FERMILAB-PROPOSAL-0891

CDMS II

A Search for Cold Dark Matter with Cryogenic Detectors at the Soudan Mine

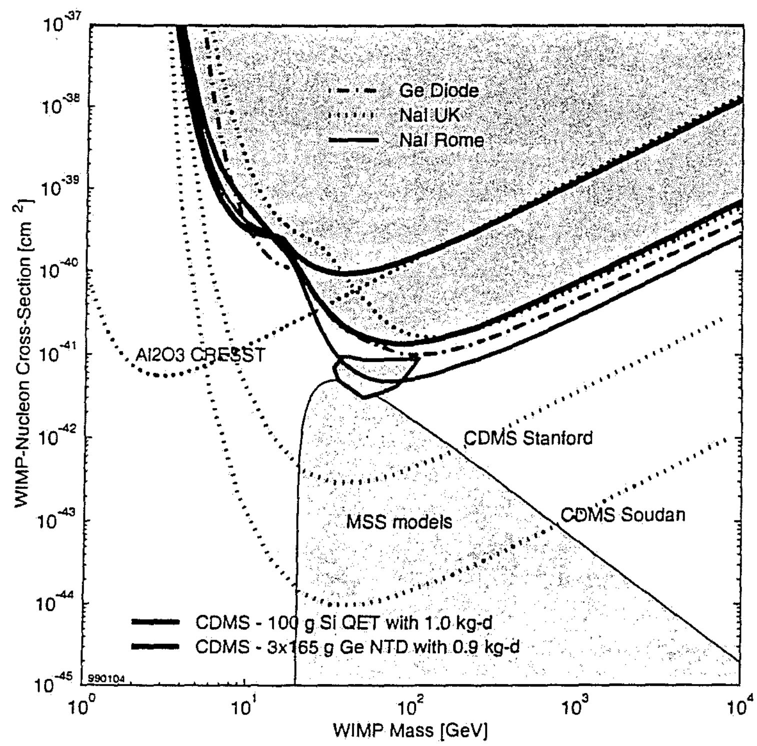
Proposal

March 1999

EXECUTIVE SUMMARY

In the last decade considerable additional evidence has been gathered supporting the hypothesis that at least 90% of the mass in the universe is dark: it does not emit or absorb any form of electromagnetic radiation. Understanding this dark matter has become one of the more central problems in astronomy and cosmology. A number of observations indicate that the predominant form of the dark matter is nonbaryonic, presumably in the form of elementary particles produced in the early universe. Weakly Interactive Massive Particles form a particularly interesting generic class of candidates as there appears to be a convergence between cosmology and particle physics. The direct observation of the interaction of WIMPs in a terrestrial detector would be of tremendous importance to particle physics and cosmology. The observed WIMPs would be particles that reflect physics beyond the Standard Model of strong and electroweak interactions, and the identification of these WIMPs would solve the central problem of dark matter and help us understand the evolution of the early universe and the formation of structure.

The figure below summarizes the situation with the current searches. All the results have been converted to WIMP-nucleon cross sections assuming scalar interactions scaling as the square of the atomic number. We have plotted the current exclusion regions of the most sensitive NaI and Ge diode experiments. The heart shaped in the middle is the region corresponding to the controversial modulation signal claimed by the DAMA group. The lower light shaded region represents the prediction of minimal super symmetry models. The shaded region at the top is currently excluded by CDMS I. The dotted lines give the goals of CRESST, CDMS I at Stanford and CDMS II in Soudan.



Because of a long development effort funded both by NSF (through the Center for Particle Astrophysics) and DOE, we now have the sensor technology to provide a great step forward in this type of search, giving the best chance for a positive result. The simultaneous measurement of the phonons and the ionization produced by the WIMP interactions provides a powerful discrimination against radioactive background, and this technique is now being utilized at Stanford, in our Cryogenic Dark Matter Search Experiment (CDMS I). We have validated our ability to design a facility producing a low-background environment, a suitable cryogenics apparatus, and data acquisition and control, and we have demonstrated our ability to search for dark matter interactions at levels more sensitive than other existing technologies. Our goal is to achieved the sensitivity labeled "CDMS Stanford" in the above figure, consistent with our measured backgrounds in the experiment. Our principal remaining limitation comes from the shallowness of the Stanford site. During this most recent run, we are measuring the expected background from muon-induced neutrons, and by the end of 1999 we will clearly be limited by that background at Stanford. The competition in Europe and Japan have already installed their experiments at deep sites, and although they are currently behind in their detector technology, we must move to a deep site to keep ahead.

It is therefore important for us to begin immediately the construction of a second generation experiment (CDMS II) at a deep site We propose to install a second cryogenic detector system deep underground in the Soudan mine in northern Minnesota, and increase the target mass from 1 kg to 5 kg of germanium and 2 kg of silicon, instrumented with an advanced detector technology. This ZIP technology (for Z-surface-rejection Ionization plus Phonon) combines our athermal phonon technology, which provides x-y positions transverse to the ionization drift direction, our improved ionization contacts, which decrease the effect of the dead layer, and our phonon pulse shape rejection of the z surfaces. Combined with an aggressive reduction of our radioactive background, this technology will result in much better use of the installed target mass than is obtained at competing experiments, less sensitivity to systematics and a much greater physics reach for our experiment.

We estimate the construction cost at $18.4M including $2.3M of contingency. Taking into account the existing base programs, this amount represents an increment of $10.9M. In addition, we are requesting an increment of $4.1M for operation for 2 years.

If we receive full approval from the funding agencies by 1 July 1999, we will have the new Ice-box installed and tested in Soudan at the end of March 2000, start physics in Soudan in October 2000 with detectors already tested at the Stanford Underground Facility. We will rapidly ramp up the installed mass with a completion of CDMS II construction in July 2002 (7 towers, 7 kg). Our current plans call for three years of operation in this configuration till July 2005. This should allow us to surpass our sensitivity goal labeled "CDMS Soudan". We will thus significantly extend the current WIMP searches, explore more decisively the Supersymmetry parameter space and perhaps discover the nature of the dark matter pervading the universe.

The CDMS II Collaboration

Case Western Reserve University
D. Akerib, A. Bolozdynya, D. Driscoll, T. Perera, R. Schnee
Fermilab
M. Crisler, R. Dixon, S. Eichblatt
Lawrence Berkeley National Laboratory
E.E.Haller, R. McDonald, R. Ross, A. Smith
NIST Boulder
J. Martinis
Princeton University
T. Shutt
Santa Clara University
B. Young
Stanford University
B. Cabrera, C. Chang, R. Clarke, T.Saab
University of California, Berkeley
R. Gaitskell, S. Golwala, J. Hellmig, M.Isaac, V. Mandic, B. Sadoulet, A. Spadafora
University of California, Santa Barbara
D. Bauer, R.Bunker, D. Caldwell, H. Nelson, A. Sonnenschein, S. Yellin
University of Colorado at Denver
M. E. Huber

Principal Investigators names are underlined.

1. Introduction:

1.1. Scientific motivation

In the last decade considerable additional evidence[1] has been gathered supporting the hypothesis that at least 90% of the mass in the universe is dark: it does not emit or absorb any form of electromagnetic radiation. Understanding this dark matter has become one of the more central problems in astronomy and cosmology. Once a subject of controversy among astronomers, its existence is now well established at a variety of scales.

The debate has shifted to measuring the amount of dark matter in the universe, studying its distribution and unraveling its nature. A central question is whether this dark matter is made of ordinary baryonic matter or is nonbaryonic. A number of cosmological observations, reviewed in section 1.2, indicate that it is probably nonbaryonic.

Searches for nonbaryonic dark matter are therefore well motivated and essential. After a brief description of other nonbaryonic dark matter searches (section 1.3), we review in section 1.4 the current direct detection efforts for Weakly Interacting Massive Particles (WIMPs).

