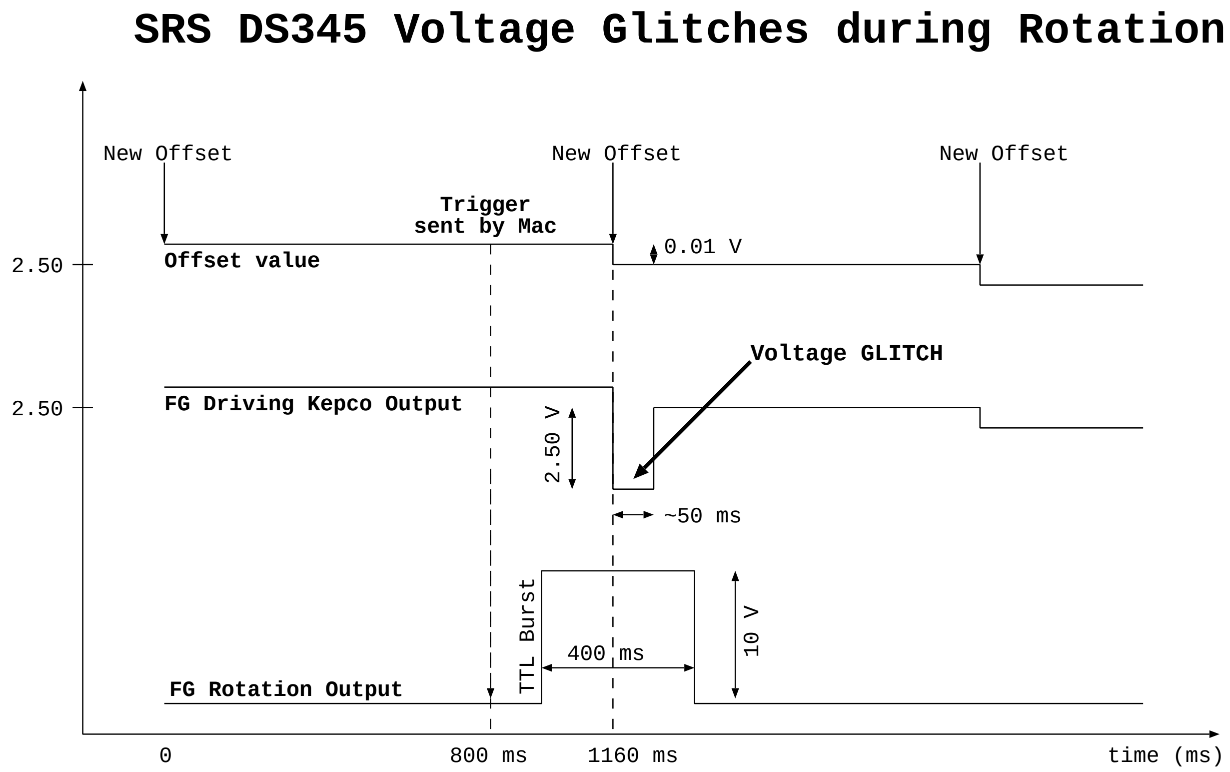

Figure 5: drawing showing on the first line the offset value sent by the Macintosh to one of the DS345 function generators during the rotation, the output of the function generator on the second line (with the glitch) and the output of the Wavetek function generator producing the TTL burst during which the voltage applied to the KEPCO power supplies is kept constant.

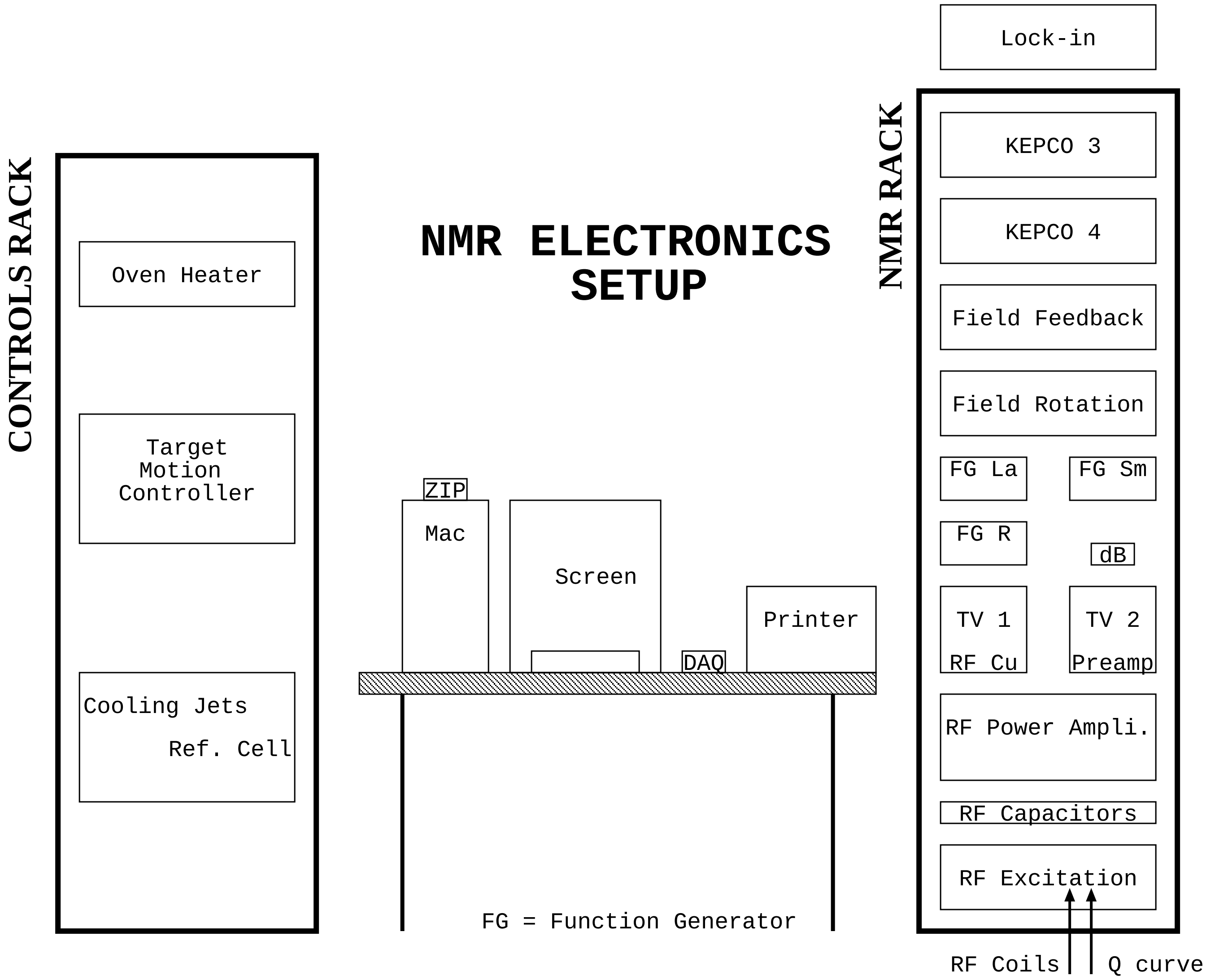

Figure 6: drawing of the NMR setup in the counting house ; the controls rack is located close to the white board and the NMR rack is located on the Macintosh right hand side.

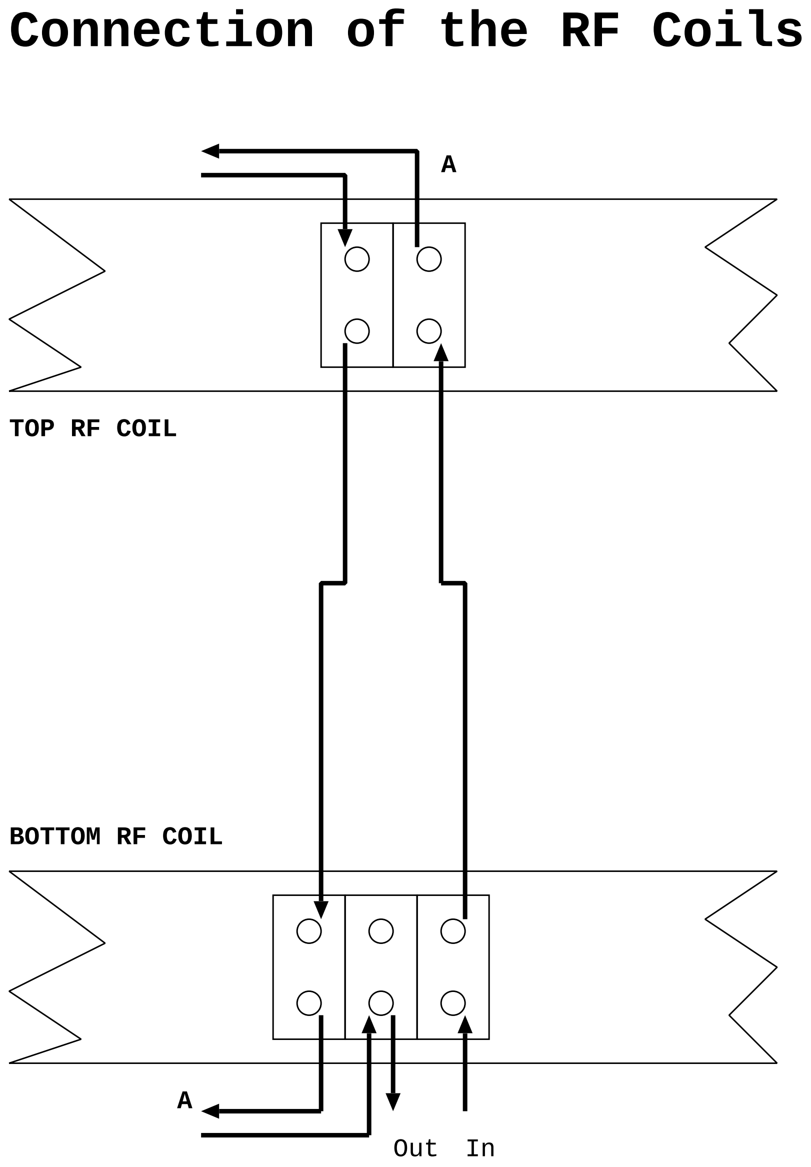

Figure 7: description of the series connection of the RF coils, on the RF mounting.

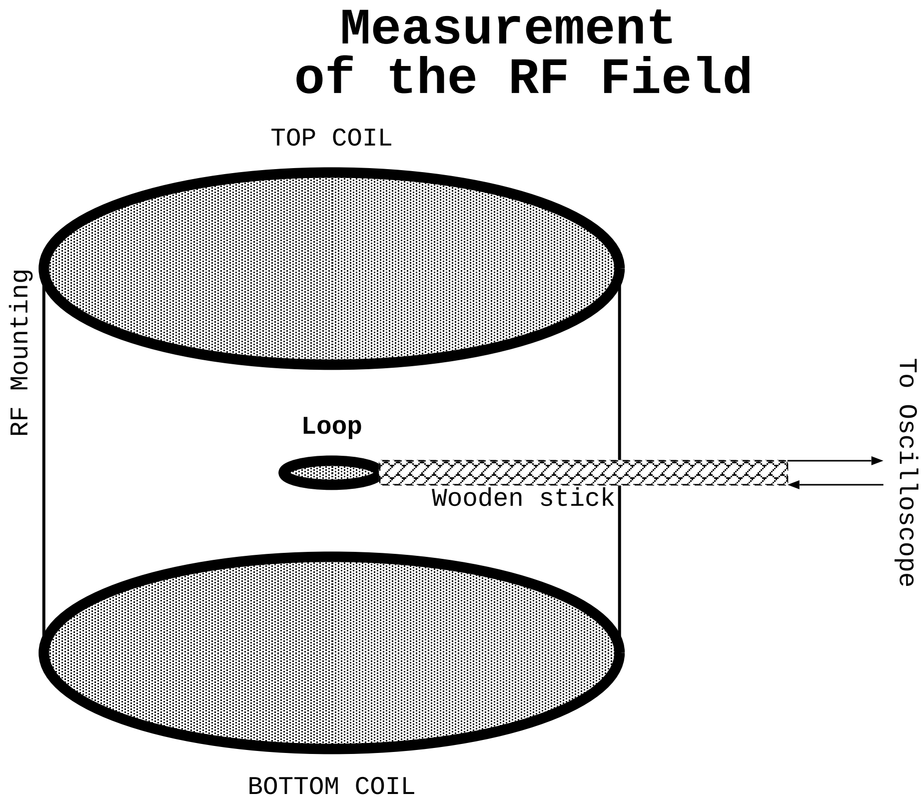

Figure 8: principle of the measurement of the H_1 field using for example a wooden stick. The output of the loop is connected to the oscilloscope. The optimal position of the stick should give the maximum induced voltage, when the loop is parallel to the RF coils.

