Michel Borghini

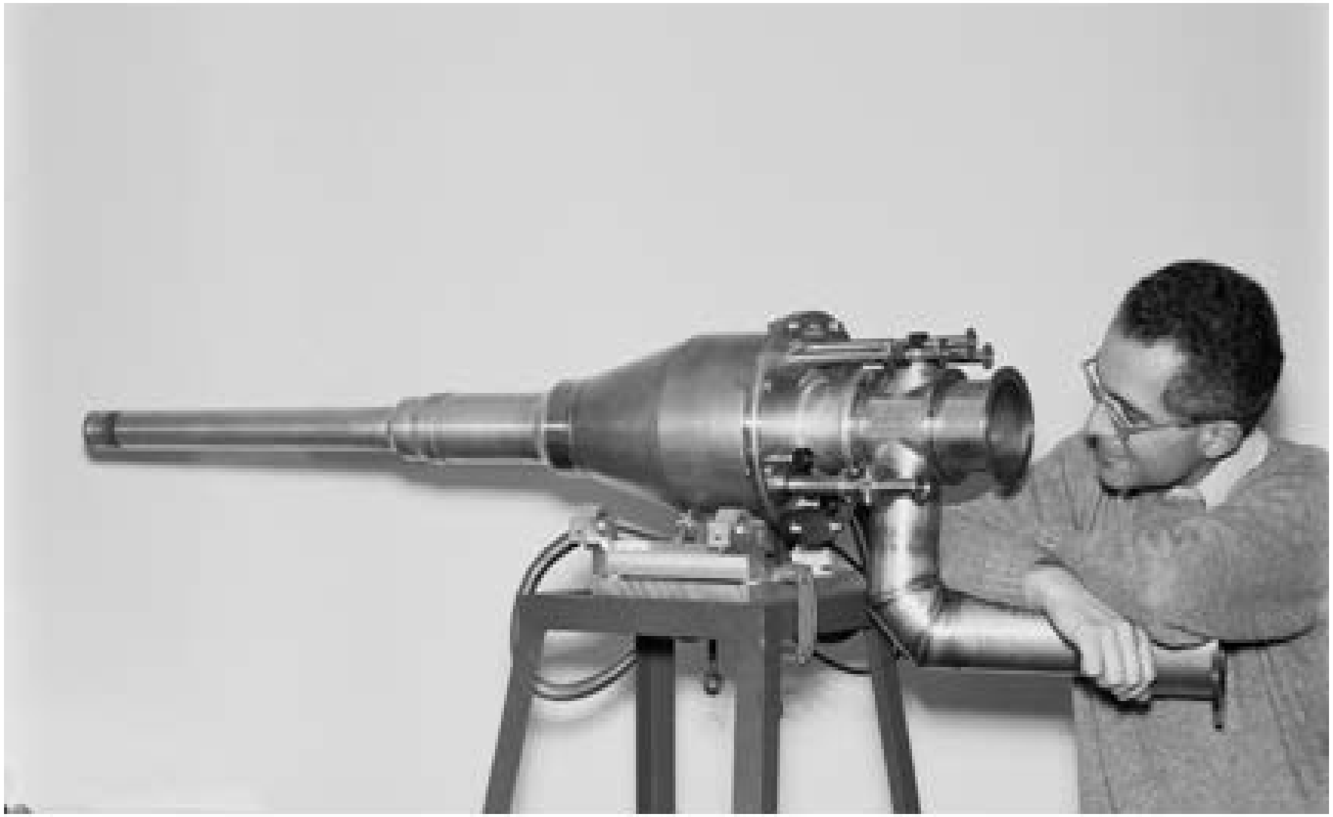
Radiation Doped Target Materials

Michel Borghini

- Obituary was published in CERN Courier of 28 March 2013, with biographic information including references to his work on polarized targets and spin physics b
- “Spin temperature model of DNP” remains one of his best recalled contributions for this community (Phys. Rev. Lett. **20** 419, 1968)
- This model extended the general QS treatment of magnetic resonance saturation to electron spin systems at low temperatures where the polarization is high
- Borghini and his team at CERN proved also experimentally the validity of his hypothesis that all nuclear spin species cool towards a common temperature, that of the dipolar energy reservoir of the electronic spin system under saturating microwave field

Michel Borghini

† 15 December 2012, at age of 78 years



Michel Borghini and WA6 Polarized Target cryostat in 1976

Stephen's

CERN 66-3
Nuclear Physics Division
31 January 1966

ORGANISATION EUROPÉENNE POUR LA RECHERCHE NUCLÉAIRE
CERN EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CHOICE OF SUBSTANCES FOR POLARIZED PROTON TARGETS

by

M. Borghini

GENEVA
1966

D. G. CRABB

CERN 68-32
Nuclear Physics Division
5 August 1968

ORGANISATION EUROPÉENNE POUR LA RECHERCHE NUCLÉAIRE
CERN EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

PROTON SPIN ORIENTATION

M. Borghini
CERN, Geneva, Switzerland.

Lectures given in the Academic
Training Programme of CERN

GENEVA
1968

FICHE D'ACHEMINEMENT - ROUTE SLIP

A / TO : DONALD CRABB

Veuillez/Please

- [x] Donner suite/Take action
- [ ] Approuver/Approve
- [ ] Commenter/Comment
- [ ] Signer/Sign
- [ ] Noter/Note
- [ ] Payer/Pay
- [ ] Classer/File
- [ ] Retourner/Return

P(H) and P(D) are implicitely related by

$$P_H = \tanh \frac{h f_H}{2kT}$$

$$P_D = \frac{4 \tanh \frac{h f_D}{2kT}}{3 + \tanh^2 \frac{h f_D}{2kT}}$$

T : spin temperature, is a parameter (varying around a few millidegrees)

h = Planck's constant
k = Boltzmann "
f_H = proton Larmor frequency (106.5 MHz)
f_D = deuteron " " (16.5 ")

SIS/RD/53

De / From: M Borghini

No. Tel. 3428

Date 26.1.77

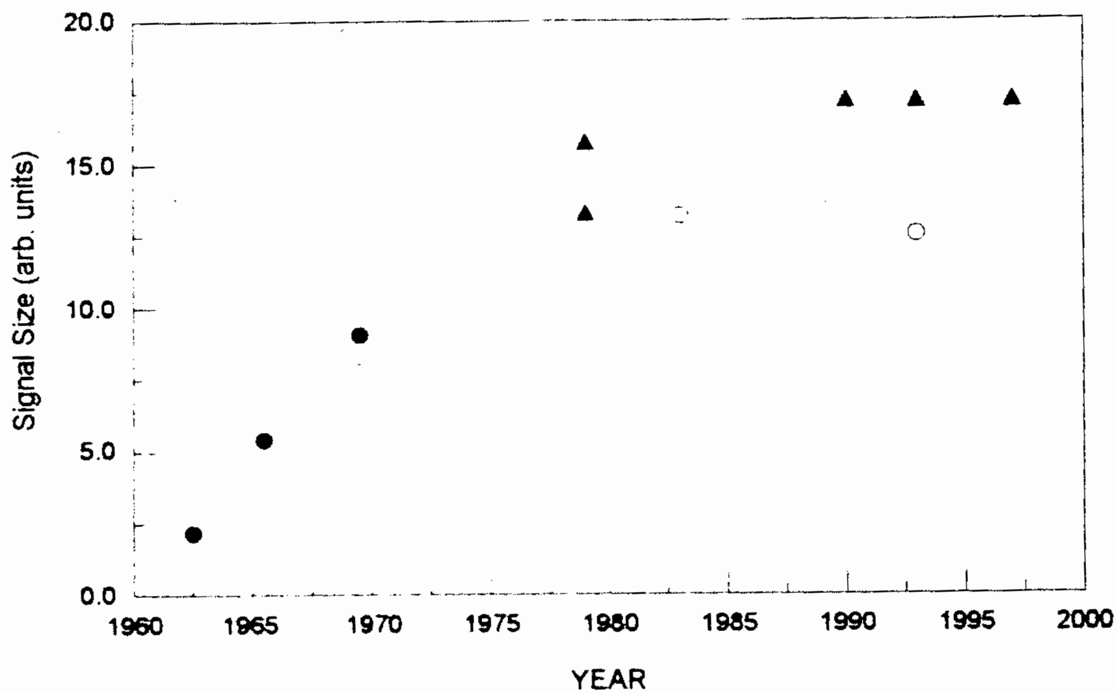


Figure 1. Plot of proton NMR signal size by year. Circles: LMN in 1962/3 and alcohols doped with pophyrexide and CrV; Triangles: radiation doped ammonia