1.2. The case for non baryonic dark matter

1.2.1. Comparison of Ω and Ω_b

Figure 1.1 summarizes the current attempts of measuring the average density Ω of the universe in units of the critical density

$$\Omega = \frac{\rho}{\rho_c} \text{ with } \rho_c = 1.88\times10^{-26}\, h^2 \text{ kg m}^{-3}$$

where h is the Hubble expansion parameter in units of 100 km/s/Mpc (h = 0.65±0.1). Ω can be determined through an inventory of the masses of the various objects in the universe, for instance using the virial velocities in galaxy clusters. These techniques can give only a lower limit of Ω, since they only measure local density inhomogeneities. Dynamic methods attempt to relate the observed velocity deviations from the Hubble flow to the density concentrations and deduce an effective Ω, which unfortunately depends on how well the number density of galaxies tracks the mass density fluctuations. Cosmological tests can also be used to directly probe the geometry, but since very distant objects are used, it is difficult to correct the measured quantities for evolution. This fundamental difficulty, which foiled the earlier attempts,[2] is still a cause for concern in the interpretation of high redshift supernovae.[3] Taken at face value, these exciting observations indicate that the universe is accelerating. They provide an approximate measurement of the difference between the vacuum energy density and matter density, $\Omega_\Lambda - \Omega_m$. The sum of these quantities, $\Omega_\Lambda + \Omega_m$, can be obtained from the acoustic ("Doppler") peak in the microwave background power spectrum indicated by the Saskatoon and CAT data. Together these observations give $\Omega_m = 0.25$ (+0.18-0.12, 95%CL interval).[4]

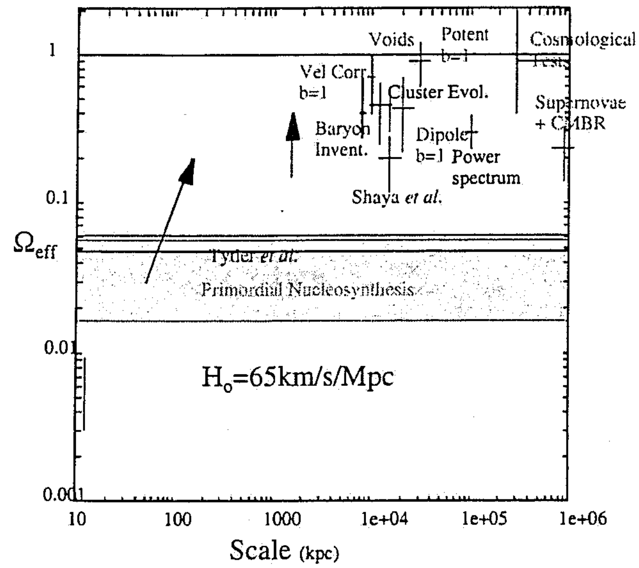


Figure 1.1: Effective Ω as a function of scale of measurement for H_0 = 65 km/s/Mpc. The bands give the Ω in baryons expected from primordial nucleosynthesis.

The combination of all observations makes a convincing case for the existence of dark matter, since the value obtained over large scales (≥ 0.3) is much greater than the contribution of stars (0.003-0.01).

The data also provides a convincing argument for the nonbaryonic nature of dark matter. The shaded band displays the narrow limits ($0.017 \leq \Omega_b \leq 0.056$) inferred from the observations of 4He, D, 3He and 7Li in the very successful standard scenario of homogeneous primordial nucleosynthesis.[5] It is clearly below large scale measurements of Ω. For the recent measurement of the D fraction in Lyman alpha systems by Tytler,[6] Ω_b may be close to the upper boundary of this band but our conclusion remains solid.

1.2.2. Formation of the large-scale structure

A second argument for nonbaryonic dark matter is based on the fact that it provides the most natural explanation of the large-scale structure of the galaxies in the universe. These cold dark matter models are based on the growth through gravitational collapse of the initial density fluctuations. Such fluctuations can be inferred from the COBE measurement of the temperature fluctuations of the cosmic microwave background. The deduced power spectrum of the adiabatic mass fluctuations on very large scales connects smoothly with the galaxy power spectrum measured at smaller scales,[7] giving strong evidence for the formation of the observed structure through gravitational collapse. The observed spectral shape is a natural consequence of models with cold nonbaryonic dark matter but cannot be explained with baryons only.

The baryons are bound up with the photons until after recombination preventing sufficient growth of the initial fluctuations to form the structure that we see today.

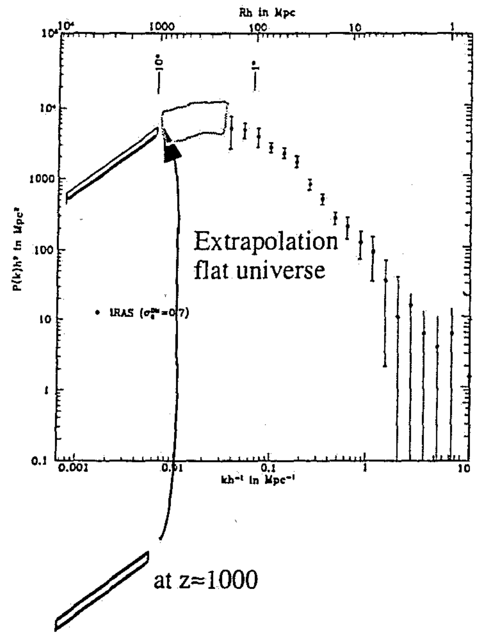


Figure 1.2: Measured power spectrum measured for IRAS galaxies and extrapolation of the COBE result assuming nonbaryonic dark matter and a flat universe (after Fisher et al., 1992). The contour in the middle gives an estimate of the power spectrum inferred from the measurement of the acoustic peak of the cosmic microwave background (after Scott et al., 1995).

Although the result is more model-dependent, the recent measurements of temperature fluctuations in the cosmic microwave background at the degree scale support this conclusion.[8] These results smoothly bridge the gap between the COBE extrapolation and the large-scale structure.

1.2.3. Inefficiency of forming compact objects

A third general argument comes from the implausibility of hiding a large amount of baryonic matter in the form of MACHOs. For instance, since the ratio of the mass in gas and stars to the total mass in clusters is about 20%, 80% of the initial gas would have to condense into invisible MACHOs. Such a large fraction is very difficult to understand within the standard scenarios of star formation. The same argument applies to galactic halos.

1.2.4. Impact of the MACHO observations

The most important result from the microlensing searches for Massive Compact Halo Objects (MACHO) is the unambiguous exclusion of brown dwarfs between 10^{-7} and 0.08 solar masses as a significant fraction of our halo (See Figure 1.3). No short duration events are observed.

However a few long duration events are observed towards the Large Magellanic Cloud and these have sometimes been interpreted as evidence that our halo is composed mostly of MACHOs around 0.5 solar masses. This conclusion cannot unambiguously be reached because the lensing duration is a degenerate function of the mass, distance and transverse velocity of the lens. We simply do know where the lenses responsible for the observed events are. In fact, the measured location of the two observed double lenses are in the host galaxies, and the low event rate towards the Small Magellanic Cloud cast considerable doubt about the MACHOs forming the majority of our halo (Figure 1.3).[9] Moreover a halo made up of 0.5 solar mass objects would not be dark unless they are primordial black holes.