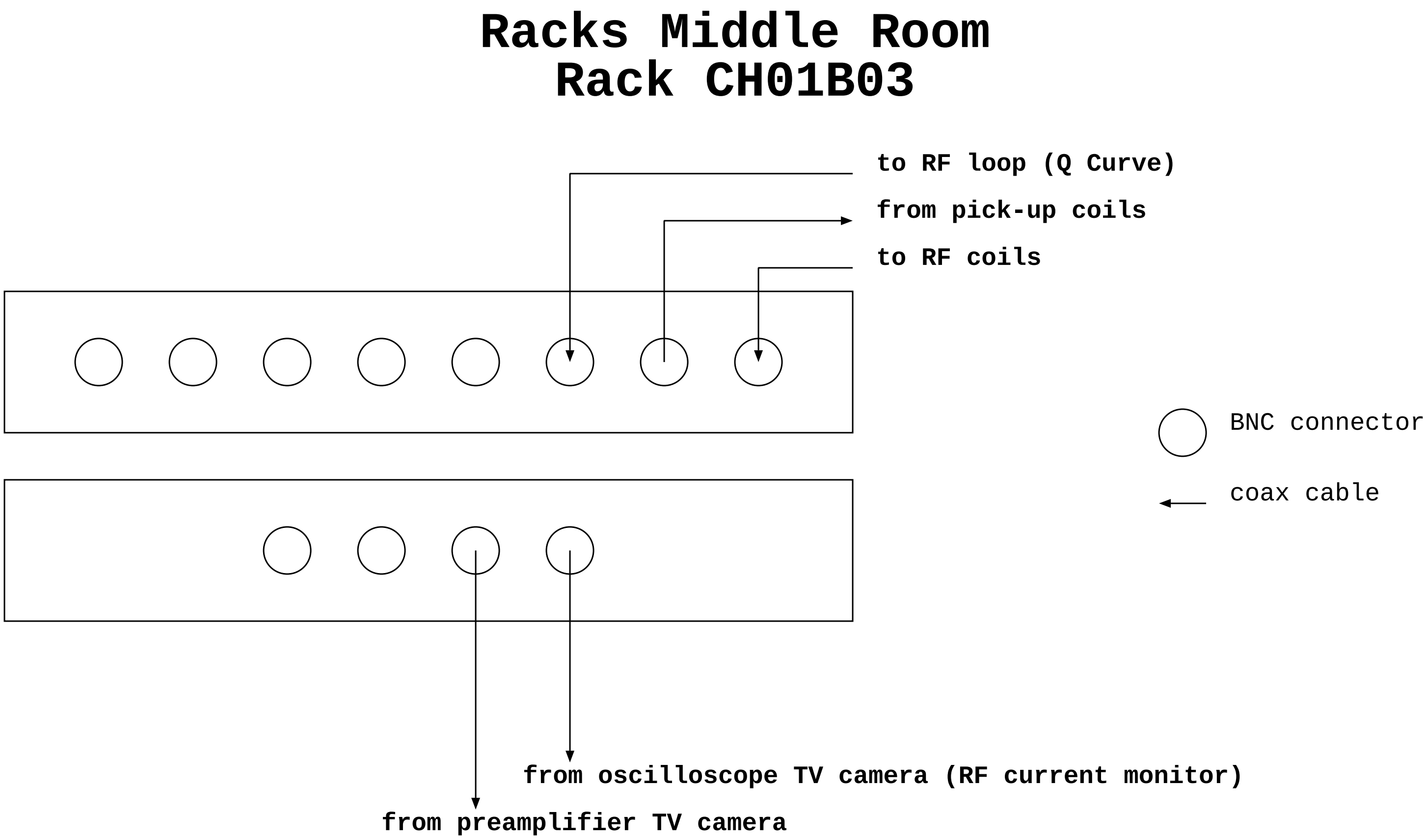

Figure 9: connection panel in the middle room rack CH01B03 of the counting house. The plugs are RG213 end series plugs with a RG58 connector. The same panel is used downstairs in the hall.

Cabling of the NMR System

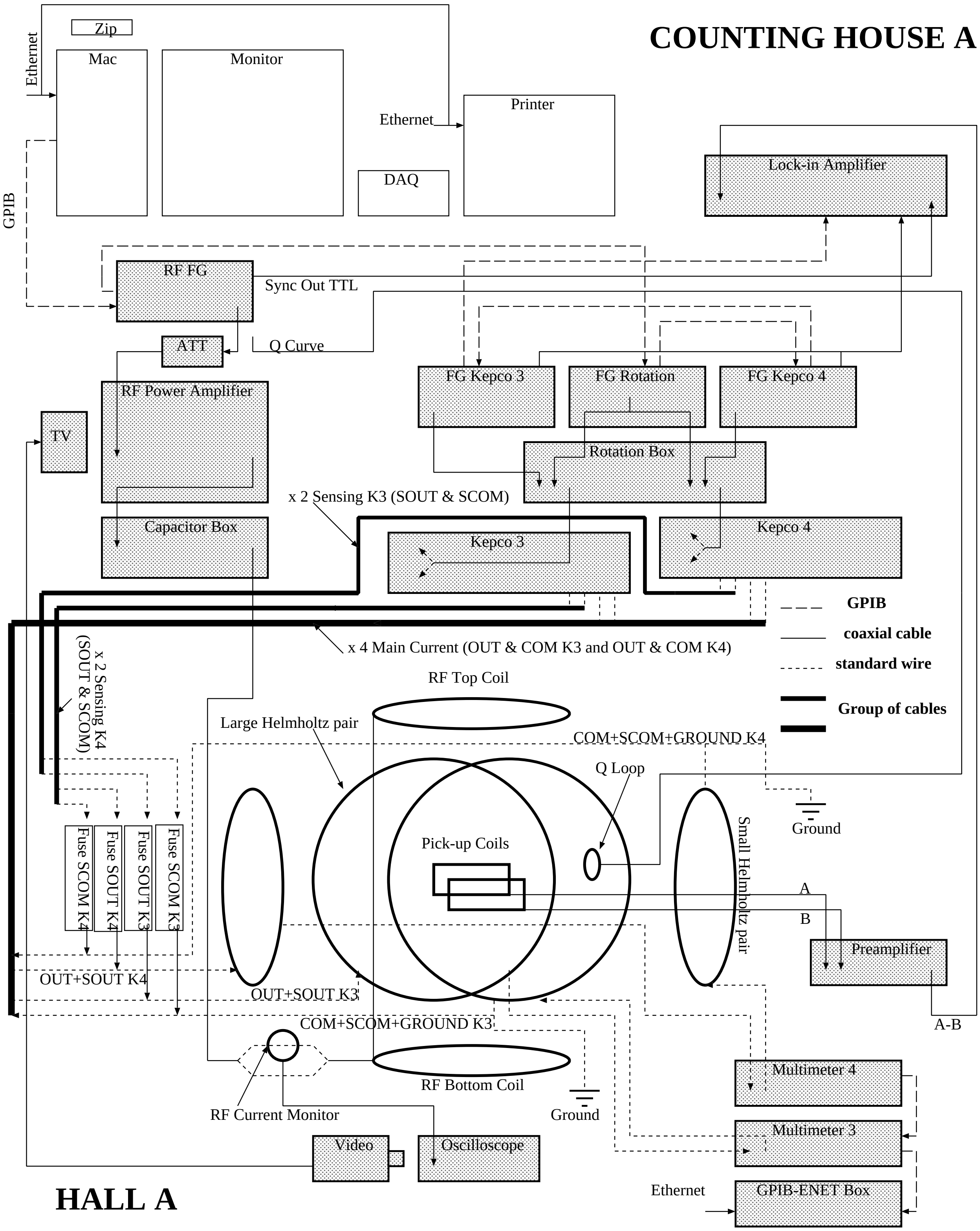

Figure 10: drawing showing you the cabling of the NMR system. The top part is located in the counting house and the bottom part down in the hall. "Coaxial cables" stands for RG58 cables.

Figure 11: picture of the Macintosh personal computer driving most of the NMR electronics using the LabVIEW software. It is located in the counting house.

Figure 12: NMR rack, located on the Macintosh right hand side in the counting house. The rack is described from top to bottom in the following pages.

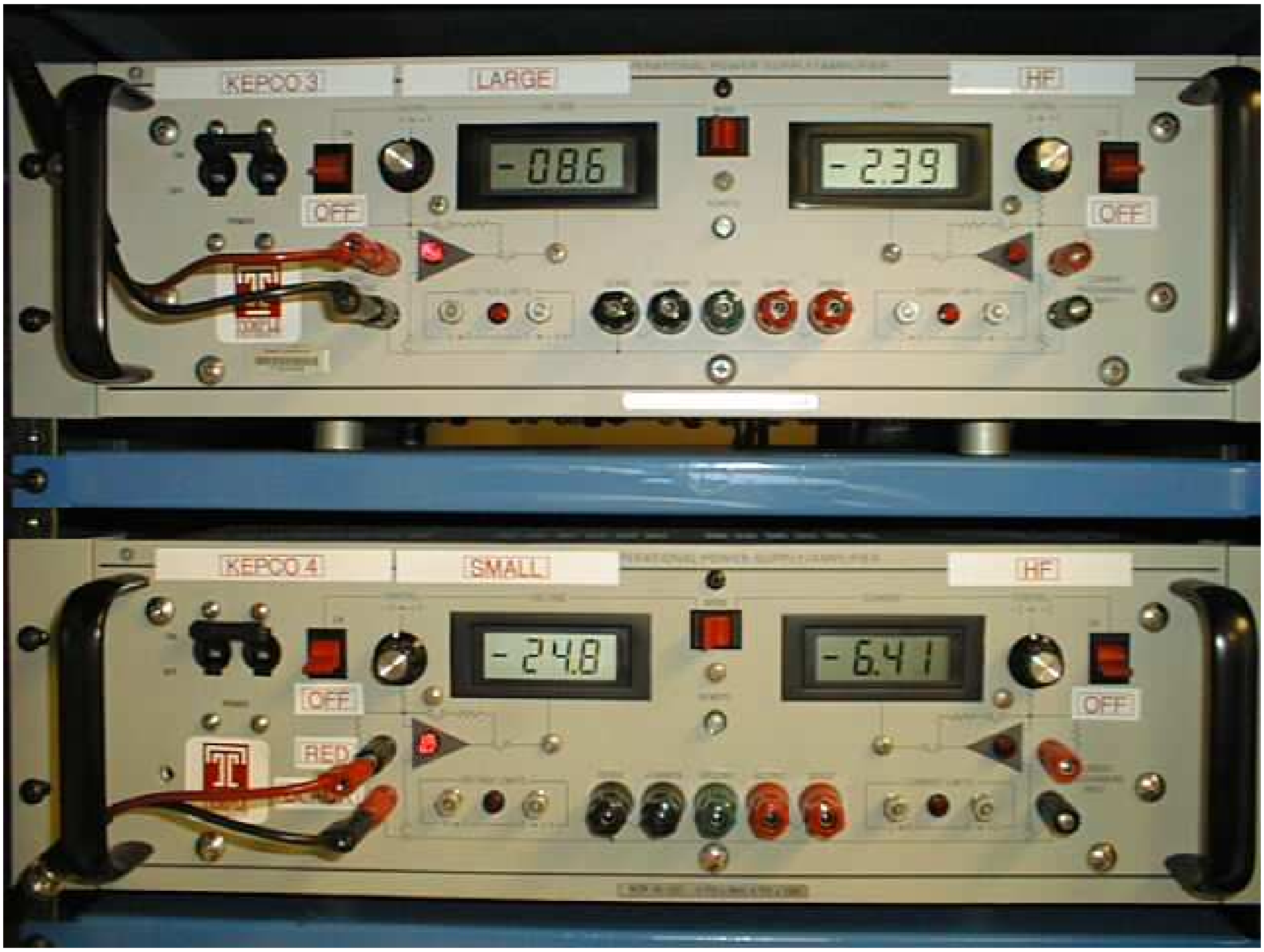

Figure 13: this picture shows you the front panel of the KEPCO power supplies. The top one drives the large set of Helmholtz coils, the bottom one, the small set of Helmholtz coils. Both of them are used in the Voltage Mode.

Figure 14: the box on the top row contains the EPR field feedback system and is not described here. The field rotation box is located on the bottom row.

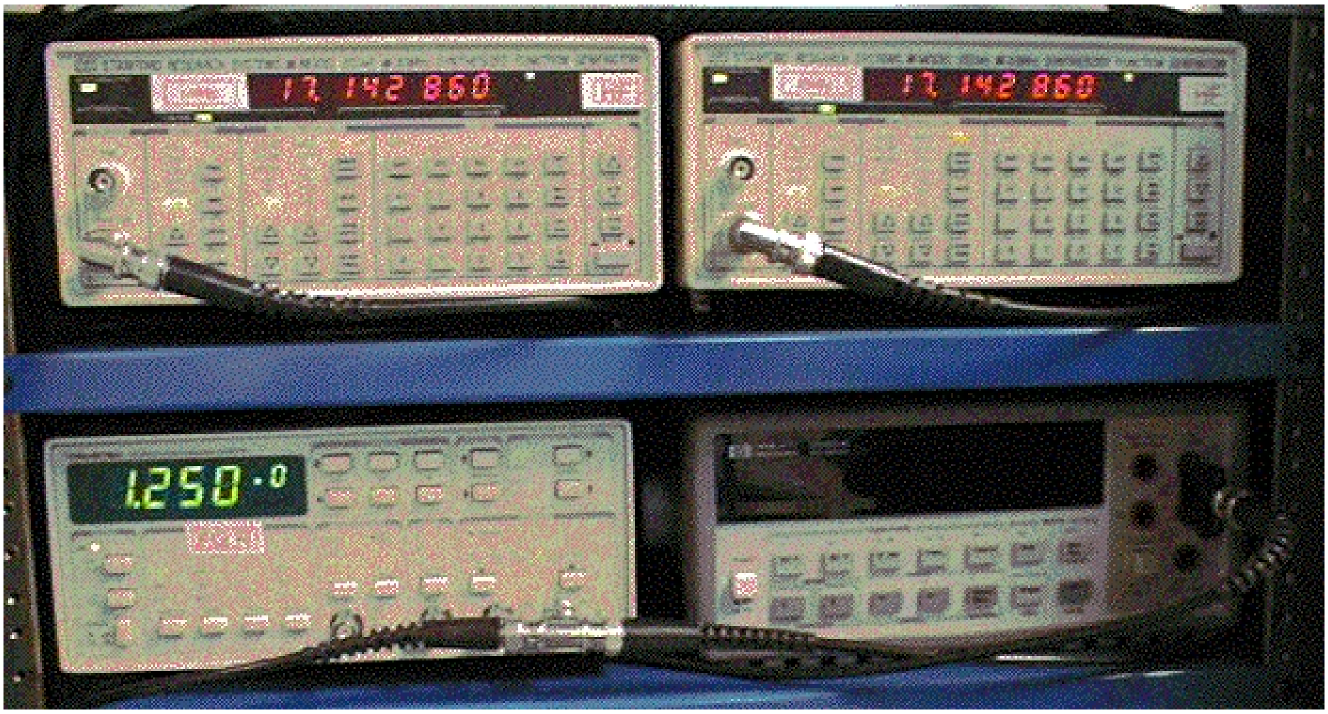

Figure 15: this picture shows you the two DS345 function generators driving each KEPCO power supply, on the top row. The function generator located on the left hand side of the bottom row is the Wavetek function generator used for the holding field rotation.