Radiation Doping

- First Irradiation

  C. F. Hwang & T. M. Sanders, Int. Symp. On Polarization, Helvetia Physics Acta, Supp. VI, 122 (1960)

  CH_2 irradiated with electrons, photons and neutrons

  P_{max} = 1.2 % with B = 3.2 kG, T=1.3K

- Second Irradiation

  D. Hill et al., Phys. Letts., 23, 63 (1966)

  CH_2 irradiated with fast neutrons

  P = 10% with B = 2.5 T, T = 1.2 K

Suggested irradiating at LN_2 temperatures

Radiation Doping II

- After the Borghini EST theory, very little effort in Radiation doping for ~ 10 Years.
- Increasingly the demand for radiation resistant materials in experiments turned attention back to radiation doping and by the end of the '70s, two workshops (precursors of the current PSTP Series) ANL(1978), Cosenors House (Rutherford Lab.) were showing results of radiation damage to the standard materials and some attempts at irradiating materials.
- Geoff Court at Liverpool started the modern era of doping NH_3 by irradiating ammonia in a reactor.
- Some of this material was polarized at CERN to ~90%

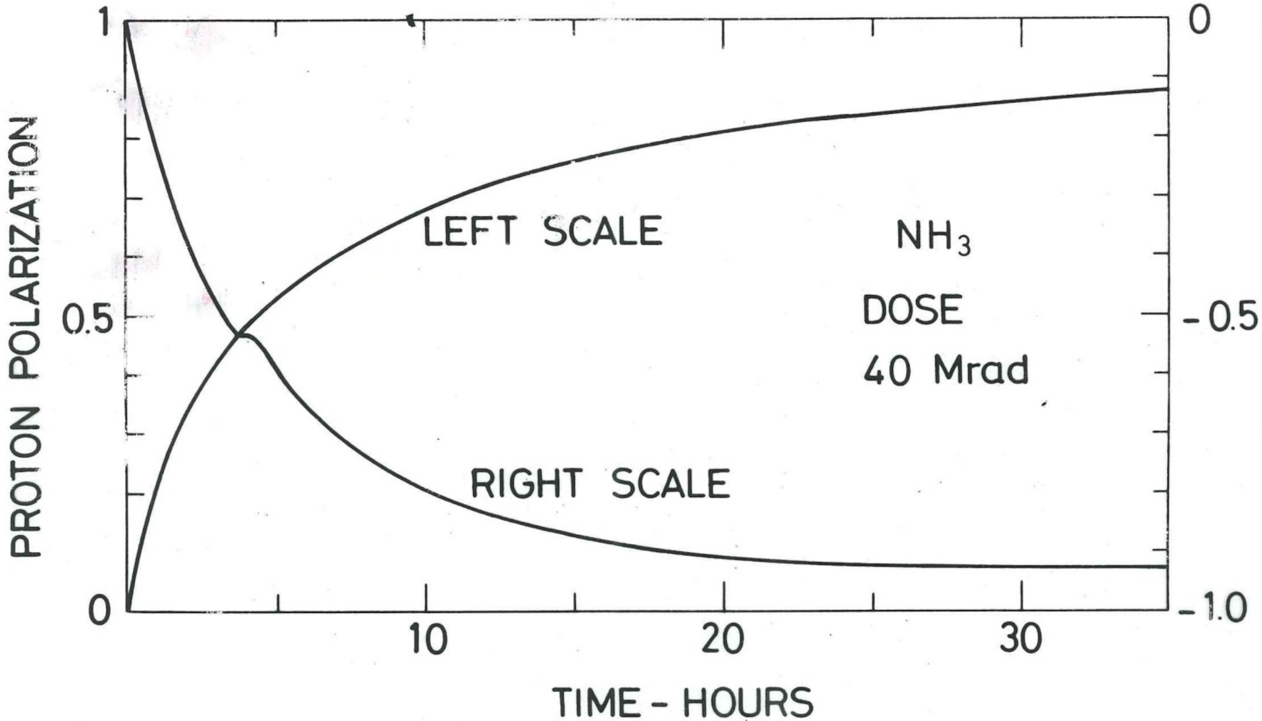
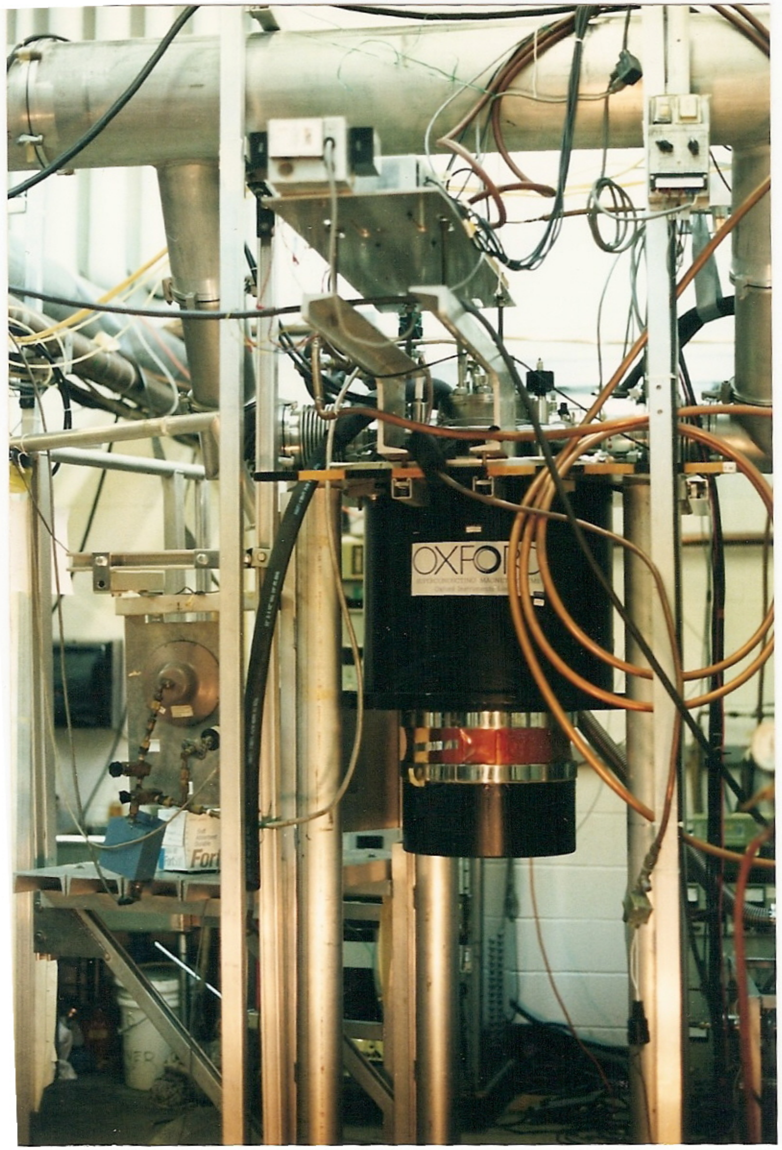
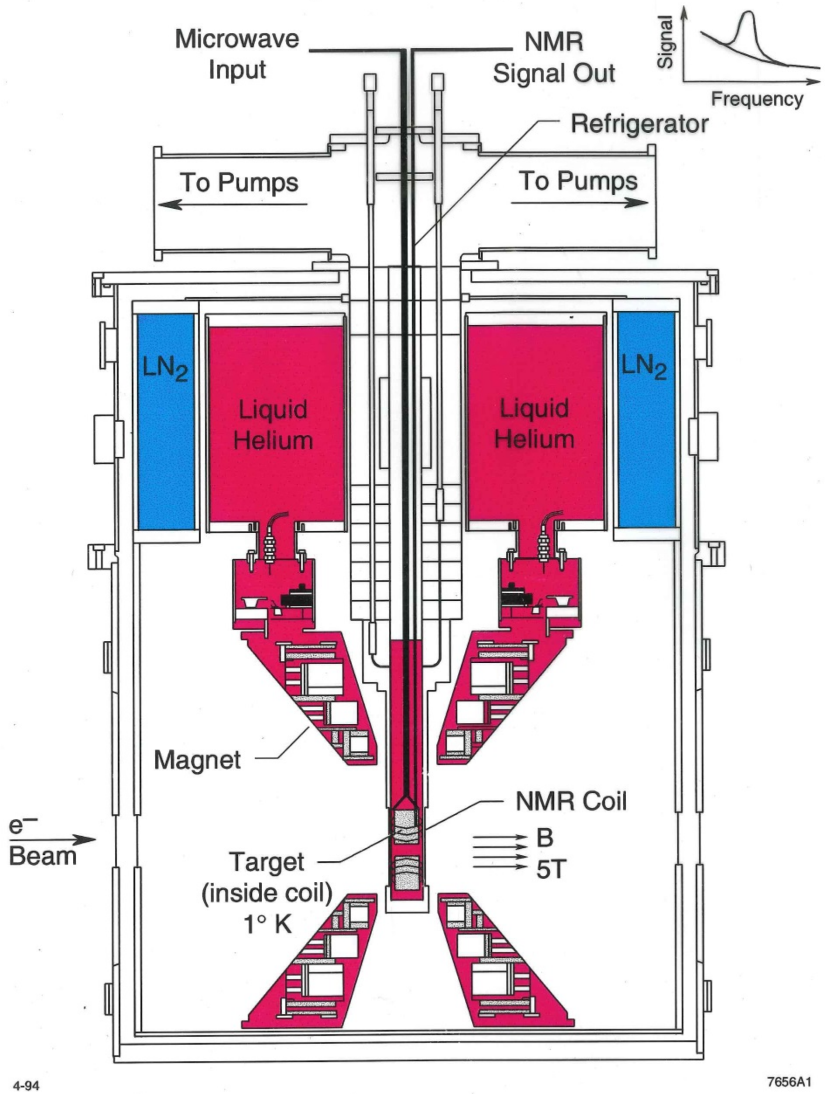