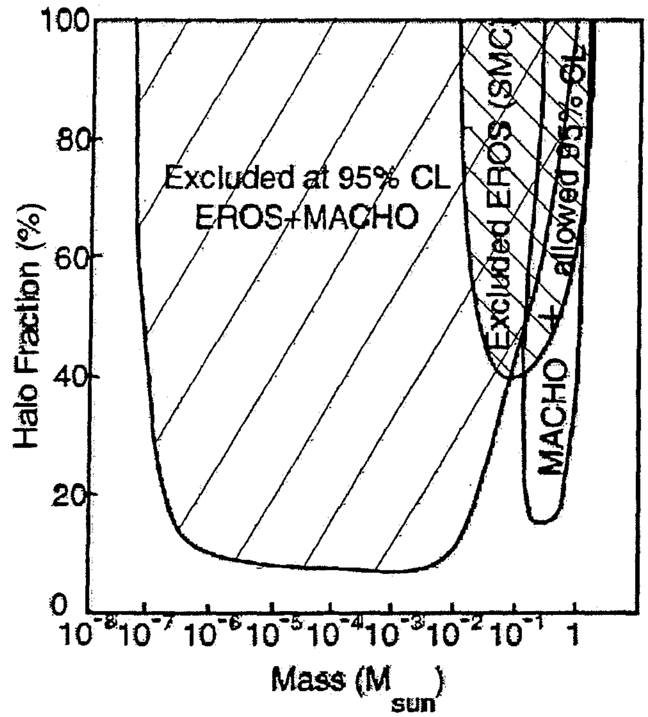


Figure 1.3: Excluded region (at 95% confidence level) of the halo fraction in MACHOs as a function of their mass in a standard halo model. The ellipse on the right is the 95% confidence level range allowed by the 2 year data of the MACHO collaboration. We display also the region excluded recently by the EROS observations of SMC[10]. Note that large MACHO fractions are disfavored!

Finally, if a cold nonbaryonic component exists, it is difficult to prevent it from accreting into galactic halos. Even in the presence of some MACHOs in the halos, it would constitute a significant portion of the halo and be present locally for detection. In fact, taking into account all kinematic information on the galaxy and the combined MACHO observations, the most likely density for a nonbaryonic component is close[11] to the canonical 0.3 GeV/cm^3 as inferred from the rotation curves of our galaxy.[12]

1.3. Non-baryonic dark matter searches

In conclusion, it is very difficult to construct a self-consistent cosmology without cold nonbaryonic dark matter, and the hypothesis that MACHOs constitutes a large fraction of our galactic halo is disfavored by the newest observations. Thus, searches for nonbaryonic dark matter have the highest scientific priority!

A large number of candidates have been proposed over the years for such a nonbaryonic component. They range from shadow universes existing in some string models, strange quark nuggets formed at a first-order quark-hadron phase transition,[13] Charged Massive Particles (CHAMPs),[14] and a long list of usually massive particles with very weak interactions. We should probably search first for particles that would also solve major questions in particle physics. Using this criterion, three candidates appear particularly well motivated: axions, neutrinos and weakly interactive massive particles.

Axion experiments are reaching cosmologically interesting sensitivity[15] at least for one generic type of axion (hadronic models[16]). However, the current technology[17] allows the coverage of only one decade of mass out of the three decades still allowed.

Neutrinos of mass much smaller than 2 MeV/c fall in the generic category of particles which have been in thermal equilibrium in the early universe and would decoupled when they were relativistic, forming hot dark matter. Their current number density is approximately equal to that of the photons in the universe. The relic particle density is therefore directly related to its mass, and a neutrino species of 25 eV would give an Ω of the order of unity.[18] Note that even though they appear to have a small mass[19], neutrinos alone cannot lead to the observed large-scale structure, as fluctuations on scales greater than 40 h^{-1} Mpc are erased by the streaming of hot dark matter. They have to be mixed in with cold nonbaryonic dark matter[20] or seeded by topological defects. Moreover, because of phase space constraints, they cannot explain the dark matter halos observed around dwarf galaxies.[21]

A third generic class of candidates constitutes particles that were in thermal equilibrium in the early universe and decoupled when they were non-relativistic. In this case, it can be shown that their present density is inversely proportional to their annihilation rate.[22] For these particles to have the critical density, this rate has to be roughly the value expected for weak interactions (if they have masses in the GeV/c^2 to TeV/c^2 range). This may be a precious hint that physics at the W and Z^o scale is important for the problem of dark matter. Inversely, physics at the W and Z^o scale leads naturally to particles whose relic density is close to the critical density. In order to stabilize the mass of the vector intermediate bosons, one is led to assume the existence of new families of particles such as supersymmetry in the 100 GeV mass range. In particular, the lightest supersymmetric particle could well constitute the dark matter. This class of particles is usually called Weakly Interactive Massive Particles (WIMPs).

The most direct method to detect these WIMPs is by elastic scattering on a suitable target in the laboratory[23]. Elastic WIMP scattering would produce a roughly exponential spectrum with a mean energy dependent on their mass. The hope is to identify such a contribution in the differential energy spectrum measured by an ultra-low background detector, or at least to exclude cross sections that would lead to differential rates larger than observation.

Before reviewing the direct detection of WIMPs, let us note that several methods have been proposed for detecting WIMPs through their annihilation products. [24] They of course assume dark matter exists in the form of both particles and antiparticles (or is self-conjugate) as otherwise no annihilation would occur. The detection of gamma ray lines from their annihilation into two photons[25] will require the resolution of the next generation of satellites and may be masked by the galactic background, especially if the dark matter density does not strongly peak at the galactic center. The first measurements of the energy spectra of antiprotons and anti-electrons offered tantalizing hints of dark matter particle annihilations,[26]but they turned out to be inaccurate. The interpretation of such spectra would in any case be unclear because of the uncertainty in the confinement time of these antiparticles in the halo of our galaxy.

A much more promising method[27,28,29,30,31] is to search for high energy neutrinos coming from the centers of the earth and the sun. Since they can lose energy by elastic interactions, some dark matter particles would be captured by these objects, settle in their centers and annihilate with each other producing, among other products, high energy neutrinos which can then be detected by underground detectors, especially through the muons produced by their interactions in the rock. The current generation of such detectors (Baksan, MACRO and SuperKamiokande) of roughly 1000 m^2 area, put a limit of the order of 10^{-14} muon/cm^2/s above 3 GeV. Such results exclude any charge-symmetric Dirac neutrino or scalar sneutrino and put limits on supersymmetric models which are generally in agreement with but less restrictive than direct detection experiments. Fairly model-independent arguments[32] show that such an advantage of direct detection should be maintained for the next generation of detectors (cryogenic WIMP searches and 10^4 m^2 detectors such as AMANDA II), especially for scalar interactions. However, the very large neutrino detectors currently being studied (10^6 m^2) may be more sensitive than direct searches for large-mass WIMPs.[33]

1.4. Direct searches for Weakly Interactive Massive Particle

We now review the status of the various efforts to detect WIMP dark matter.

1.4.1. Experimental challenges

In specific models such as supersymmetry, the knowledge of the order of magnitude of the annihilation cross section allows an estimation of their elastic scattering, taking into account the coherence over the nucleus. Typically, if scalar (or "spin independent") couplings dominate, the interaction rate of WIMPs from the halo is expected to be of the order of a few events per kilogram of target per week for large nuclei like germanium. Note that these rates depend on the local dark matter density in the halo and are insensitive to the global value of Ω_m.We display in Figure 1.4, as the lower shaded region, the range of cross sections (rescaled to a proton target) expected[34] in grand unified theory inspired supersymmetric models, where scalar interactions usually dominate.