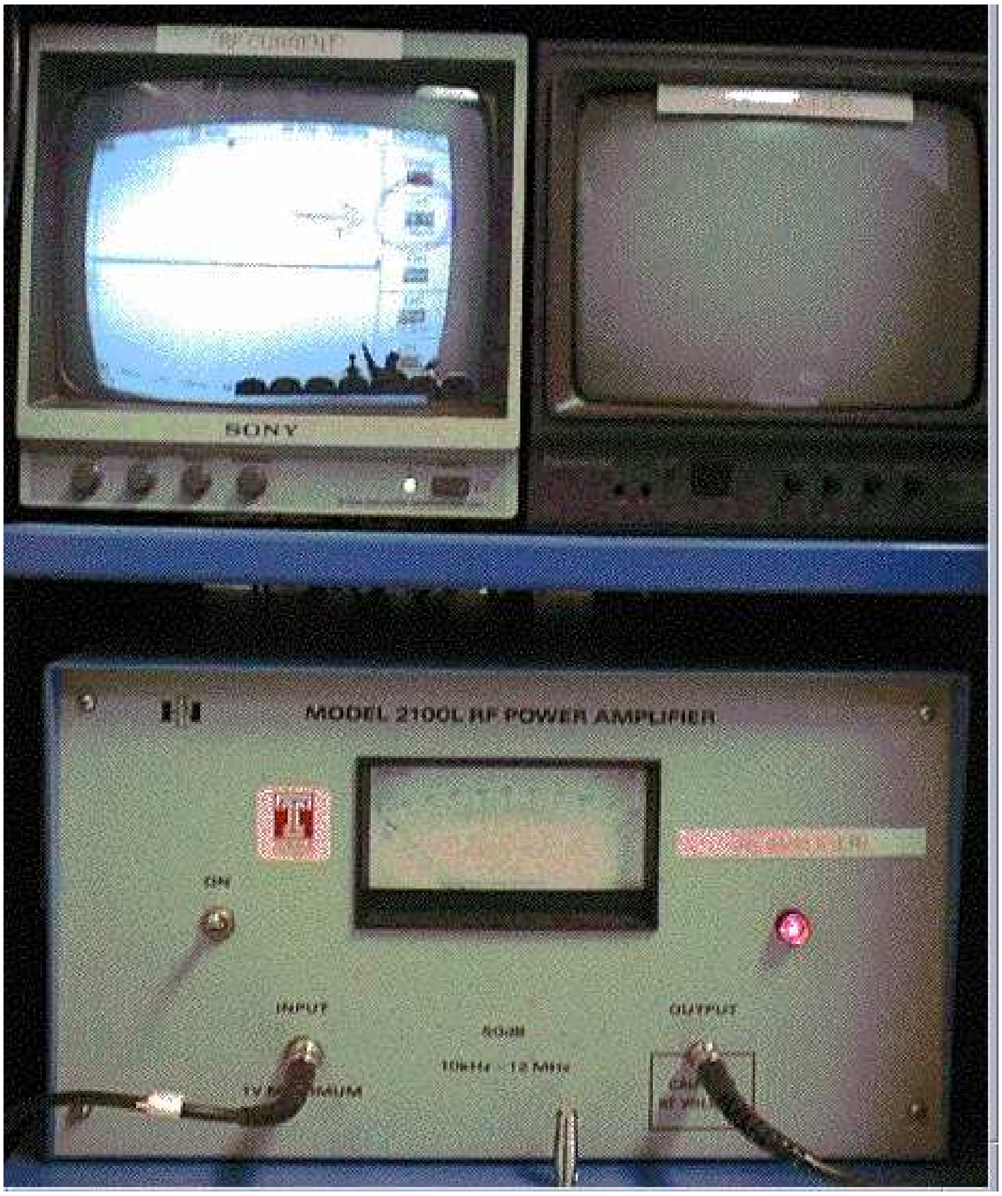

Figure 16: on the top row, you may see the TV monitor showing the screen of the oscilloscope located down in the hall and measuring the RF current flowing through the RF coils. The arrow shows you were to read the peak-to-peak value of the RF voltage. The RF power amplifier is located on the bottom row.

Figure 17: the capacitor box used to increase the RF power delivered to the RF coils is located on the top row. The RF excitation function generator driving the RF power amplifier is located on the bottom row.

Figure 18: VHF attenuator (20 dB) with the 5 dB cap.

Figure 19: front panel of the lock-in amplifier located in the counting house on the top of the NMR rack. The very right hand side display shows you the value of the phase (in degrees, -64 deg here). The adjustabe knob to change manually the value of the phase is located just below the display.

Figure 20: controls rack : oven and air flow controls, target motion, reference cell controls. It is located close to the whiteboard in the counting house. The rack is described from top to bottom in the following pages.

Figure 21: oven heater controller chassis.

Figure 22: target motion control.

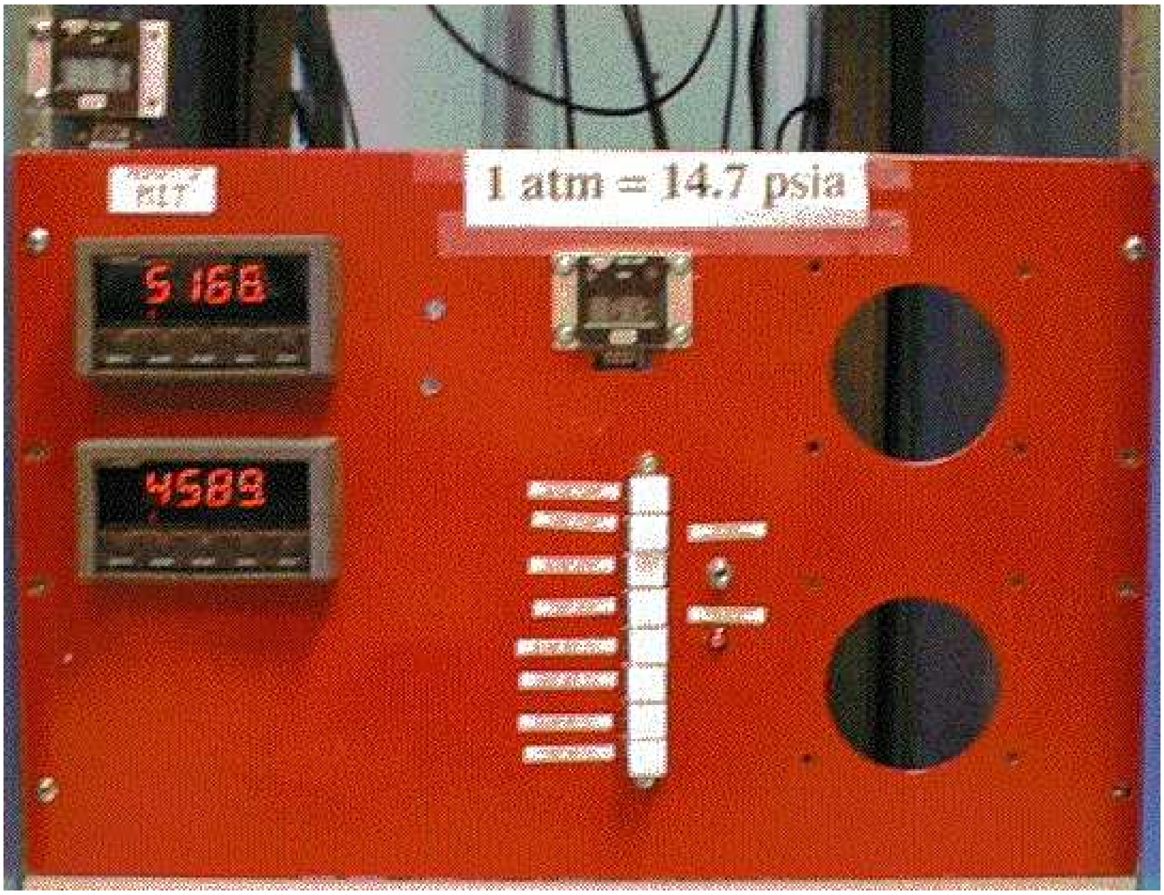

Figure 23: controls of the cooling jets and of the reference cell.

Figure 24: TV monitor in the counting house showing the control box of each lasers. Current and diode temperature are displayed.

Figure 25: X-terminal in the counting house, on the right hand side of the Macintosh, displaying the temperatures given by the RTDs (in the Temperature display area) and allowing you to turn on and off the lasers (in the Lasers display area).

Figure 26: this drawing shows you the front panel of the low-noise preamplifier located in the hall on the pivot. It is protected by a lead hut.

Figure 27: this drawing shows you the front panel of the multimeter used to read the current flowing through the large or the small Helmholtz coils. It is read through the GPIB-ENET box.

Figure 28: Hall A Hall probe used to calibrate the Helmholtz coils.

Figure 29: picture of the GPIB-ENET interface with the microtransceiver on the left hand side.

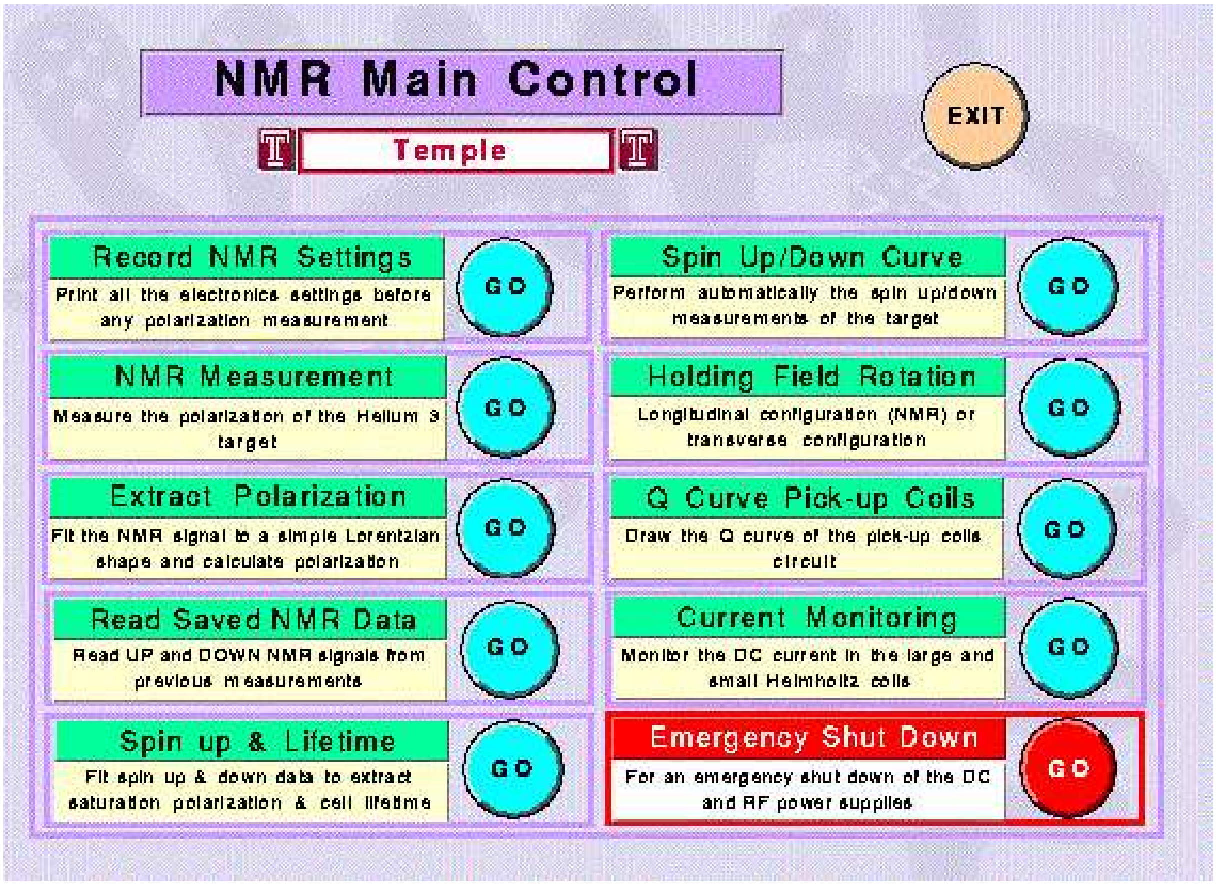

Figure 30: NMR Master panel.