PROTON POLARIZATION
1
0.5
0
0
-0.5
-1.0
10
20
30
TIME - HOURS
LEFT SCALE
RIGHT SCALE
NH3
DOSE
40 Mrad

Fig. 3

Radiation Doping III

- Around 1980 much activity at Michigan, Bonn, SLAC, ANL, Saclay ……………
- First experiment with irradiated NH_3 at BNL (0.5 K/ 2.5 T)
- Michigan moves to 5 T/ 1K


OXFOR



Schematic of the polarized NH3/ND3/LiD target. The solid cryogenic target relies on 140 GHz microwave power, 1° K temperature by evaporation of liquid He4, and 5 Tesla magnetic field to polarize the protons/deuterons (Dynamic Nuclear Polarization). Liquid He4 circulates through the cells to cool the material in the presence of beam. Two cells are located in the target, allowing for measurements of protons and deuterons by a simple vertical motion of the target cells. A NMR system serves to measure the proton or deuteron polarization.

Radiation Doping IV

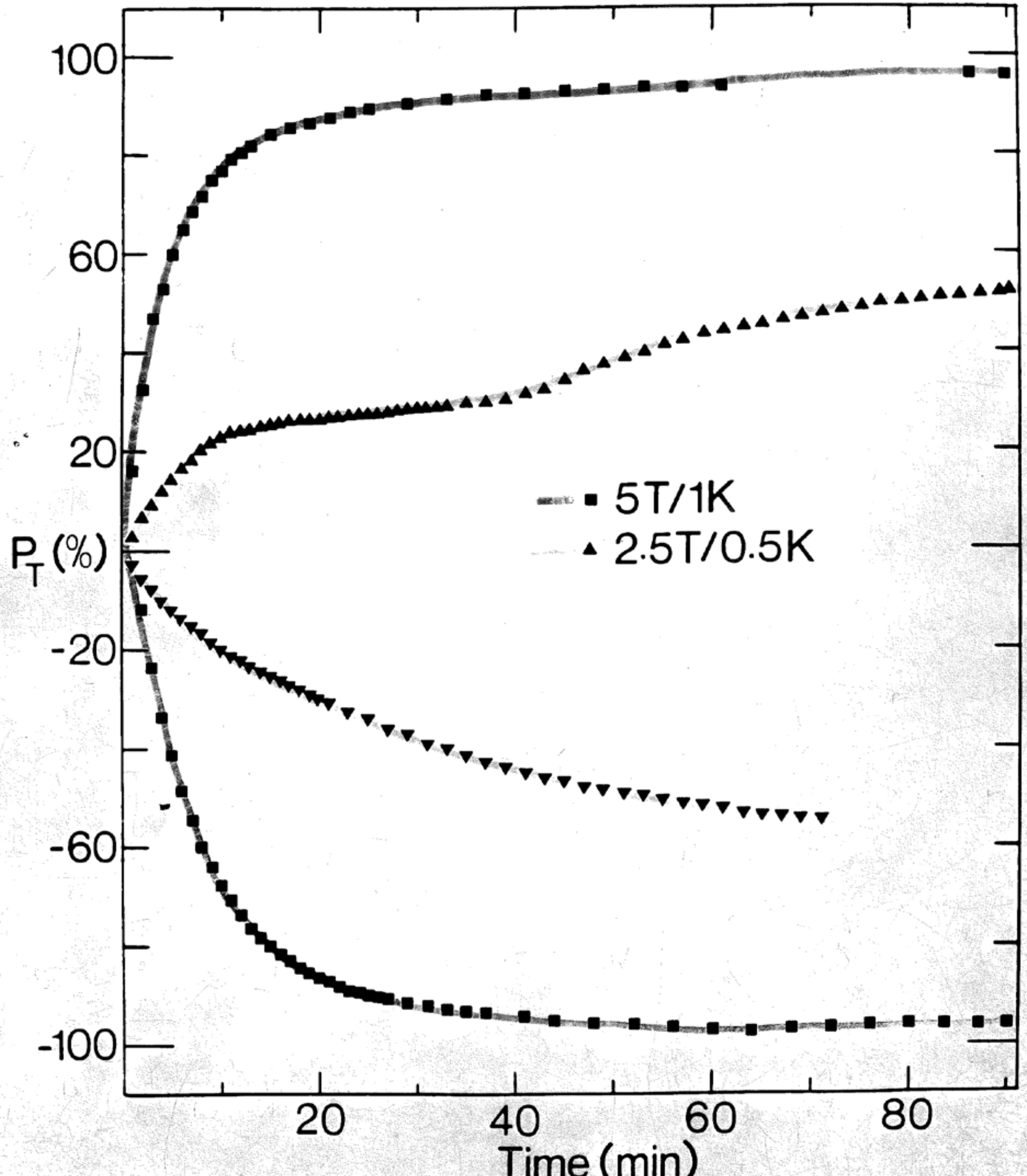
- Irradiation of NH3:

- Initially under LN2: Explosions:
  Ozone aborption
- Liquid Argon
  Proton knock out at ~ 12MeV

$e^- + {}^{40}A \rightarrow {}^{39}Cl + p$

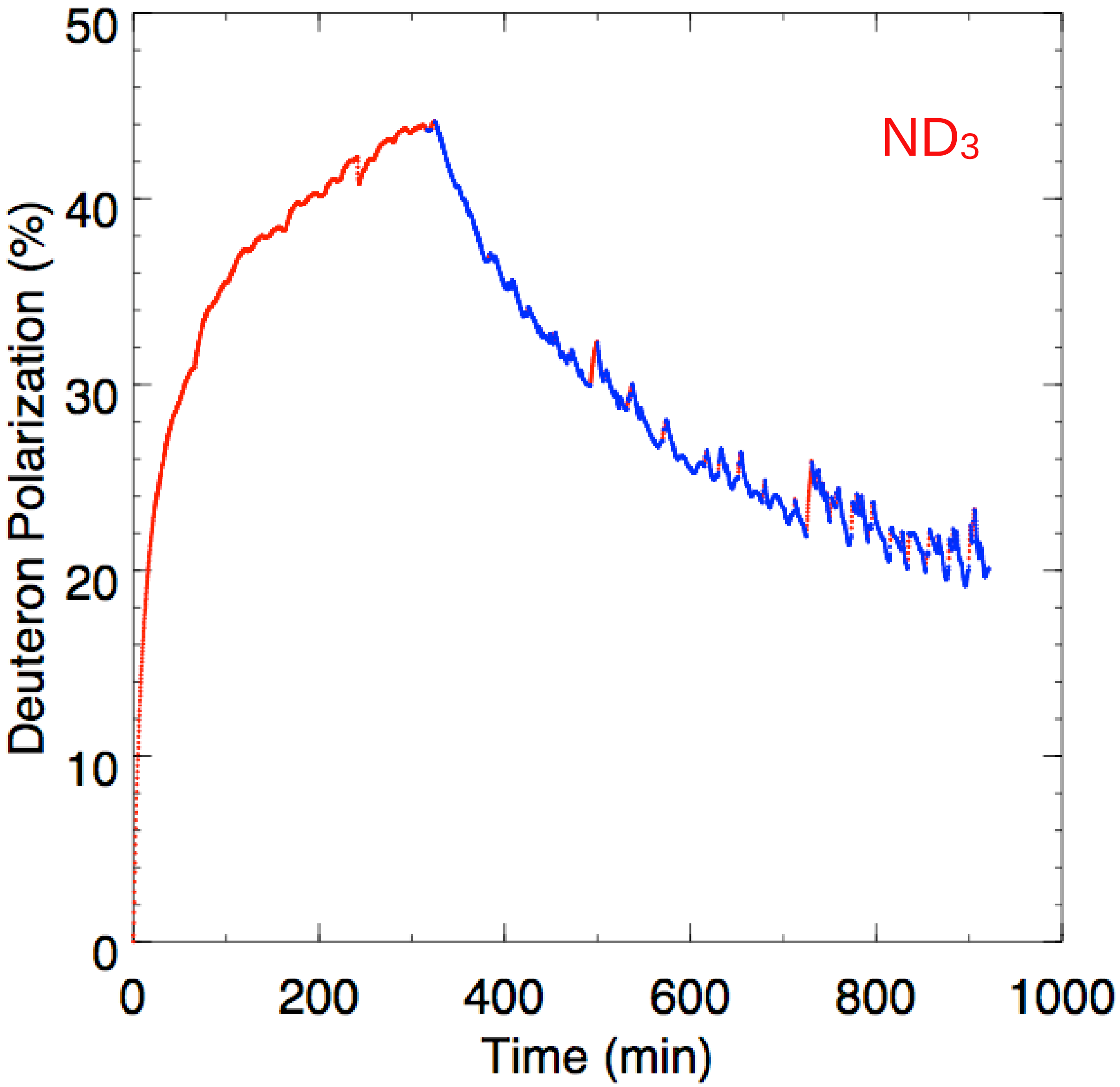
Radiation Doping V

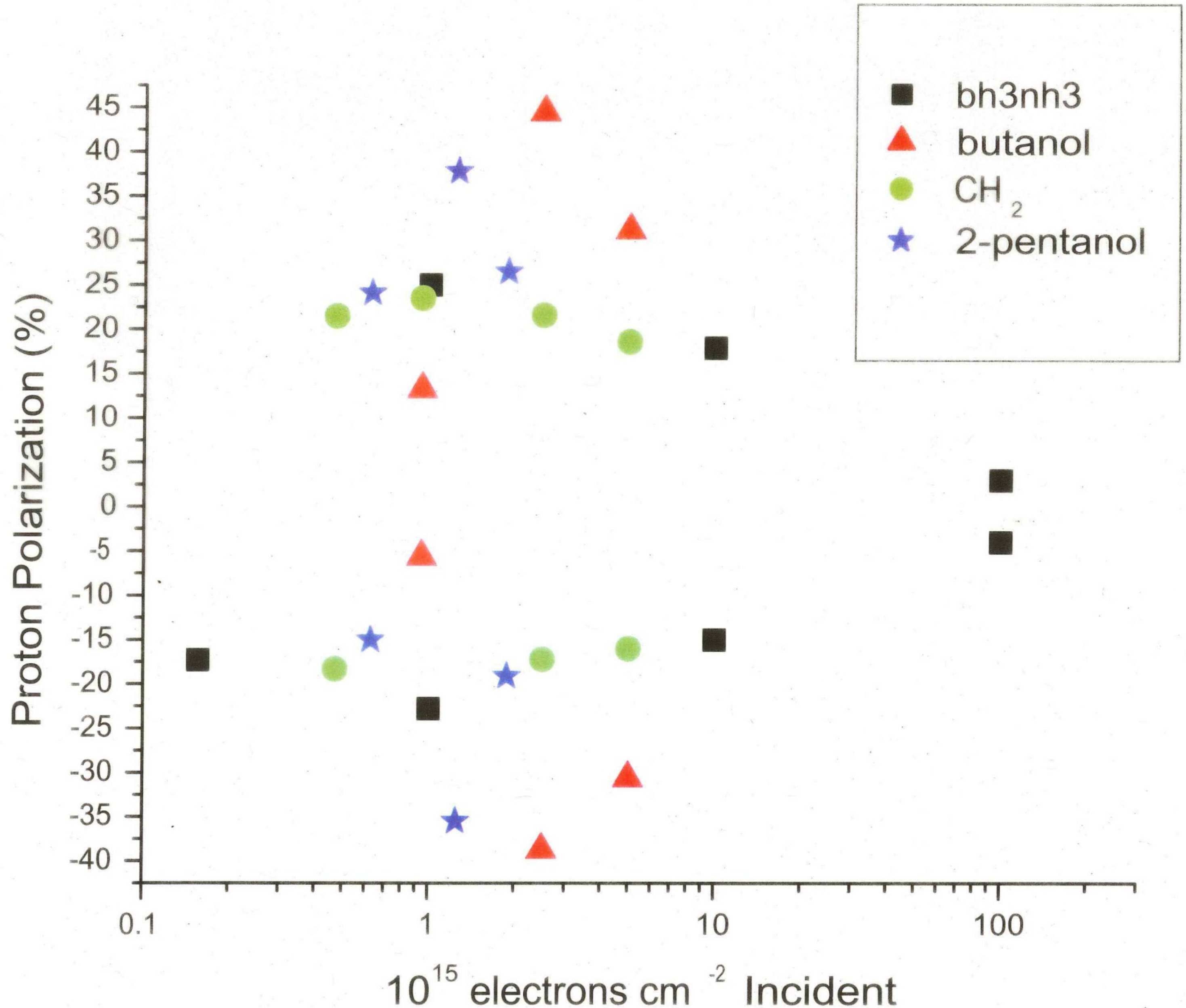
- Used in many Experiments.
- Radiation Resistance much improved over chemically doped materials, eg butanol.
- Annealing
- BNL, SLAC, JLab