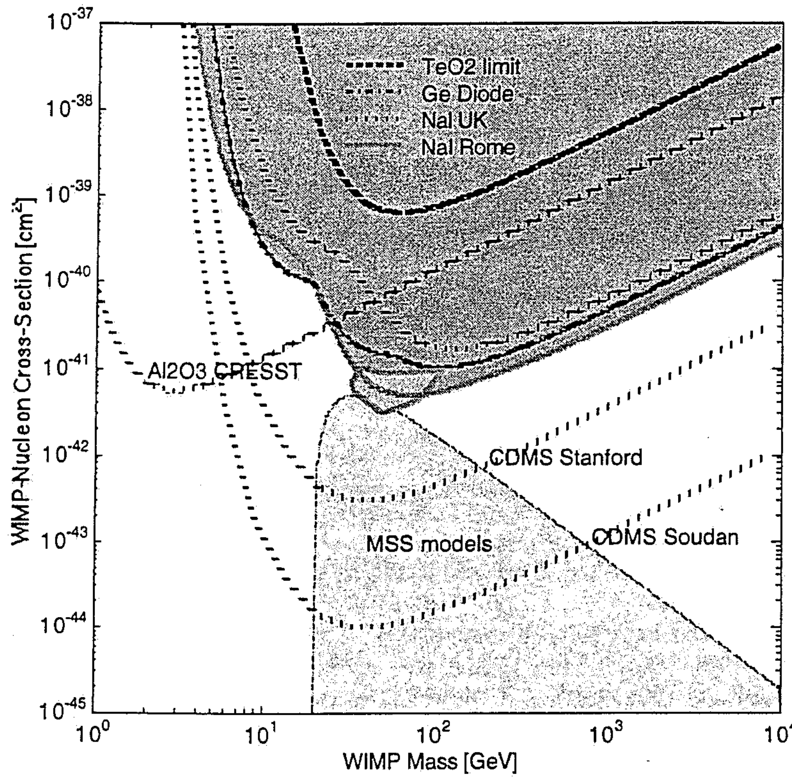


Figure 1.4: Current achieved limits for spin independent couplings as a function of the WIMP mass. This figure includes the results of the Rome[35] NaI, UK[36] NaI, Milan[37] TeO_2, Modane[38] Al_2O_3, and the Ge diode experiments: PNL-USC,[39] Oroville,[40] Neuchâtel-Caltech,[41] Heidelberg-Moscow,[42] and IGEX.[43] All the results have been converted to WIMP-nucleon cross sections assuming scalar interactions scaling as the square of the atomic number. The shaded region at the top is excluded by these experiments. The heart shaped in the middle is the region corresponding to the modulation signal claimed by Bernabei et al.[44] The shaded region at the bottom is the rate predicted by minimal supersymmetric models including the constraints from LEP and CDF. We also indicate the sensitivity projections of the current CRESST experiment, CDMS I at Stanford, and CDMS II in Soudan with the specifications given in section 4.

The upper shaded regions summarize the current limits achieved with state of the art techniques for low radioactivity background. These limits barely skirt the supersymmetric region, although relaxing the unification assumptions enlarges it somewhat.[45]

Unfortunately, the expected rates can be very small for specific combinations of parameters where axial ("spin dependent") couplings dominate. In this case, the interaction takes place with the spin of the nucleus, which limits the number of possible targets, and the current limits are very far above the supersymmetry expectation.[34]

It is therefore essential to construct experiments with very low radioactive backgrounds or, even better, with active background rejection. The main tool for this purpose is to use the fact that WIMP interactions produce nuclear recoils, while the radioactive background is dominated by electron recoils (if neutrons are eliminated).

A second challenge faced by the experimentalist comes from the fact that the energy deposition is quite small, typically 10 keV for the mass range of interest. For detectors based only on ionization or scintillation light, this difficulty is compounded by the fact that the nuclear recoils are much less efficient in ionizing or giving light than electrons of the same energy. This increases the recoil energy threshold of such detectors, and one should be careful to distinguish between true and "electron-equivalent" energy, which may differ by a factor three (Ge) to twelve (I and Xe).

A third challenge is to find convincing signatures linking detected events to particles in the halo of the galaxy. The best one would be the measurement of the direction of the scattered nucleus,[46] a very difficult task. Short of this directionality signature, it is in principle possible to look for a change in the event rate and the spectrum of energy deposition with the time of the year.[47]

1.4.2. Prominent direct search strategies

In spite of these experimental challenges, low expected rates and low energy depositions, a number of experimental teams are actively attempting to directly detect WIMPs. A number of interesting attempts have been made to use mica which integrates for billions of years,[48] superheated microdots[49] which should be only sensitive to nuclear recoil, and low pressure time projection chambers which could give the directionality.[50] However, the main developments occurred along three main experimental strategies.

1. A first approach is to attempt to decrease the radioactive background as much as possible. Germanium is the detector of choice as it is very pure, and the first limits[39,40,41] were obtained by decreasing the threshold of double beta experiments. The most impressive results have been obtained by the Heidelberg-Moscow group[42] with a background of 0.05 events/kg/day/electron-equivalent-keV around 20 keV (equivalent electron energy). This impressive performance comes from a careful screening of surrounding material, the large size of their crystal (2.5 kg), and signal shape discrimination. The IGEX and Baksan-USC-PNL[51] collaborations have achieved somewhat worse levels (0.25 events /kg/day/electron-equivalent-keV), but reached lower thresholds. The current combined exclusion plot is given in Fig. 1.4. GENIUS, an ambitious proposal[52] to immerse one ton of germanium detectors in an ultra-pure liquid nitrogen bath, pushes this strategy to the extreme.

However, this approach is fundamentally limited by the absence of discrimination against the radioactive background. Not only can this background not be partially rejected, but it also cannot be measured independently of the signal (except by multiple scattering) and subtracted. Once the background level is measured with sufficient statistical accuracy, the sensitivity of the experiment does not improve with exposure. In contrast, the combination of an active background rejection and subtraction allows a sensitivity increase as the square root of the target mass and the running time, until the subtraction becomes limited by systematics.[53] Note that with large setups like GENIUS, some discrimination will be obtained against gamma's through multiple scattering, but it is difficult to arrange self vetoing with a rejection efficiency greater than 95%.

2. A second approach has been to use large scintillators with pulse shape discrimination of nuclear and electronic recoils. The technique is simple and large masses can be assembled to search for modulation effects. The most impressive result so far has been obtained with NaI. The NaI groups[35,36] have published limits that claim to be slightly better than those obtained with conventional germanium detectors. However, these limits remain controversial, as they may not fully take into account systematics in the efficiency close to the threshold or in the rejection power from pulse shape discrimination. In any case, because sodium has a spin, these experiments so far give the best limits for spin dependent couplings. The Rome group has recently announced[44] a nearly three σ detection of a signal using the annual modulation expected for a WIMP spectrum (heart-shaped region in Fig. 1.4). This modulation signal represents less than 1% of the observed background and it is not yet clear that the systematics have been controlled at the required level. Overall, it is unlikely that NaI could make significant additional

progress, as the small number of photoelectrons at the energies of interest and the lack of power of the pulse shape discrimination make it highly susceptible to systematics.

3. Therefore, more powerful discrimination methods need to be devised. Liquid xenon with simultaneous measurement of scintillation and ionization is a promising approach, albeit with relatively high thresholds, and not enough development so far to fully judge its potential. In contrast, the active development of novel "cryogenic" detectors based on the detection of phonons produced by particle interactions is beginning to bear fruit. In spite of the complexity of the very low temperature operation, four large setups are currently being routinely operated (Milano,[37] CDMS,[54] CRESST[55] and EDELWEISS[56]), with total detector mass ranging from 70 g to 7 kg.

For dark matter searches, this technology appears to have three advantages:

• It can lead to a much smaller threshold, as phonons measure the total energy of nuclear recoil without any loss. Already the performance of thermal phonon detectors in the laboratory exceeds that of ionization detectors. We[57] are now routinely getting a resolution of better than 900 eV and 450 eV FWHM in phonons and ionization respectively with 165 g detectors. The CRESST group has also demonstrated a FWHM of 235 eV at 1.5 keV in a 250 g crystal of sapphire. Four of these detectors are now installed in the CRESST experiment, which hopes to obtain without discrimination the limits shown in Fig. 1.4. We[58] have recently shown that it is even possible to detect athermal phonons after very few bounces on the surface and get similar baseline resolution (1 keV).