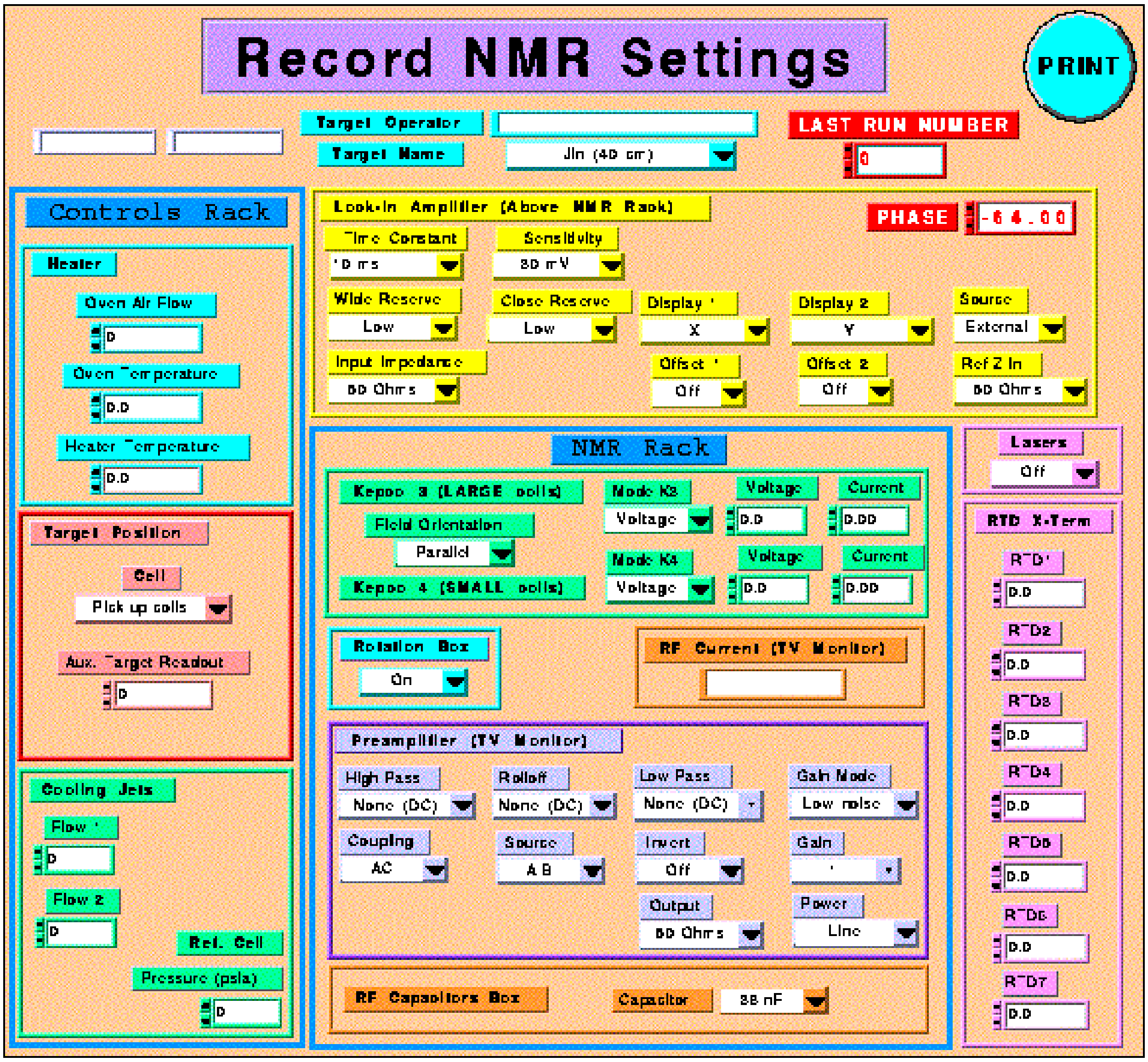

Figure 31: record NMR settings panel.

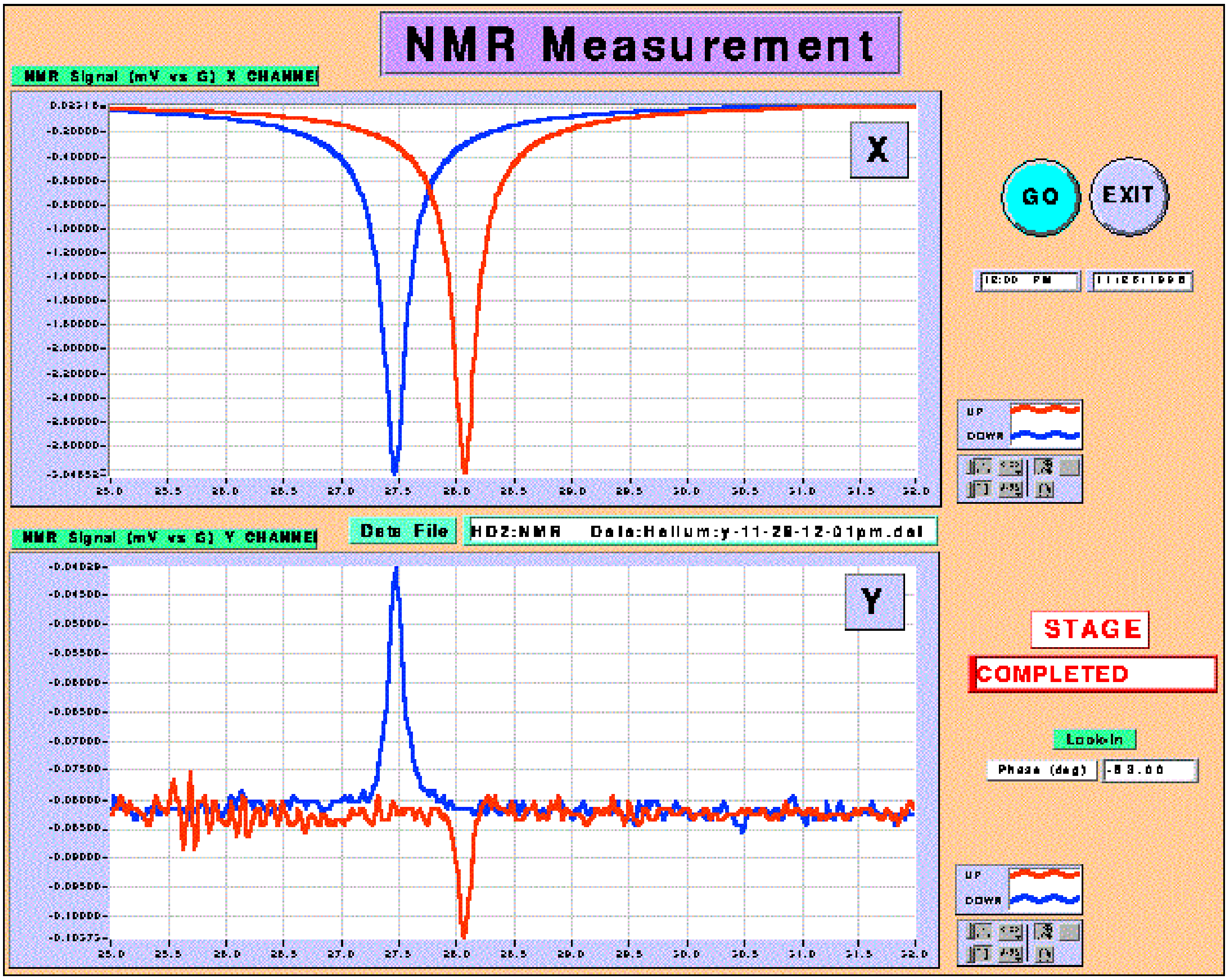

Figure 32: NMR measurement panel.

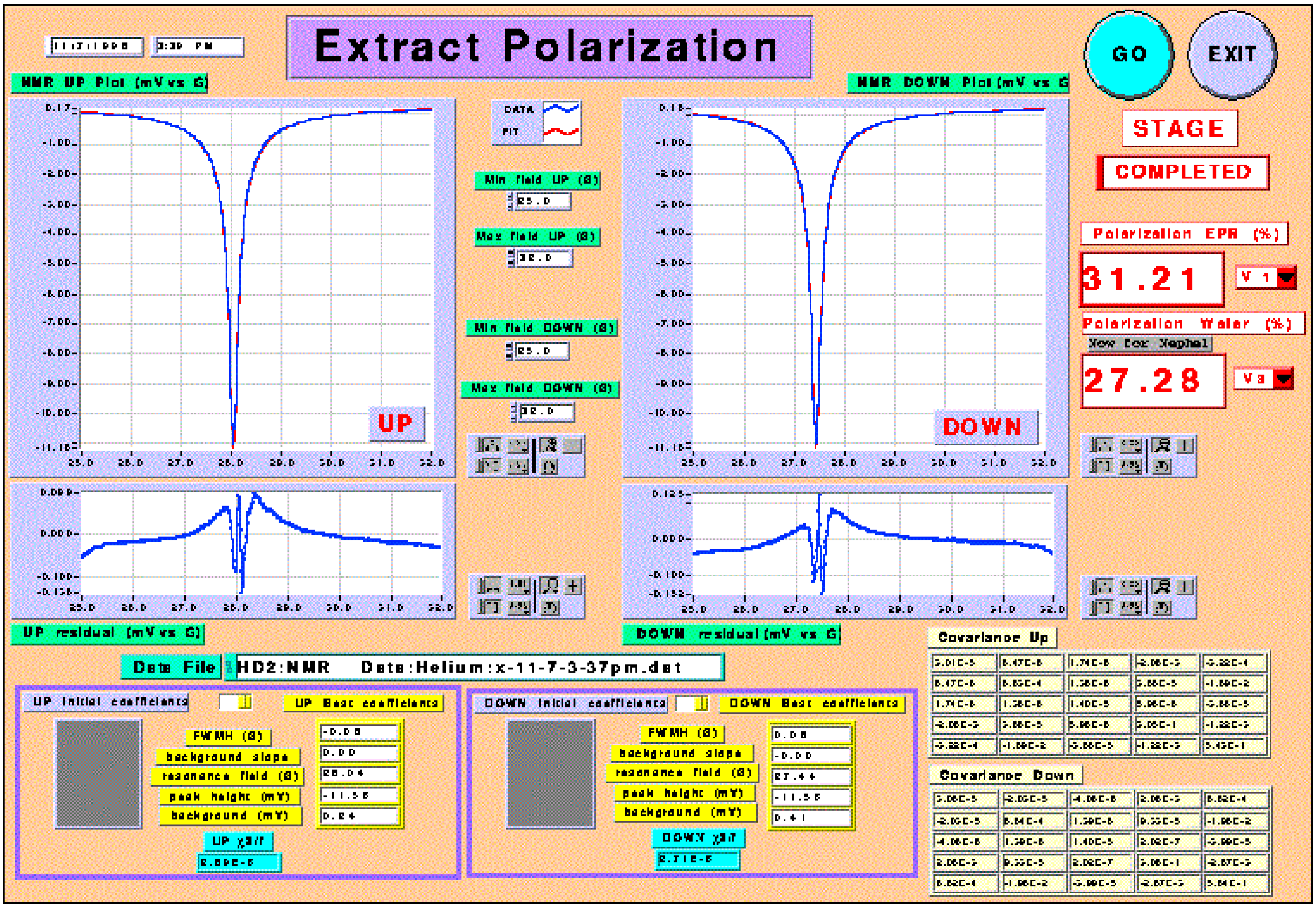

Figure 33: extract polarization panel.

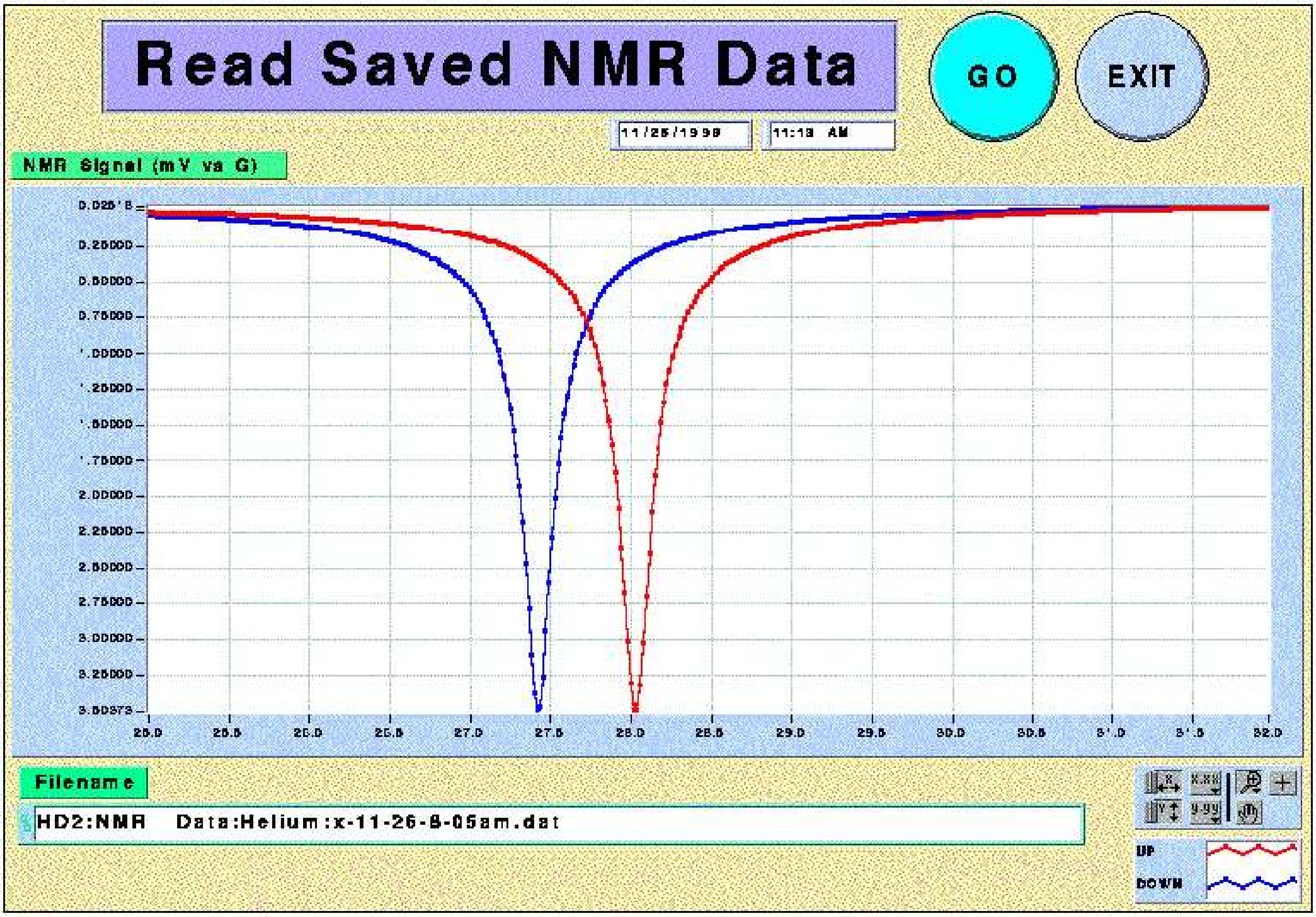

Figure 34: read saved NMR data panel.