100
60
20
-20
-60
-100
P_T (%)
5T/1K
2.5T/0.5K
20
40
60
80
Time (min)

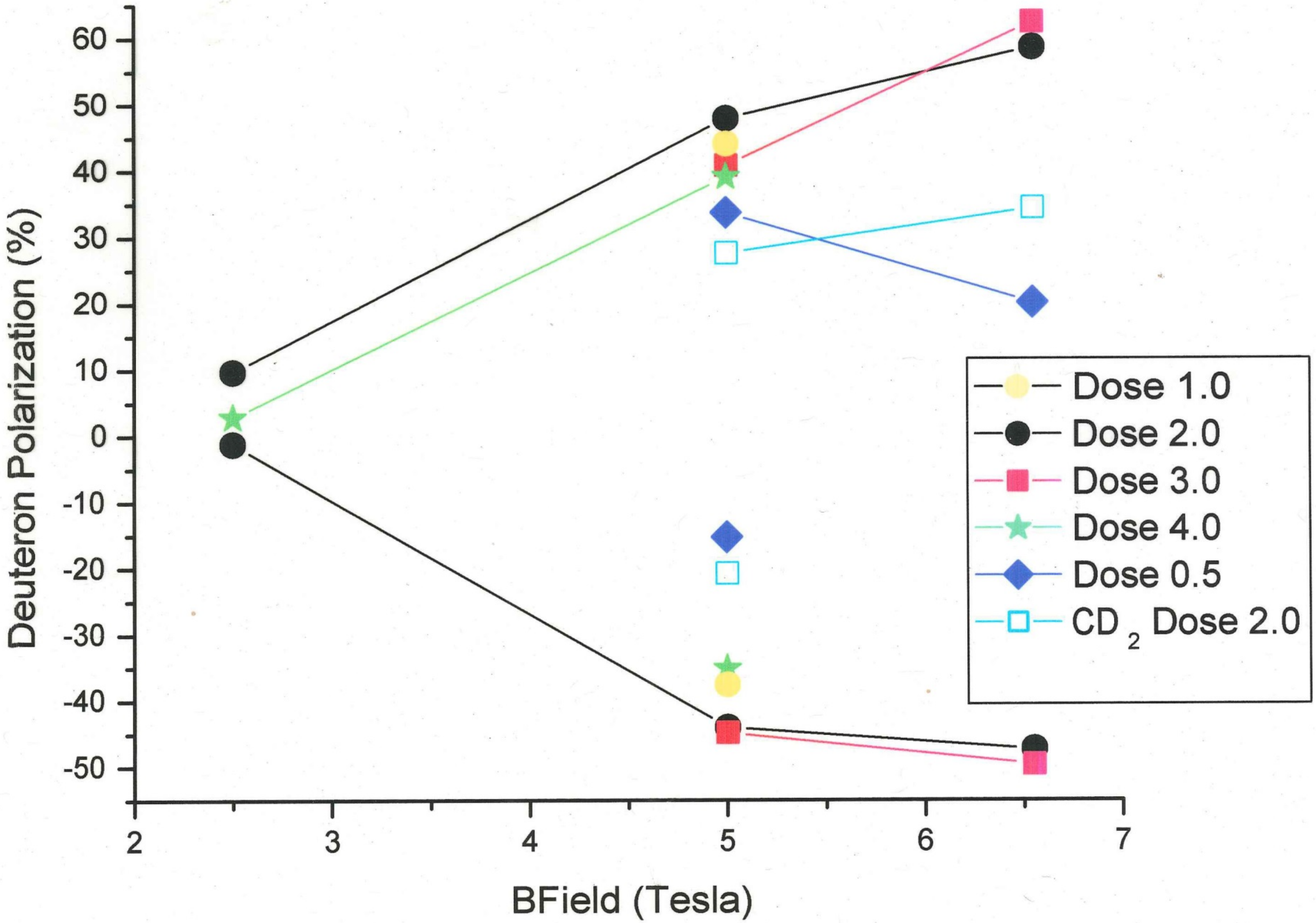
Target materials

Performance and Experience

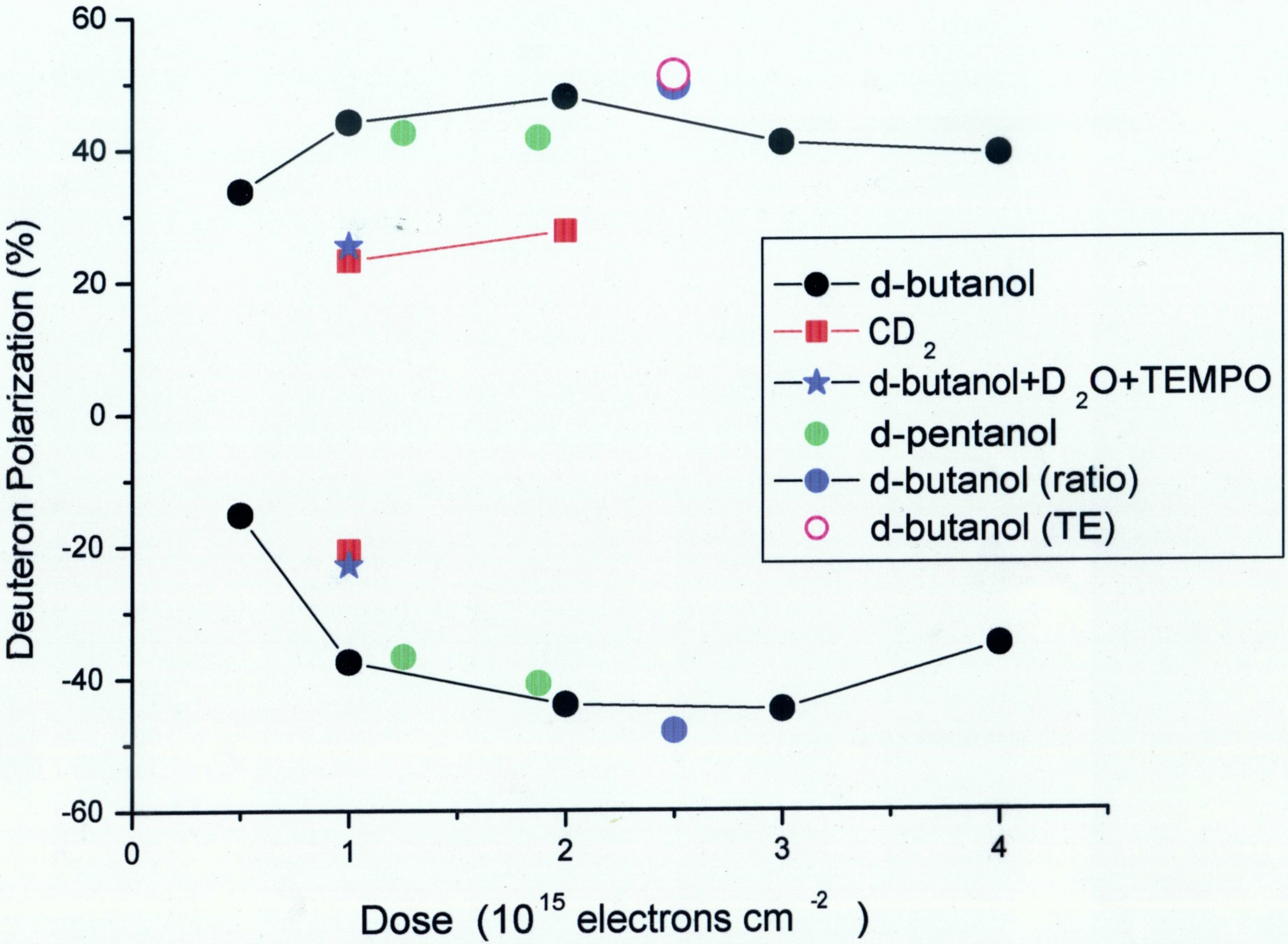




bh3nh3
butanol
CH_2
2-pentanol
Proton Polarization (%)
45
40
35
30
25
20
15
10
5
0
-5
-10
-15
-20
-25
-30
-35
-40
0.1
1
10
100
10^{15} electrons cm^{-2} Incident

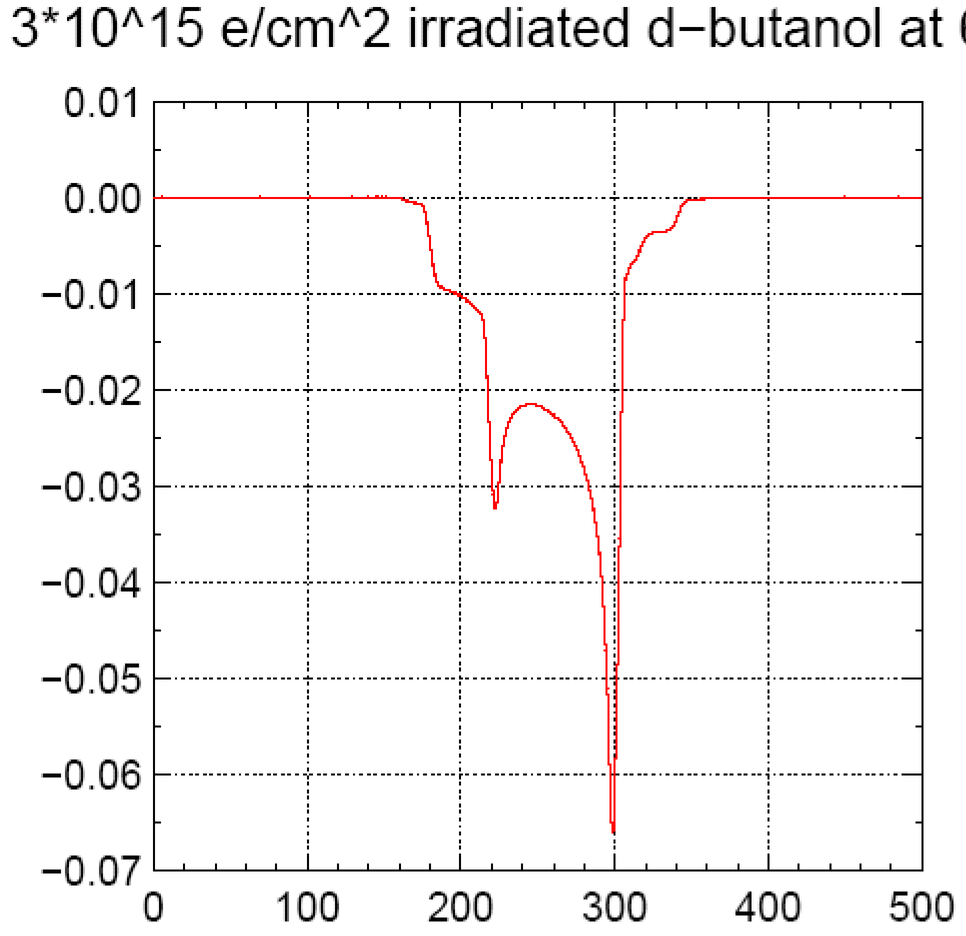


Deuteron Polarization (%)
60
50
40
30
20
10
0
-10
-20
-30
-40
-50
2
3
4
5
6
7
BField (Tesla)
Dose 1.0
Dose 2.0
Dose 3.0
Dose 4.0
Dose 0.5
CD 2 Dose 2.0



60
40
20
0
-20
-40
-60
Deuteron Polarization (%)
0
1
2
3
4
Dose (10^15 electrons cm^-2)
d-butanol
CD 2
d-butanol+D 2O+TEMPO
d-pentanol
d-butanol (ratio)
d-butanol (TE)

Deuteron Polarization of 63% at 6.5T and 1 K