• With the simultaneous measurement[59] of ionization and phonons in crystals of germanium or silicon, it is possible to distinguish between nuclear recoils and electron recoils. This approach is used by both the CDMS and the EDELWEISS collaborations. CDMS has demonstrated greater than 99% rejection with thermal and athermal phonon plus ionization technology down to 20 keV recoil energy (Figure 1.5 a and b). This allows us to reach at a shallower site an effective gamma contamination better than Heidelberg-Moscow, and with much lower thresholds. Unfortunately, as often in such situations, a new background was uncovered: soft electrons incident on the surface suffer from ionization losses in a micron-thick dead layer and partially simulate nuclear recoils (Figure 1.5 c). This dead layer is due to back diffusion of the carriers and can be decreased by suitable modification of the contacts. Combining these improvements with better shielding, we have recently been able to drastically reduce this problem (see section 2.2) and hope to reach at our present Stanford site the limit displayed in Fig. 1.4. The lower line indicates the expected sensitivity of the CDMS II experiment in the Soudan mine. A similar technique based on the detection of phonons and scintillation light has been recently demonstrated by CRESST in a 2.6 g crystal of $CaWO_4$.

• A third advantage of phonon-mediated detectors is the greater amount of information obtained about very rare events. Already the simultaneous measurement of phonons and ionization gives two pieces of information instead of one, and allows a more efficient rejection of microphonics and spurious instrumental effects. The detailed measurement of out-of-equilibrium phonons is even more promising.

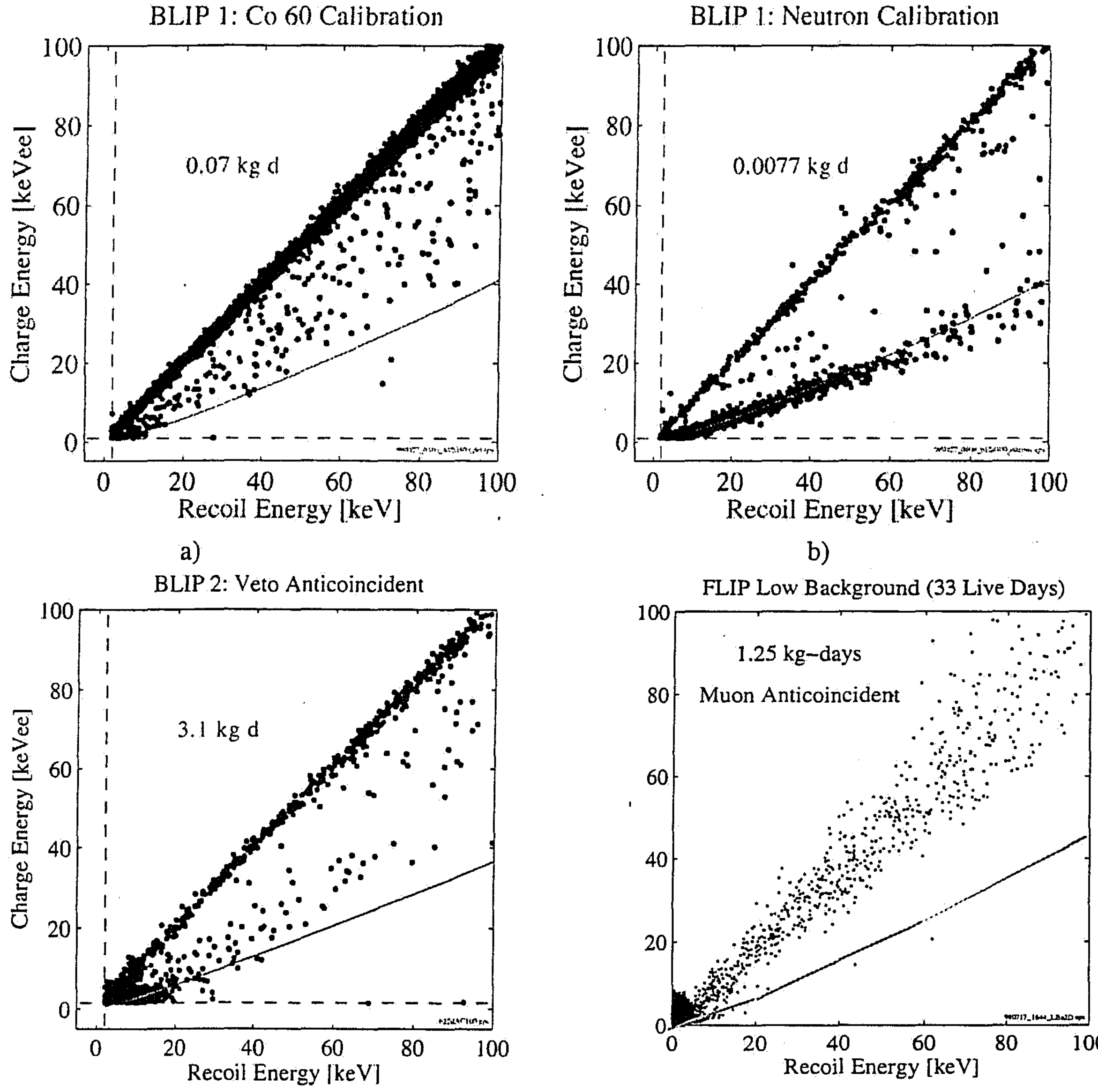


Figure 1.5: CDMS scatter plots of the ionization measurement versus the recoil energy measurement for (a, b, c) a 165 g Ge detector with thermal phonon readout (BLIP), and (d) a 100 g Si detector with athermal phonon sensing (FLIP) obtained at the Stanford Underground Facility Icebox. The ionization measurements are normalized to electron equivalent energy. Panels (a) and (b) show results of calibration runs with a ^{60}Co photon source (a) and a ^{252}Cf source producing neutrons (and photons). The line represents a fit to the region of nuclear recoil events. Panels (c) and (d) are obtained in low background running conditions. Note in (a) and (c) the soft electron component, intermediate between the diagonal photon line and the nuclear recoil line. In panel (d), after an athermal phonon signal rise time cut, only two events are left in the nuclear recoil region.

CDMS has recently demonstrated that geometrical fiducial cuts can be imposed using the phonon information (see Sec. 2) and that the problematic surface electrons can be eliminated by a phonon rise time cut (Figure 5 d). In the long run, athermal phonons may allow a determination of the directionality for isotopically pure targets.

1.5. The need for CDMS II

In conclusion, Dark Matter is one of the central problems of astronomy and cosmology and deciphering its nature has the highest scientific priority. A number of observations indicate that the predominant form of the dark matter is non baryonic, presumably in the form of elementary particles produced in the early universe. Weakly Interactive Massive Particles form a particularly interesting generic class of candidates as there appears to be a convergence between cosmology and particle physics. The direct observation of the interaction of WIMPs in a terrestrial detector would be of tremendous importance to particle physics and cosmology. The observed WIMPs would be particles that reflect physics beyond the Standard Model of strong and electroweak interactions, and the identification of these WIMPs would solve the central problem of dark matter and help us understand the evolution of the early universe and the formation of structure.

Because of a long development effort funded both by NSF (through the Center for Particle Astrophysics) and DOE, we now have the sensor technology to provide a great step forward in this type of search, giving the best chance for a positive result. The simultaneous measurement of the phonons and the ionization produced by the WIMP interactions provides a powerful discrimination against radioactive background. This technology is now being operated at Stanford, in our Cryogenic Dark Matter Search Experiment (CDMS I), and we have validated our ability to design a facility producing a low-background environment, a suitable cryogenics apparatus, and data acquisition and control. We have demonstrated our capability to search for dark matter interactions at levels more sensitive than other existing technologies. Our goal is to achieved the sensitivity labeled "CDMS Stanford" in the above figure, consistent with our measured backgrounds in the experiment. Our principal remaining limitation comes from the shallowness of the Stanford site. During this most recent run, we are measuring the expected background from muon-induced neutrons, and by the end of 1999 we will clearly be limited by that background at Stanford. The competition in Europe (notably the CRESST[55] and EDELWEISS[56] cryogenic experiments) and Japan have already installed their experiments at deep sites, and although they are currently behind in their detector technology, we must move to a deep site to keep ahead.