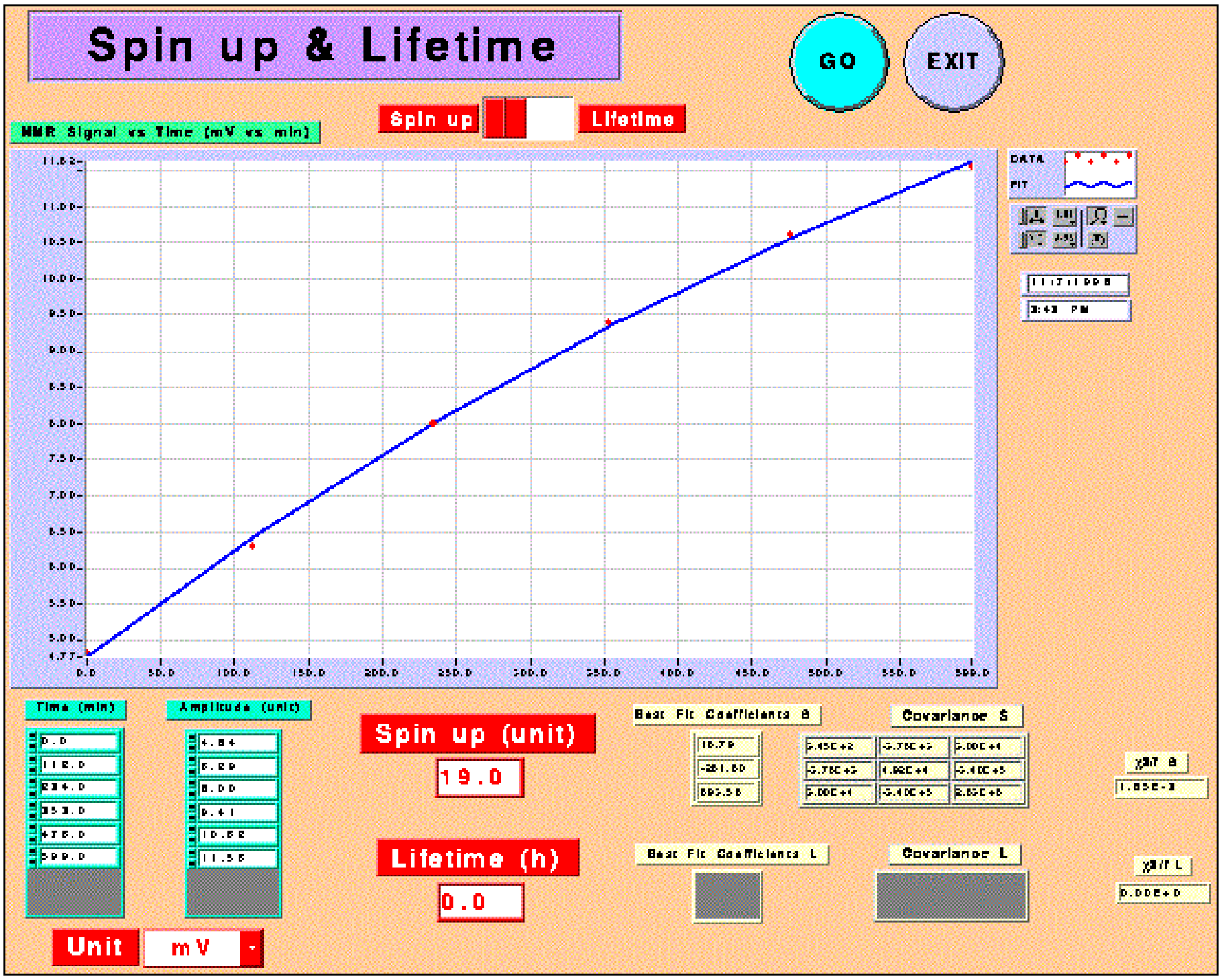

Figure 35: spin-up and lifetime panel.

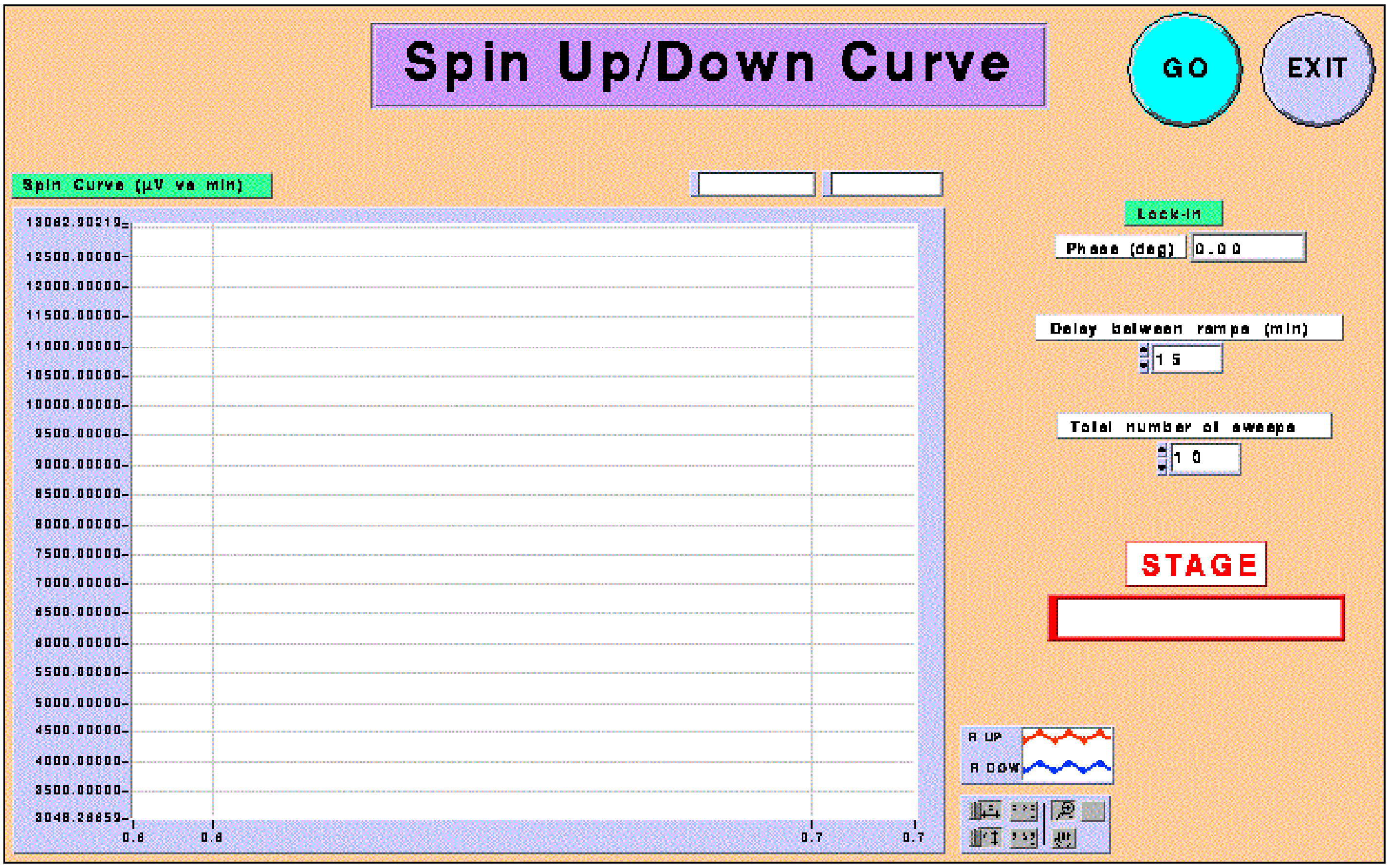

Figure 36: spin-up / down curve panel.

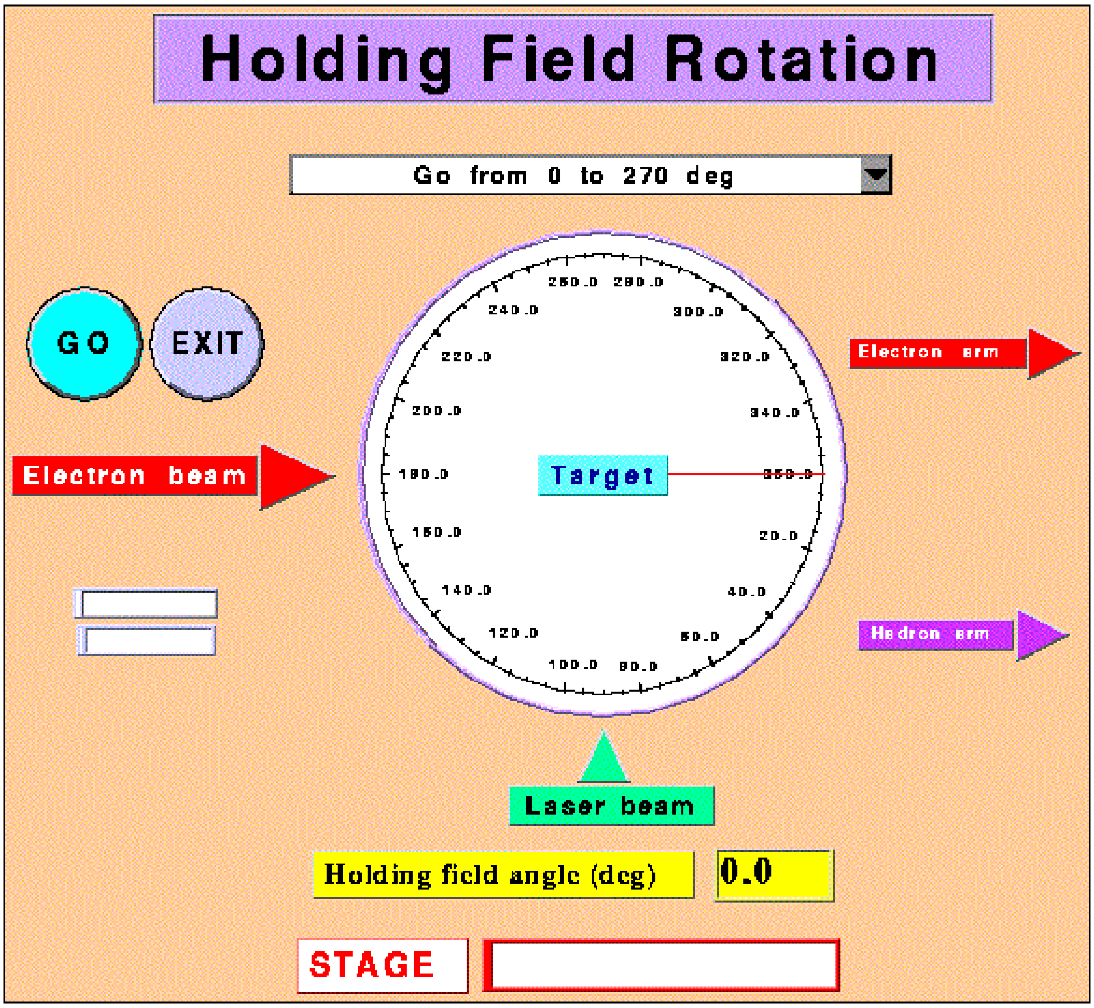

Figure 37: holding field rotation panel.