In lithium hydride two types of sample were produced after irradiation, distinguished by their colour. It was noticed that the samples produced by irradiation when they were below the surface of the liquid argon were red while those just above the surface, i.e. at a slightly higher temperature were blue. The red samples either did not polarise at all or so slowly as not to be useful whereas the blue polarised very quickly. The blue colour was definitely produced by F-centres while the red colour was also probably F-centres since the EPR frequency was the same in both cases.

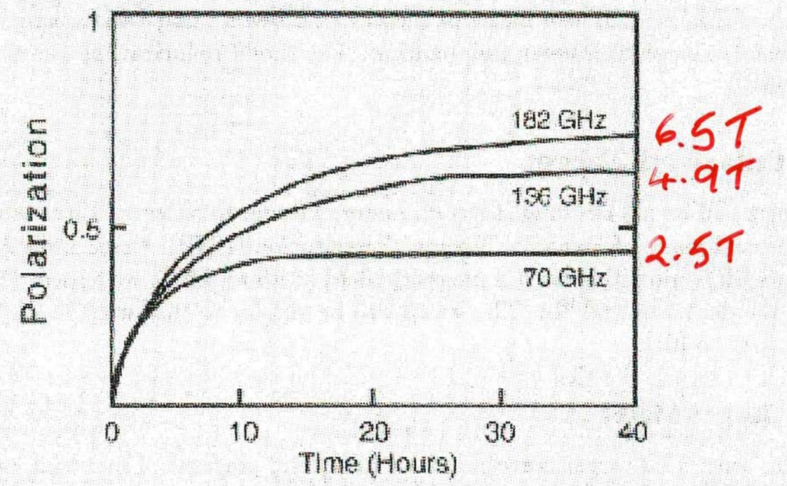
The irradiated samples of lithium fluoride were also red but, unlike the lithium hydride samples of the same colour, polarised very quickly.