We therefore propose to begin immediately the construction of a second generation experiment (CDMS II) at a deep site, the Soudan mine in northern Minnesota. Deploying 7 kg of germanium and silicon over three years of operation should allow us to surpass our sensitivity goal labeled "CDMS Soudan" in Fig. 1.4.

2. Results from Previous NSF and DOE Funding

2.1. CDMS Detector Development

For over a decade we have been developing methods to measure simultaneously the phonons and the ionization produced in particle interactions. We briefly describe the results of such a development, discussing the ionization and phonon measurements, before turning to results from the CDMS I experiments where these technologies are being applied in the search for Weakly Interacting Massive Particles.

2.1.1. Low Temperature Ionization Measurement

The low-temperature ionization measurement[62] is in some respects similar to conventional ionization measurements in 77 K detectors; however, the detailed physics is quite different. At higher temperatures, charges from impurities are thermally excited, and this free charge must be removed by application of a depletion voltage on the order of 1 kV for cm thick devices. At low temperatures (< 1 K), however, all charges are "frozen out". Thus the applied field need only be strong enough to prevent trapping or recombination of charges, and no rectifying contacts are necessary. It is important to use small fields (< a few volts) to collect the ionization, because the energy acquired by carriers when they drift in the electric field (Luke-Neganov effect) goes into phonons and can confuse the separation of electron and nuclear recoils, if it becomes large compared to the original energy of the interaction, Germanium and silicon are materials of choice because they are available with high purity: we typically use germanium with n_a-n_d = 5x10^{10}cm^{-3}, and the highest purity silicon, which is about 100 times worse. Thus, full charge collection can be obtained with fields as low as 0.1 V/cm in Ge, while in Si fields of 3 V/cm are needed to achieve ≈90% efficient charge collection. Until recently, we had mostly used implanted contacts for Ge and Shottky barriers for silicon.

Combined with the phonon measurements described below, this ionization technology already has achieved impressive discrimination between nuclear and electron recoils. Figure 2.1 gives results obtained with 165 g Ge and 100 g Si detectors in the Stanford Underground Facility.[63] . We have an effective gamma background rejection of the order of 99.5% or better above 20 keV for both target materials.

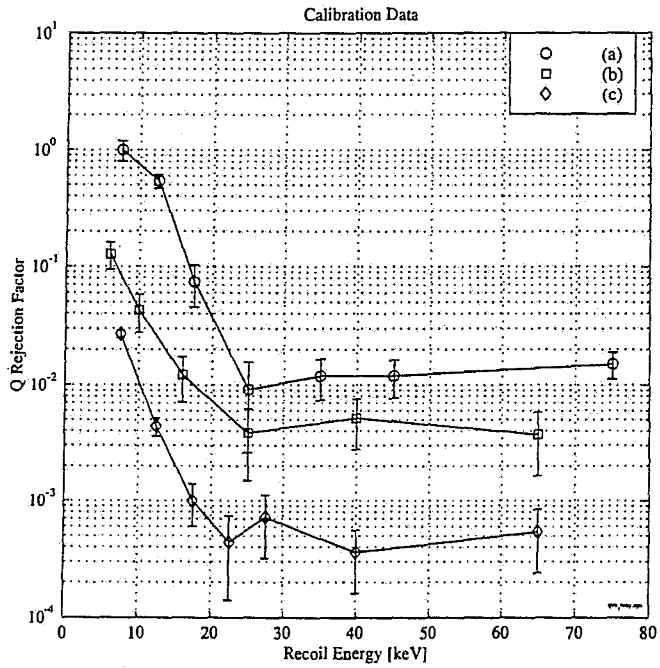


Figure 2.1: Q effective rejection factors for (a) discrimination of betas from nuclear recoils in a 100g Si detector, (c) discrimination of gammas from nuclear recoils in the same 100g Si detector (also see Figure 2.3a in Section 2.1.2), and (b) effective discrimination of calibration gammas from nuclear recoil in a 165g Ge (some coincident soft electrons are included in the sample). In order to take into account both the contamination β from remaining electron recoils, and the efficiency α for retaining nuclear recoils, Q is defined[64] as $Q = \beta(1-\beta)/(\alpha-\beta)^2$. The final statistical accuracy after subtraction is proportional to $\sqrt{Q}$, and for the Si detector the separate beta (a) and gamma (c) rejection factors must be combined through a weighted average reflecting the background rates of betas versus gammas.

The main limitation of this ionization measurement comes from a "dead layer" where the ionization is only partially collected because of the back diffusion.[65] Although this dead layer is only 20 µm thick and represents less than 0.5% of the detector volume, it strongly affects the measurement of electrons incident on the surface of the detector since their practical range is only a few microns. The effect is more pronounced in germanium but is also present in silicon. This dead layer is responsible for the degradation of the gamma rejection at low energy (electrons are ejected from the material surrounding the detector during the gamma calibration, see e.g., Fig. 1.5a and 2.1.(curve b)). Even more importantly, it makes the experiment vulnerable to surface low-energy beta backgrounds: their incomplete ionization measurement moves many of these events into the nuclear recoil band (see Fig 1.5c).

Over the last year, we have been able to minimize this problem by improving the electrode design. We have shown that back-diffusing carriers are efficiently reflected by the larger energy gap of an amorphous Si layer deposited over the Ge surface (with an Al Shottky barrier contact on top of the Si layer). In Fig 2.2, we demonstrate the improvement over the older ion implanted design used in previous detectors. We plot the ionization yield obtained with a ^{14}C β source as a function of deposited energy and compare it with the yield expected for electron and nuclear recoils. Fig 2.2a shows the results with our implanted electrodes: the betas significantly overlap the nuclear recoil band and dominate the background once gamma discrimination has been used. The results obtained with amorphous Si electrodes are shown in Fig 2.2b where the beta band has been raised significantly. Now only a small portion at low energy is confused with the nuclear recoils. As we discuss below, this amorphous silicon layer also has the advantage of providing an excellent etch stop, which allows us to utilize the photolithographic processes developed for silicon on germanium. Its slight conductivity is also useful since it allows us to decrease the effect of the surface metal patterns on the electric field inside the crystal. This amorphous silicon layer is part of our baseline ZIP design for CDMS II.