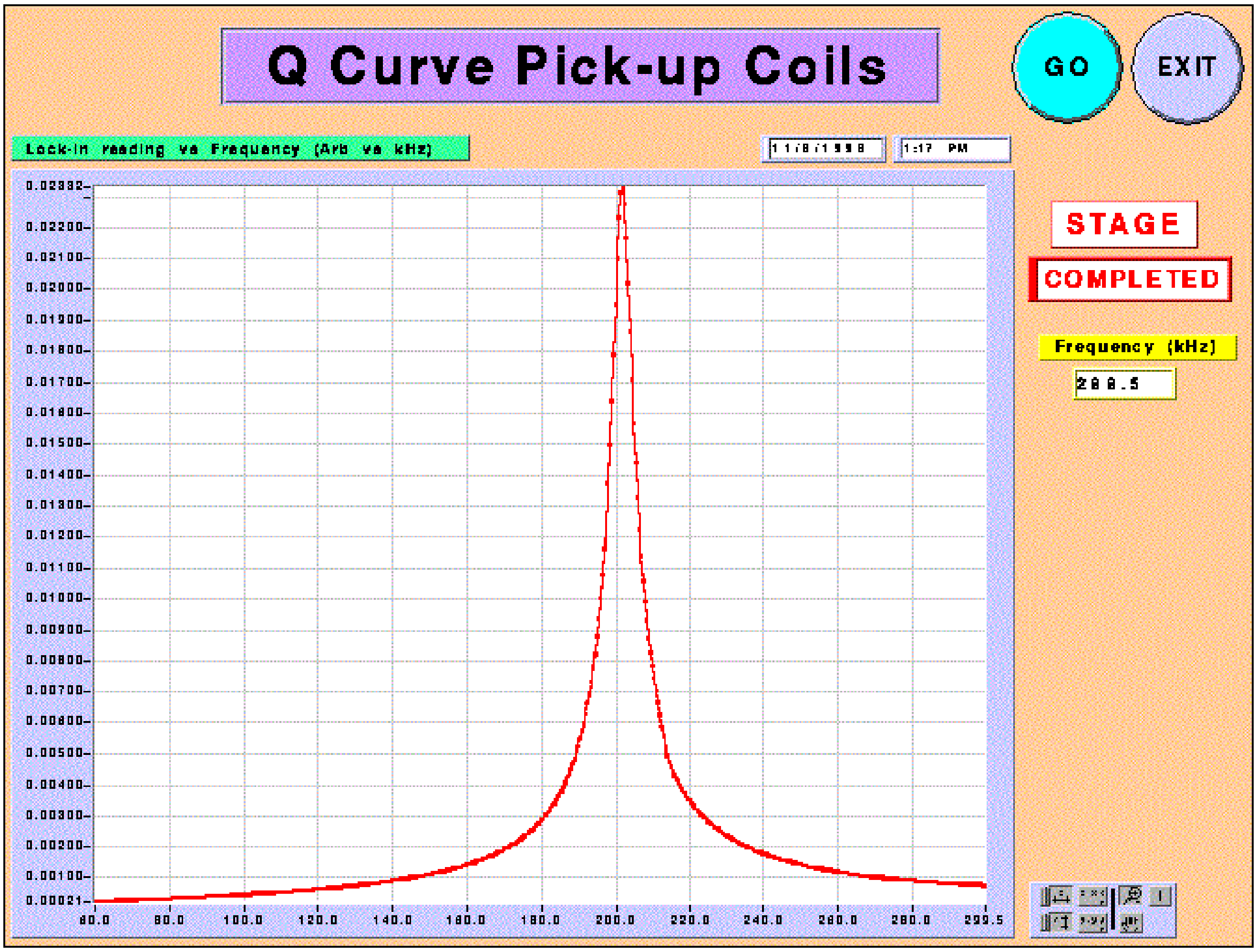

Figure 38: pick-up coils Q curve panel.

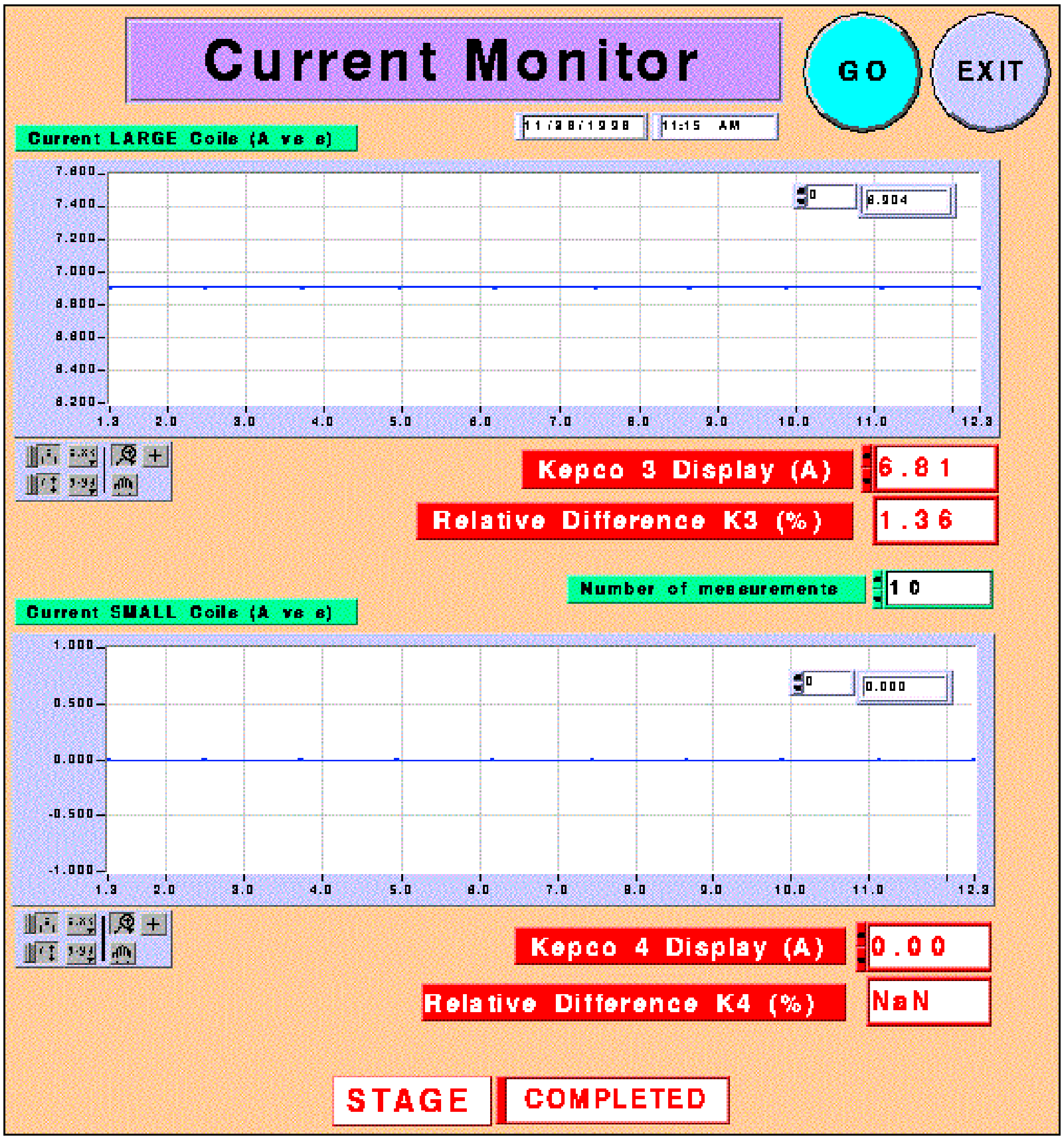

Figure 39: current monitoring panel.

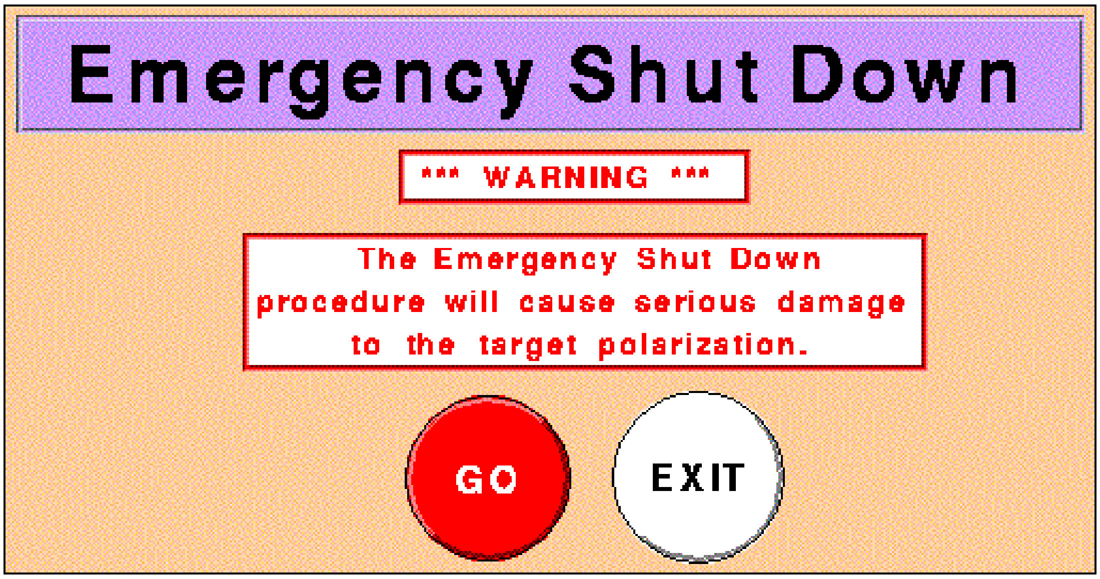

Figure 40: emergency shut down panel.

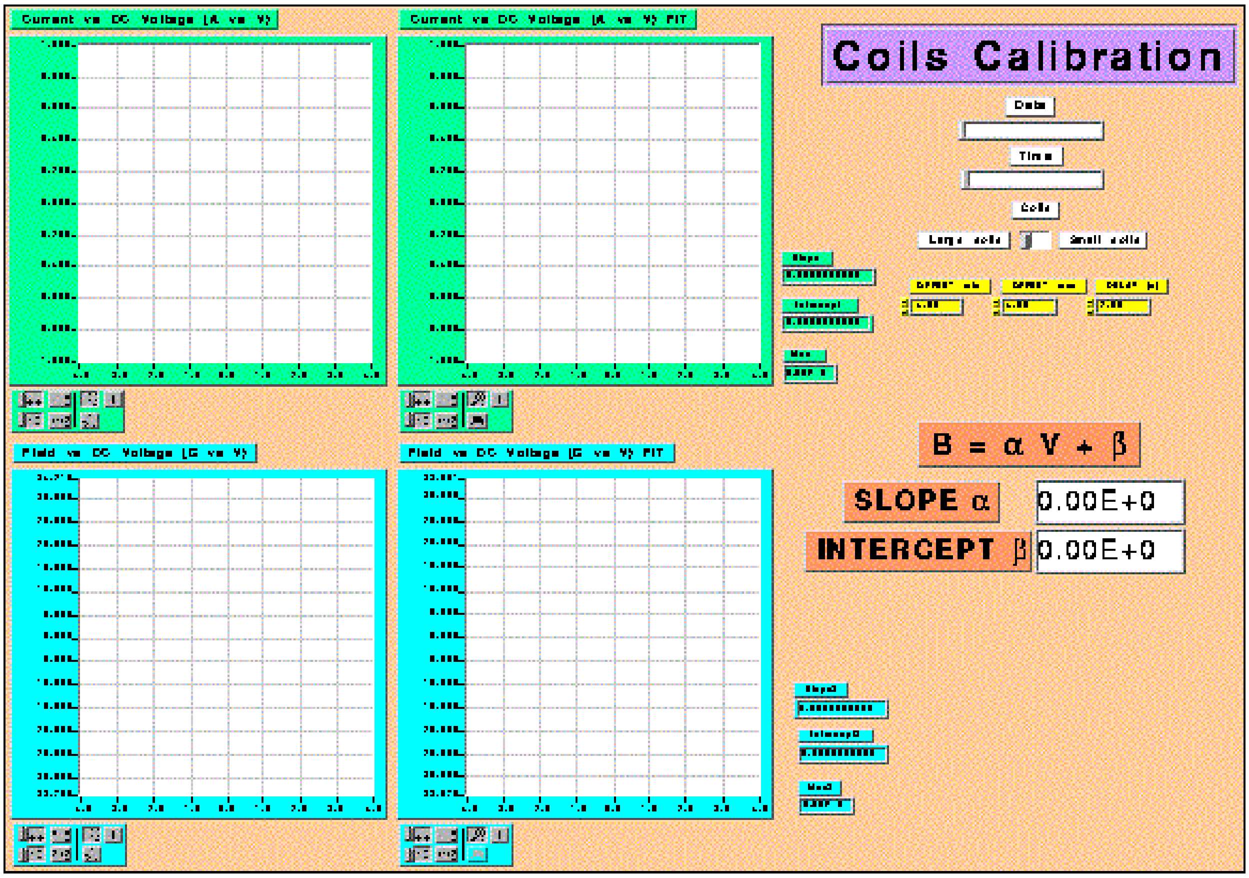

Figure 41: NMR coil calibration FG-V panel.