The polarisations obtained in the various samples are given in the following table:

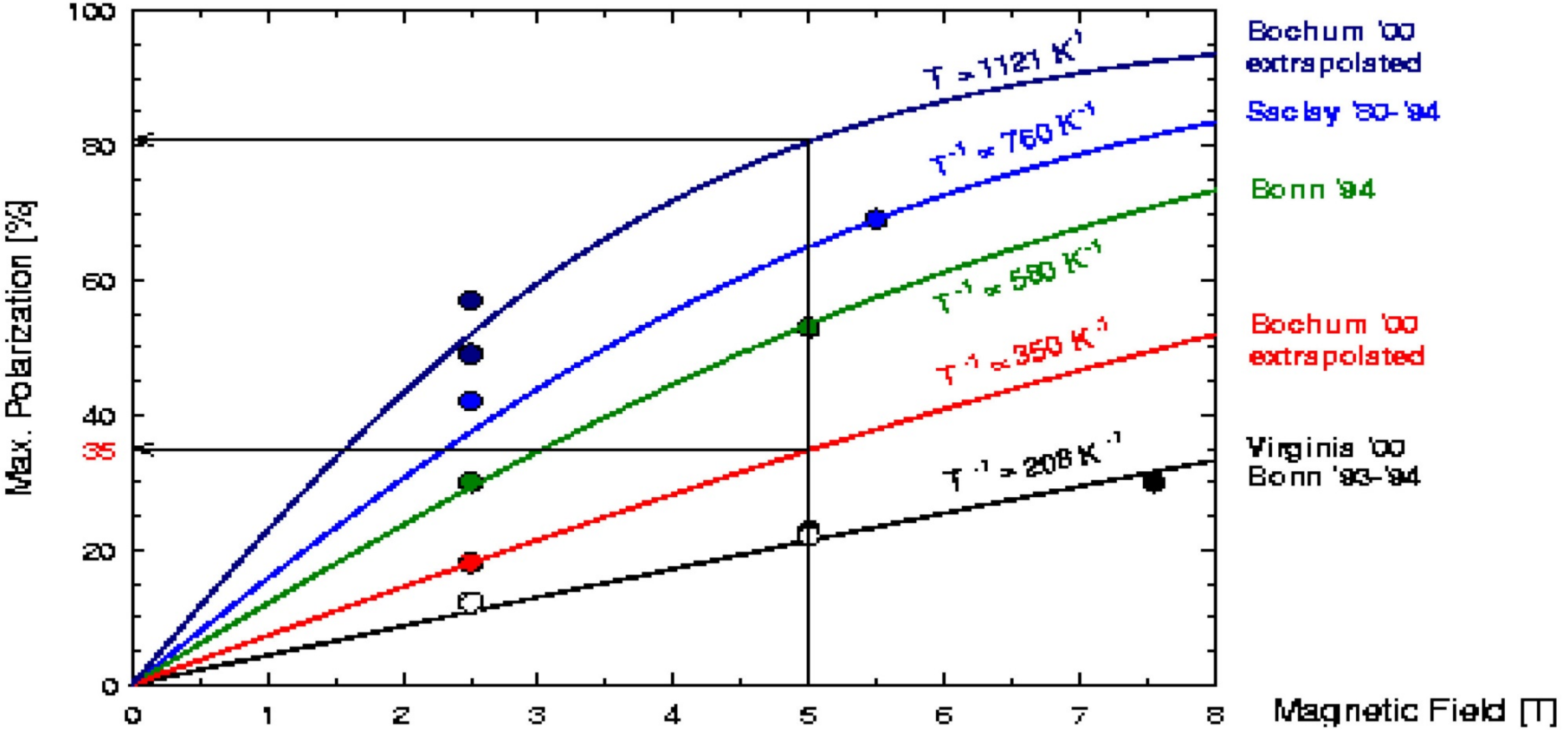
Substance	Nuclear Spins		T_{1e} (sec)	T_P (hr)	P_{MAX} (%)		Field (T)	Refrigerator
LiF	$-3/2$	$1/2$	0.1	4	60	80	5.5	He-3(0.7K)
LiH	$3/2$	$1/2$	1	40	94	99	6.5	Dil.(0.2K)
^{6}LiD	1	1	1	40	70	70	6.5	Dil.(0.2K)

In this table the values of the electron relaxation time T_{1e}, polarisation time T_p and the maximum polarisation attained P_{max} are typical values for the samples examined, except for the value of P obtained with lithium hydride which is the best value obtained. The two values given in the P_{max} column are for positive polarisations of the respective species. No polarisation was done in the negative direction.

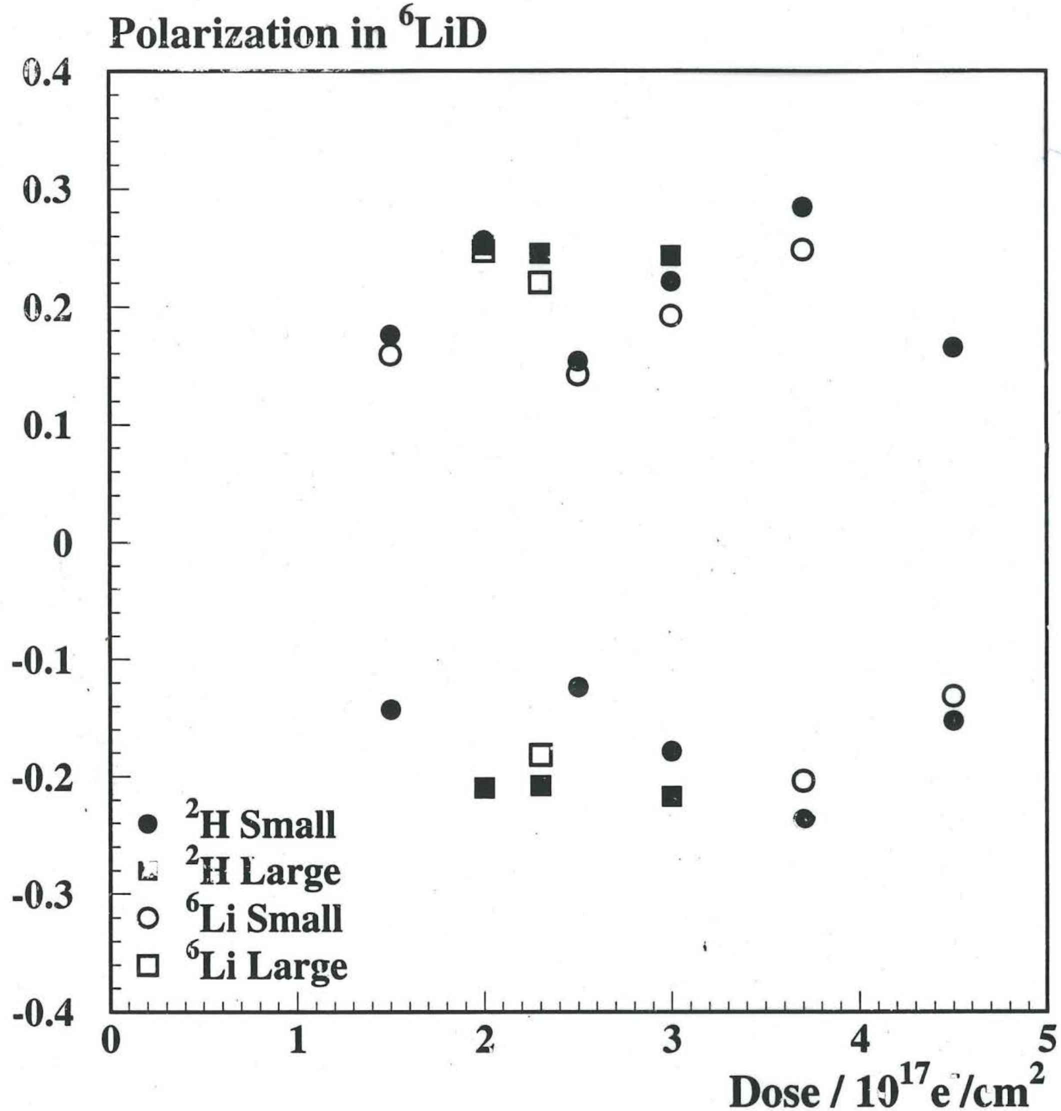
For lithium hydride T_{1e} varied from 1-200 sec which showed that the



Inverse Spin Temperatures of the ^{6}LiD World Pol. Data



$$P = \frac{4 \tanh(g_d \mu_k B / 2kT)}{3 + \tanh^2(g_d \mu_k B / 2kT)} \sim 4/3\,(g_d \mu_k B / 2kT)$$



Polarization in 6LiD
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
0
1
2
3
4
5
Dose / 10^17 e-/cm^2
2H Small
2H Large
6Li Small
6Li Large