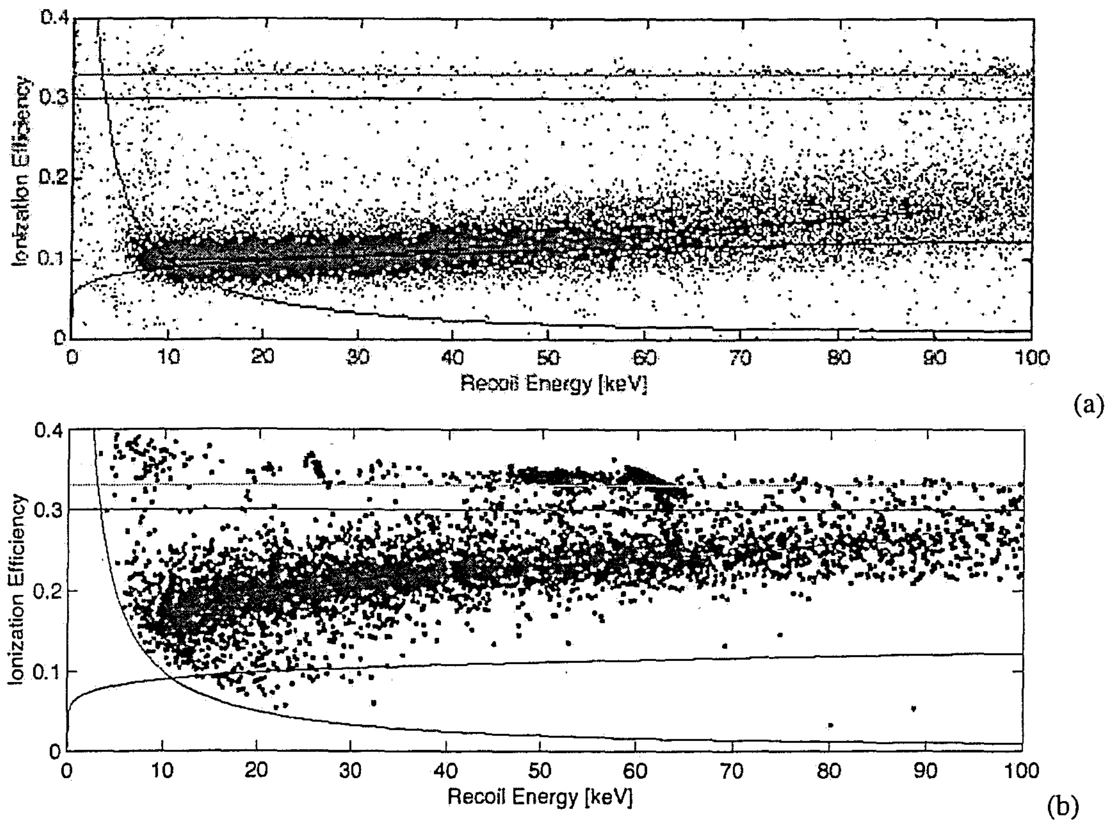


Figure 2.2: Ionization yield versus recoil energy for events from a ^{14}C β source (a) for the original ion implanted electrodes and (b) for the new 200 Å amorphous Si and Al Shottky contact. In each plot, the dotted line indicates the position of gammas, the line curving up to the left is the detector threshold, and the line curving down to the left indicates the position of the nuclear recoil band.

2.1.2. Phonon Measurement

For the phonon measurement, we have achieved the performance necessary to search for Weakly Interacting Massive Particle with two different technologies.

The first technology primarily measures quasi-thermal phonons with neutron-transmutation-doped germanium (NTD) eutectically bound to the crystals. We now have six 1.2-cm-thick 6-cm-diameter 165-g cylindrical crystals of high-purity germanium (nearly 1 kg) operating continuously in the Stanford Underground Facility for CDMS I. We have nicknamed these detectors "BLIPs" (Berkeley Large

Ionization Phonons sensors). The resulting energy measurement has a FWHM resolution of 900 eV at 10 keV (650 eV intrinsic). The use of two NTDs permits the rejection of events that originate in an NTD, which unfortunately have non-negligible radioactivity. Although quite sensitive and mature, this technique has the drawback of being very slow (5ms pulse rise time and 50 ms decay time), making it difficult to use a phonon trigger in anti-coincidence with a veto counter. Moreover, by waiting for phonons to nearly thermalize we loose the information contained in the initial phonon wave-front (position, energy spectrum).

These limitations prompted us to choose for CDMS II (the detector design is described in detail in Section 4.1), a technique which is primarily sensitive to the athermal phonons generated in the interactions, before significant thermalization has occurred. Our athermal phonon detectors are based on the coupling of large area superconducting films with superconducting transition-edge sensors[66]. In this QET (Quasiparticle-trap-assisted Electrothermal-feedback Transition-edge sensor) technology, athermal phonons generated by an energy deposition in the Si or Ge target are absorbed in the thin film superconducting aluminum pads covering most of one of the target's surfaces. The electronic excitations generated in the superconductor, called quasiparticles, diffuse through the pads on the time scale of tens of microseconds to 'traps' formed by the overlap of Al and W films. Here the potential energy of the quasiparticles is efficiently transferred to heat in the electron system of the tungsten. The W films are patterned into transition edge sensors which measure the energy absorbed. The sensor temperature is maintained within the superconducting-to-normal transition by the Joule heating via negative electrothermal feedback associated with the voltage bias.[67] The intrinsic stability of the voltage bias allows every one of the several hundred parallel W meanders to be self-biased near its most sensitive temperature bias point, even if there is a gradient in the W film's transition temperature across the surface of the target. The Si or Ge crystal can be maintained at a lower temperature than the transition temperature of the W meanders (approximately 80 mK) because of the relatively weak coupling between the electron and phonon systems at these temperatures. This electrothermal feedback also plays a role during a pulse: the increase in the W's electron temperature raises its resistance and results in a drop in the Joule power dissipated. The integral of the corresponding drop in current multiplied by the bias voltage gives the energy absorbed by the W. Because only the electron system of the W film heats up, and the heat is removed by electrothermal feedback, the W/Al sensors are intrinsically very fast, with pulse rise times of ~5 μs and fall times of ~60 μs.

A 100 g silicon detector using this QET phonon sensing method and Shottky ionization contacts (a technology that we nicknamed "FLIP", for "Fast large Ionization + Phonons sensors") has been run for 6 months. It has fully demonstrated the power of athermal phonon sensing. The baseline phonon resolution of <1 keV FWHM is well adapted to the WIMP mass region we want to explore. The timing resolution not only allows us to use the phonon pulse as a trigger but also to locate the event in the crystal transverse to the drift direction. Even more importantly, the pulse rise time allows us to reject events close to the crystal surface, providing us with an additional tool to fight the soft electron background. The power of this discrimination technique is shown in Figure 2.3a, where we plot the risetime versus the charge over phonon yield (ionization yield) for events around 60 keV generated by beta, gamma and neutron calibration sources. The ionization yield discriminates nuclear recoils versus electron recoils using the reduced electron-hole production of nuclear recoils. By utilizing the additional information from the phonon risetime, the figure shows that there are three clear regions in this two dimensional plot where the bulk-volume gammas (upper right), the surface electrons (lower left) and the nuclear recoils (upper left) lie. Figure 2.3b shows the charge versus phonon plot for events of all energies with rise times longer than 6.25 μsec and clearly shows the discrimination between the gamma and nuclear recoil bands. Thus, the risetime cut has been shown to discriminate surface electron events from nuclear recoil events with a rejection efficiency of more than 95% above 15 keV, at a cost of a 50% efficiency.

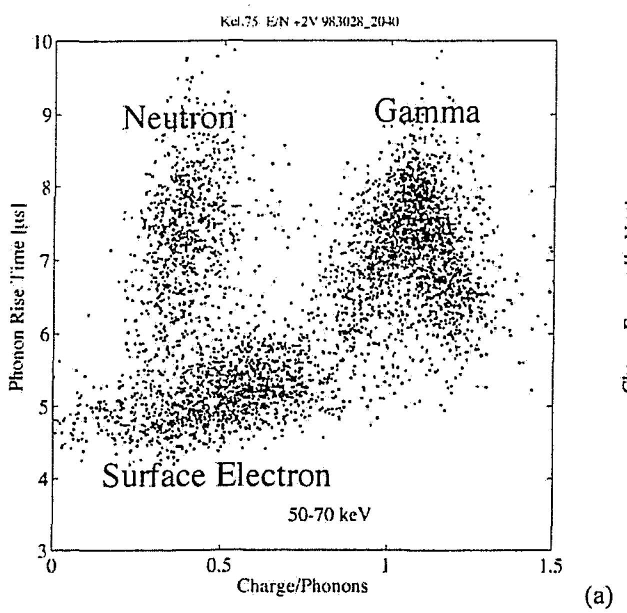


Figure 2.3: Beta, gamma and neutron source calibration run showing (a) discrimination of nuclear recoils from surface electrons using risetime (also Figure 2.1 curve a) and discrimination of gammas from nuclear recoils using the charge to phonon ratio (also Figure 2.1 curve c), (b) charge versus phonon for long risetime events (>6.25 µs).