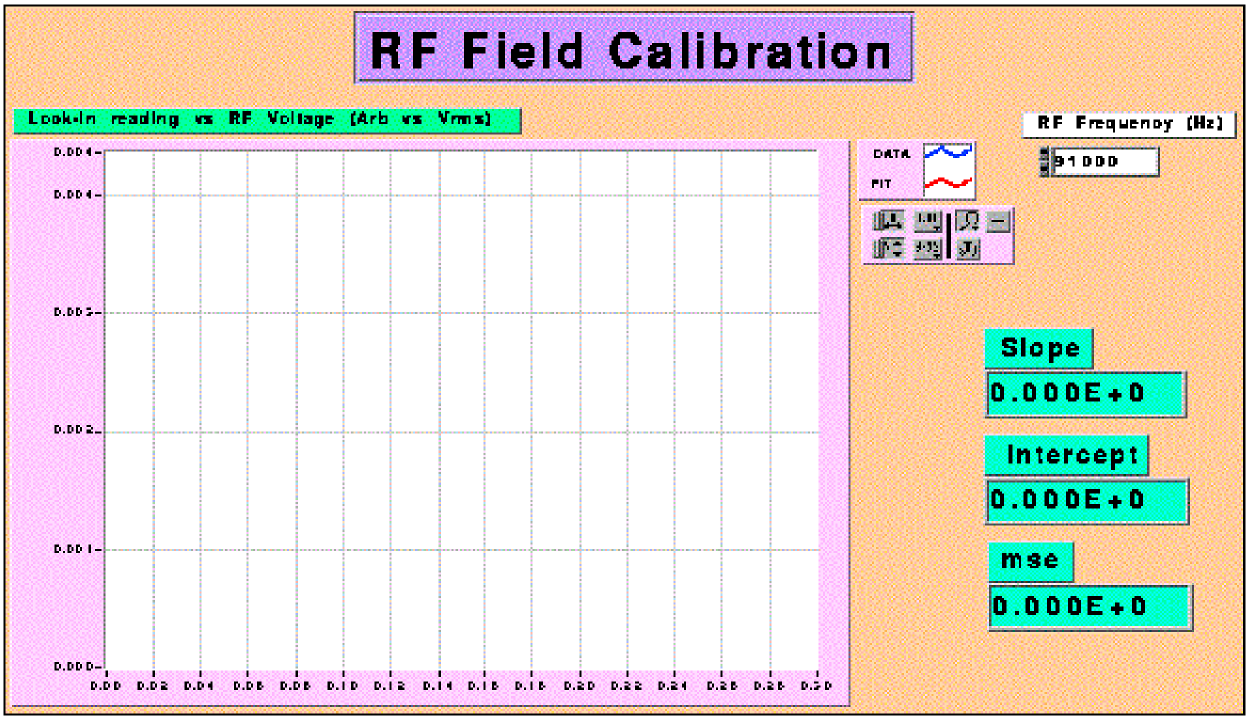

Figure 42: NMR H1 vs VRF panel.

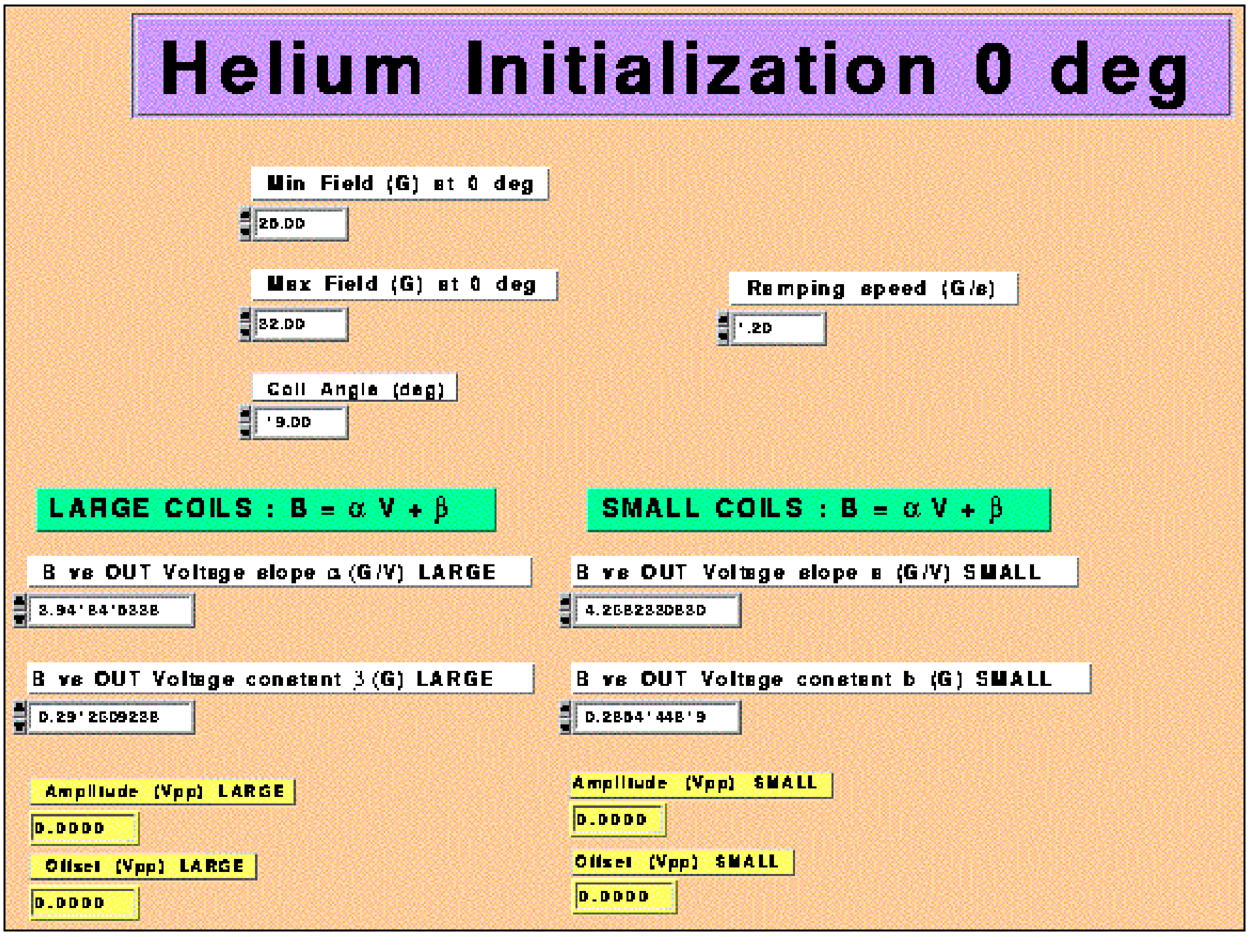

Figure 43: NMR Helium Initialization 0 deg panel.

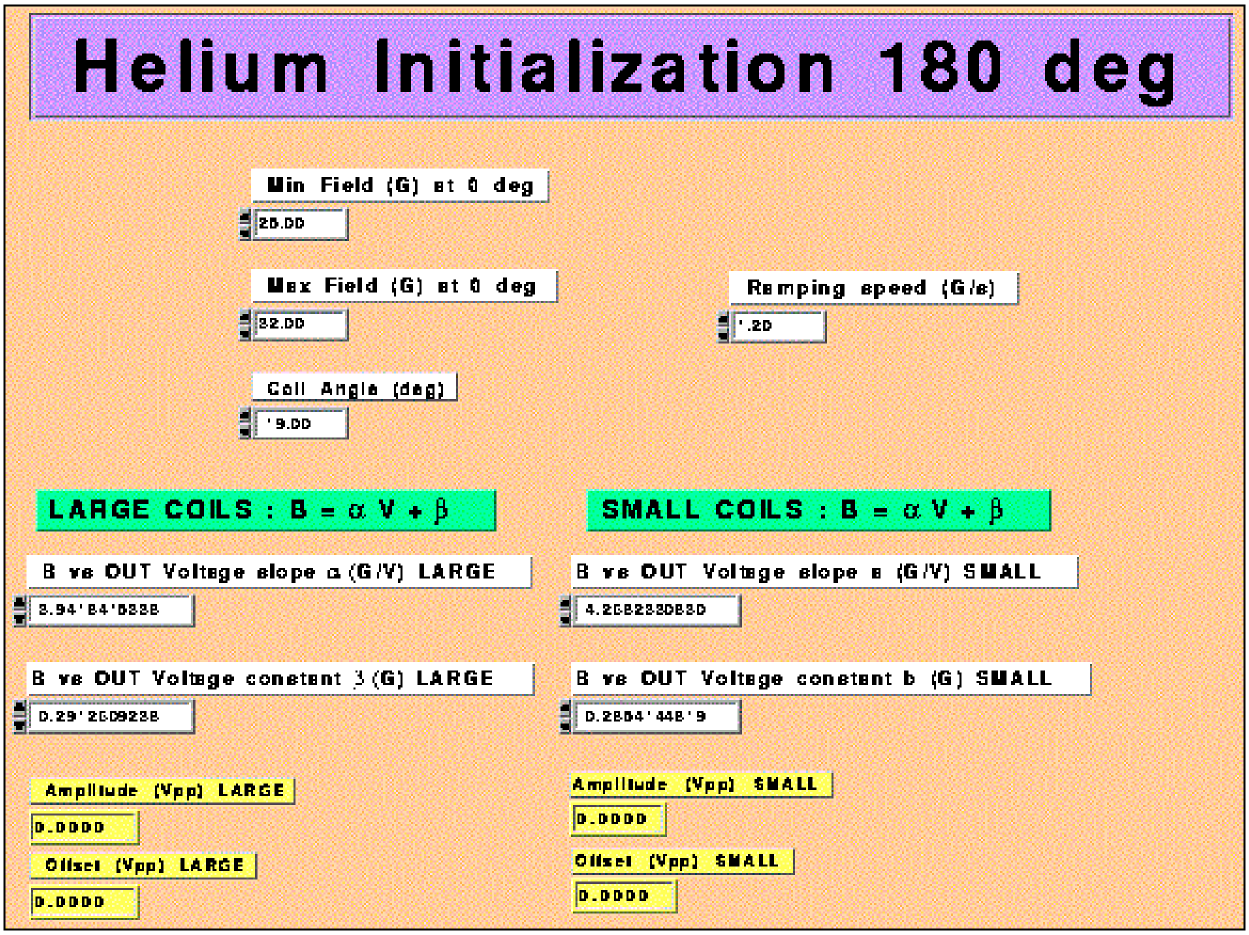

Figure 44: NMR Helium Initialization 180 deg panel.

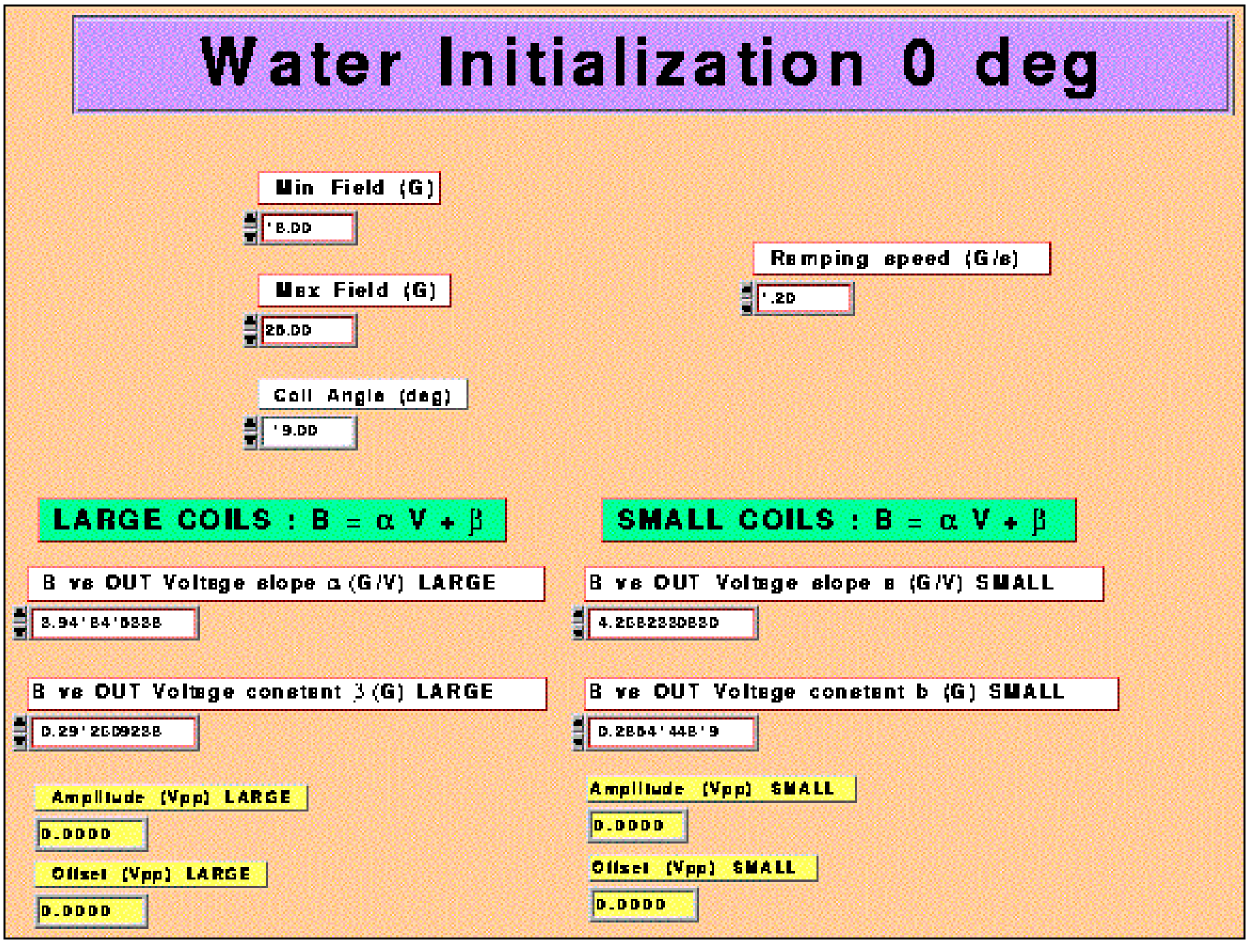

Figure 45: NMR water initialization FG-V panel.