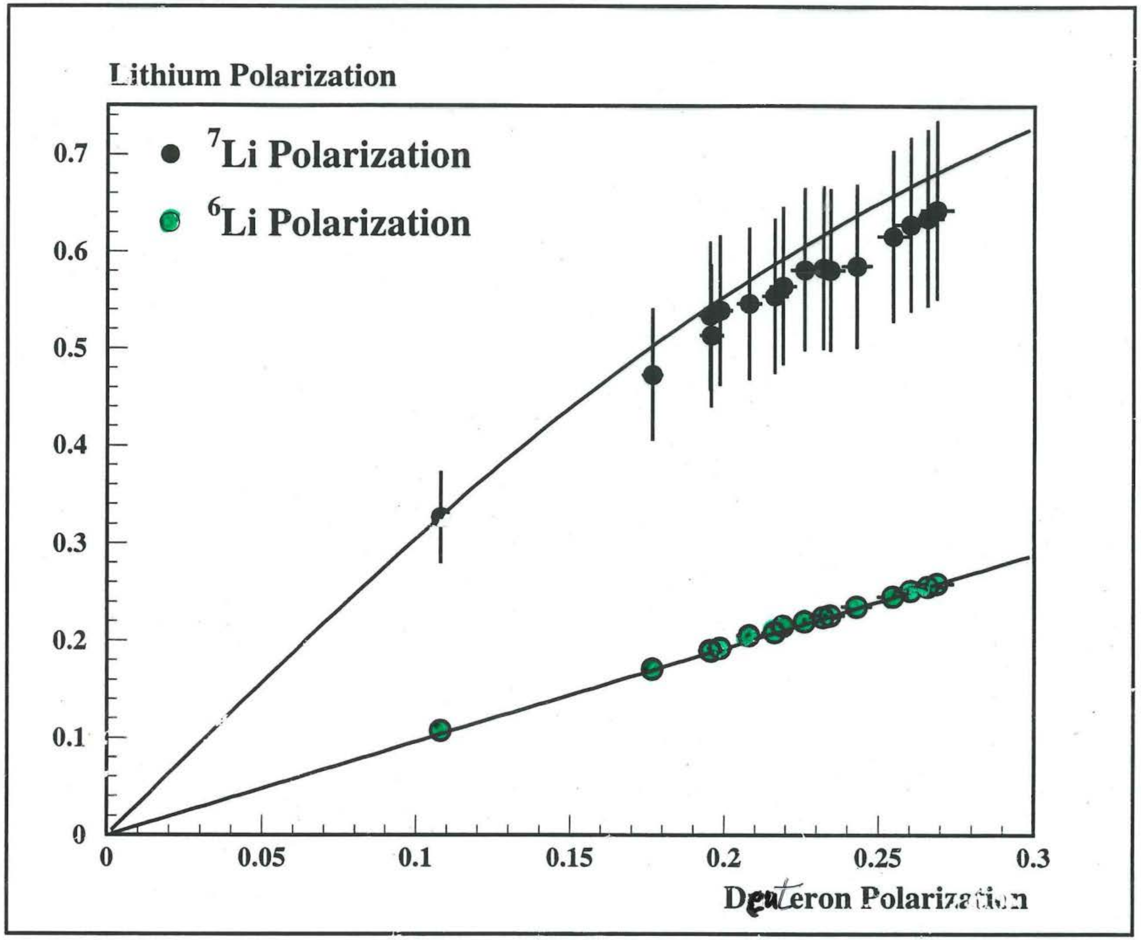
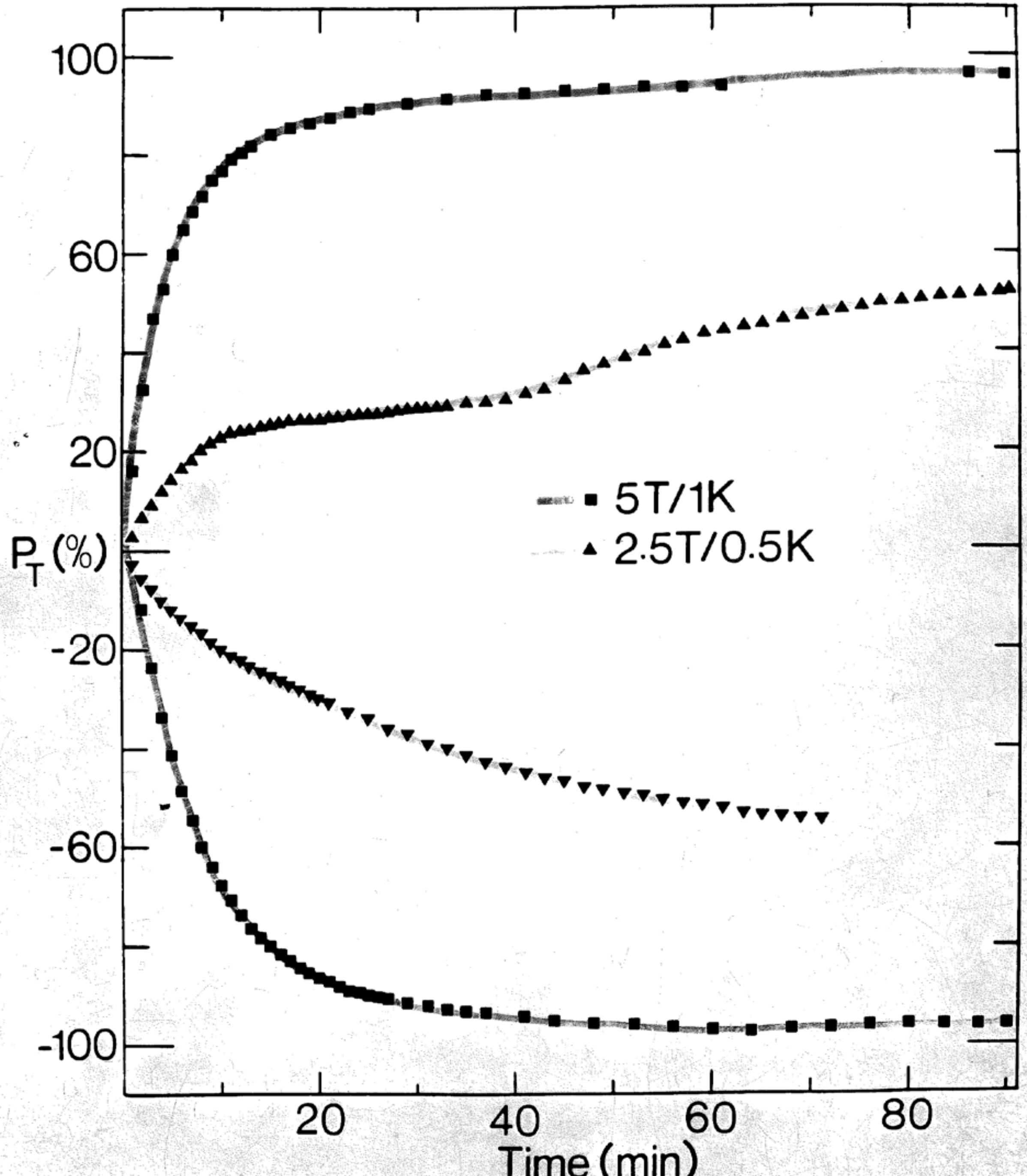


Figure 4: Measured polarization of ^{6}Li and ^{7}Li nuclei as a function of the measured deuteron polarization. The EST predictions for the lithium polarizations basing on the deuteron polarization are shown by the full lines is validated by the data.



100
60
20
-20
-60
-100
P_T (%)
5T/1K
2.5T/0.5K
20
40
60
80
Time (min)