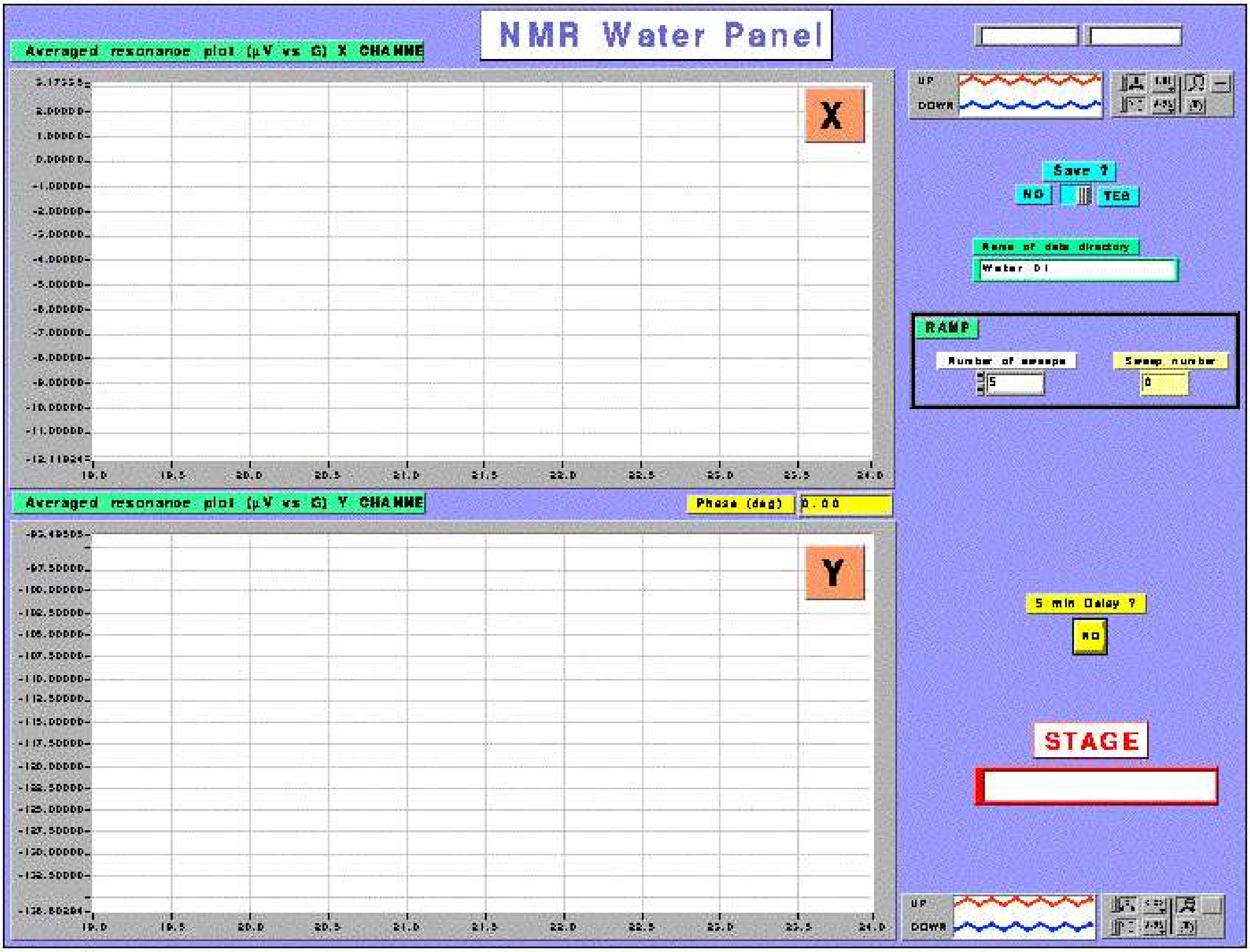

Figure 46: NMR water XY FG-V panel.

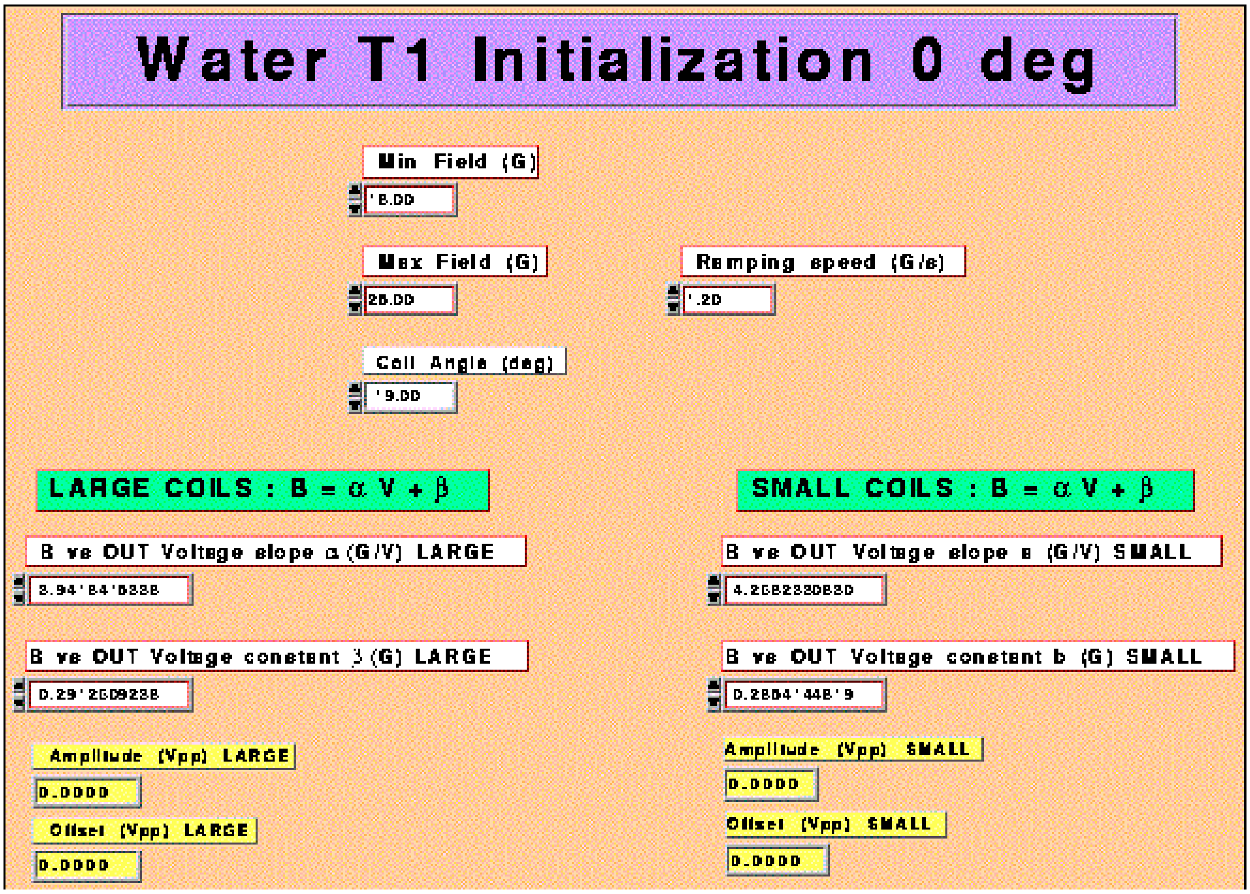

Figure 47: NMR water init T1 FG-V panel.

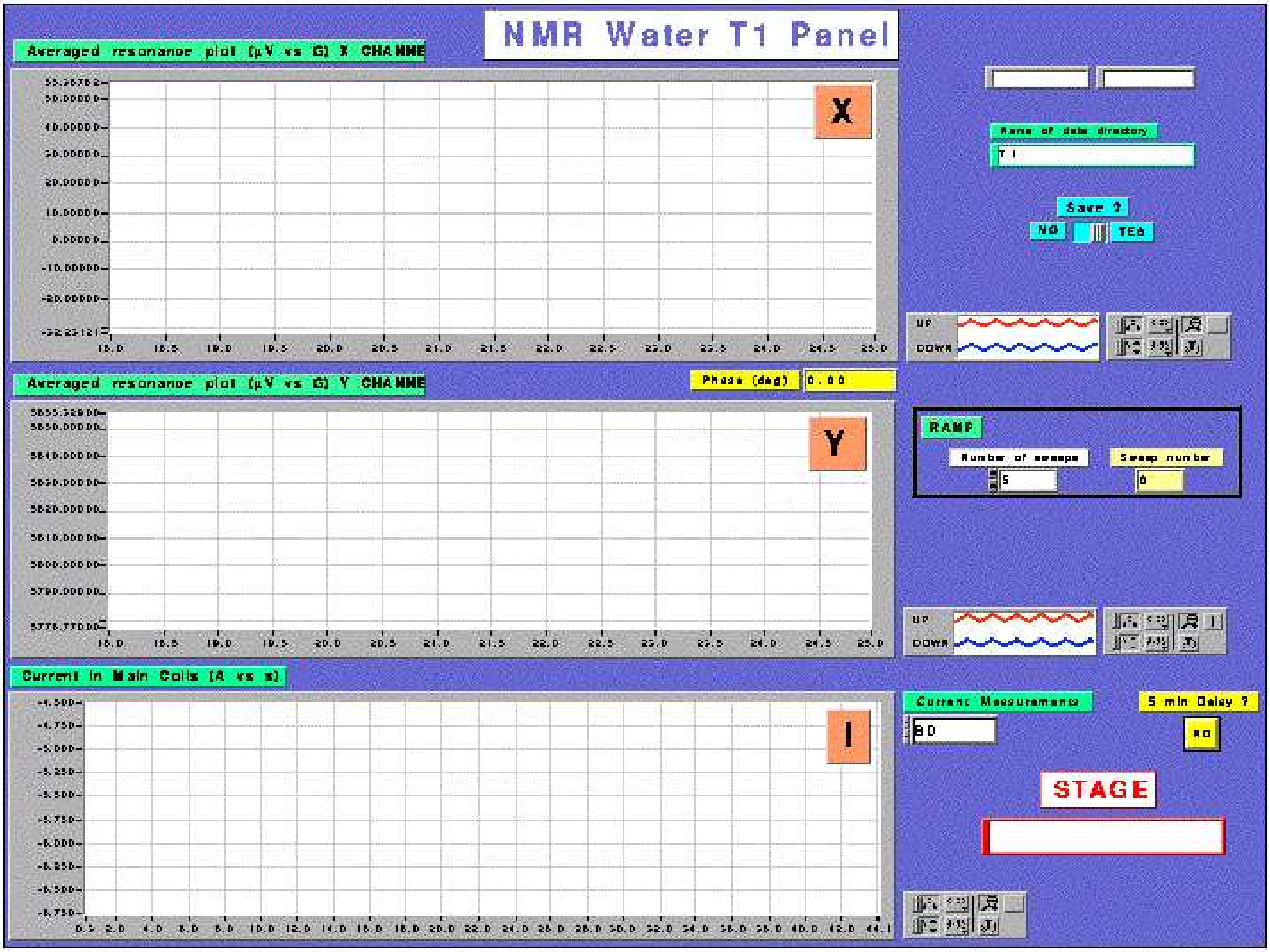

Figure 48: NMR water T1 FG-V panel.

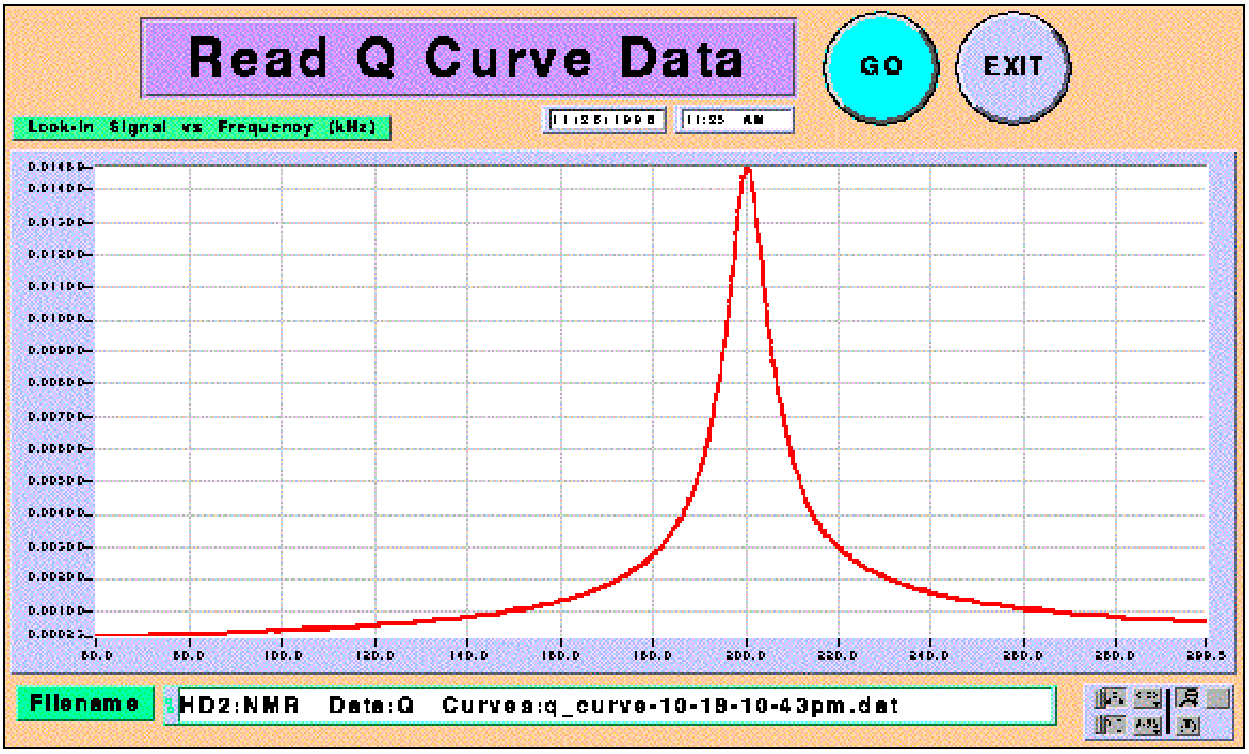

Figure 49: NMR read Q curve data panel.