A second major achievement of the last year has been our implementation of the QET technology on germanium. Our strategy has been to use the amorphous Si layer described above as an etch stop so that the same processing that was successfully developed for Si phonons sensors can be utilized on Ge. Last summer we completed the fabrication of test devices and we obtained test data in the fall and winter. We have demonstrated that the athermal phonons are not affected by the thin amorphous layer and that the energy collected by the W sensors remains the same. The main differences between the Ge and Si detectors are caused by the stronger isotope scattering in Ge versus Si and by the slower speed of sound in Ge versus Si. Because of these effects, the collection of the phonon energy is four times slower in Ge versus Si. Fig 2.4 shows data demonstrating the operation of a Ge ZIP test detector. On the left side, Fig 2.4a shows the response of the detector to gammas from an internal ^{241}Am source which emits 60 keV gammas and an external ^{60}Co source with gamma lines at 122 and 136 keV. On the right side, Fig 2.4b shows the response to a PuBe neutron source. The neutron source contributes higher energy gammas, as does the internal ^{241}Am gamma source. These data demonstrate the successful operation of the QET Ge devices and this combination of phonon sensor and electrode technologies form the basis for the baseline Ge and Si ZIPs to be fabricated and operated in CDMS-II (Sec 4.1).

2.2. CDMS I Experiment

The goals of the CDMS I experiment were to deploy BLIP and FLIP detectors in a low-background environment to search for Weakly Interactive Massive Particles. Our experimental apparatus, operational since 1996, consists of specialized low-activity detector-housing modules ("towers"), which allow us to run both BLIP and FLIP detectors. The towers are mounted in a shielded cryostat made from a set of nested copper cans. The cans are cooled by conduction through a set of concentric horizontal tubes extending from the side of a dilution refrigerator. An external, 15-cm-thick lead shield reduces the flux of background photons by a factor of ~1000, while 25 cm of polyethylene shielding reduces the flux of neutrons by a factor of ~100. Samples of all materials internal to the shield have been carefully screened in a low-background HPGe counting facility for radio contaminants. Further shielding close to the detectors is achieved with 1 cm of ancient, ultra-low-activity lead, which has a low concentration of ^{210}Pb, a beta-emitter. The 17 meters water-equivalent overburden of the shallow site at Stanford University (SUF) is enough to eliminate the hadronic cosmic-ray flux. However, the overburden reduces the cosmic-ray muon

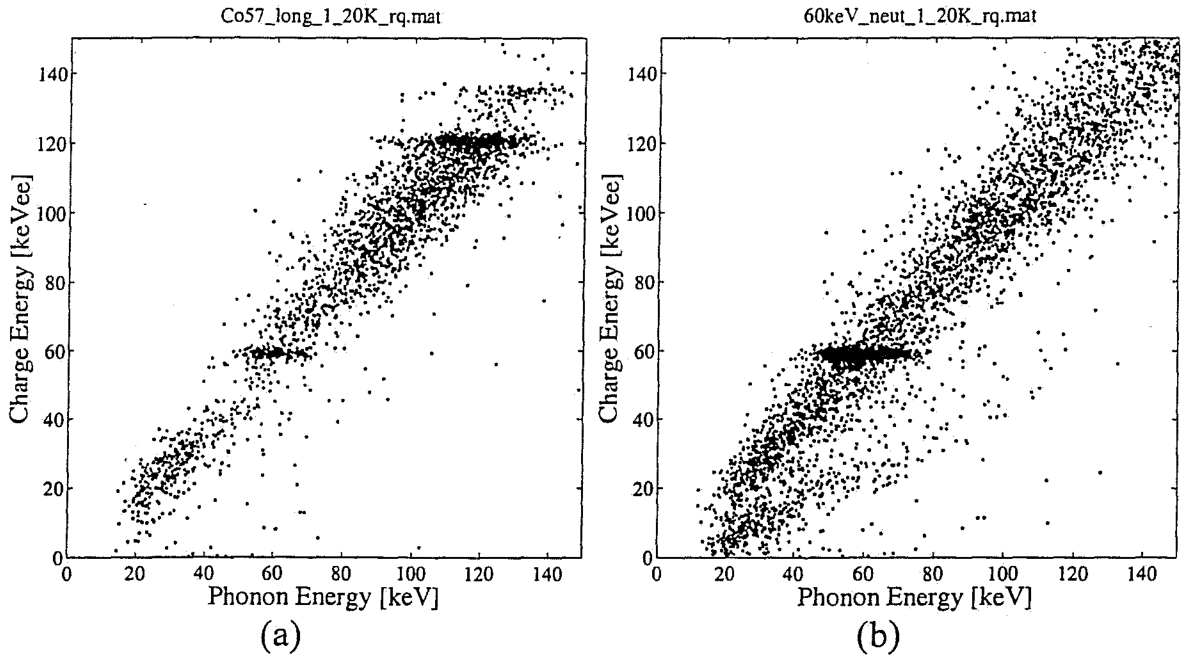


Figure 2.4: Operation of Ge ZIP test device showing (a) phonon energy versus charge using an internal 241Am source and an external 60Co source, (b) phonon energy versus charge for PuBe neutron source with internal ^{241}Am.

flux by a factor of only 5, requiring further rejection of backgrounds with a four pi plastic-scintillator muon veto. After improvements made in March 1998, this veto has consistently been over 99.99% efficient at rejecting muons passing through the detectors.

Several data runs have been taken in the low-background facility over the past three years, indicating that the experiment can successfully operate over months-long time-scales with consistent energy resolutions. A major goal of our recent effort has been to decrease the soft surface electrons that have limited our sensitivity. We had four tools at our disposal: a) decrease the beta contamination, b) maximize the self shielding of the detectors, c) improve the ionization contacts, d) use the information contained in the athermal phonons. Most significant are the recent results from a 100 g Si QET detector (run in spring-summer 1998) which demonstrated the power of the athermal phonon sensors and the results from an array of six 165 g Ge NTD detectors (currently running) which showed the effectiveness of the first three approaches. We describe in turn these two sets of results, which clearly demonstrate that we have broken through the beta background barrier.

2.2.1. 100 g Silicon QET detector

The QET detector was operated continuously at Stanford for a period of several months accumulating 33 total live days of data. An electronics threshold of ~3 keV was maintained throughout the course of background running, although the charge noise and phonon noise removed the effectiveness of the surface-electron cut below ~15 keV, causing a large increase in backgrounds at low energies. The measured photon rate coincident with muons passing through the active veto was ~200 events/kg/keV/day, while the neutron rate was ~10 events/kg/keV/day at 30 keV, consistent with the rate predicted by Monte Carlo simulations (see Fig. 2.5a). The raw gamma event rate anti-coincident with muons was lower than the coincident rate by more than a factor of 40 (see Fig. 2.5b). Applying a charge-yield cut reveals a large surface beta background. These events have significantly faster rise times (4-5 μs) than bulk events (7-8 μs) and clearly do not represent an unexpected neutron background. Two events above 20 keV survive a 6.25-μs phonon rise-time cut, consistent with the fraction of surface events expected to survive such a cut, and only slightly higher than the ~0.5 events expected from the background of neutrons produced outside the muon veto with sufficient energy to penetrate our neutron shield. The WIMP sensitivity for this data run are shown in Fig 2.6 and show the intrinsic insensitivity of Si versus Ge as a target material for WIMPs. The same spectrum in a Ge crystal of the same volume would produce a limit more than ten times lower. We operate both materials, because Si has a higher sensitivity for neutrons, and because the detection of a WIMP signal would be much more convincing with the relative rates between Si and Ge.

2.2.2. 165 g Ge NTD detectors

While the QET technology was transferred to Ge, we began running an array of four Ge NTD detectors with the improved amorphous Si electrodes (in addition to two existing ones with implanted contacts). Although without any surface-event rejection capability, these detectors benefit from an improved cleanliness regimen and clean passive Ge shielding, a close-packed design to maximize detector self-shielding and improved contacts (three of the four tools at our disposal). Preliminary results from the beginning of the current data run, 7 live days collected last fall, are shown in Figure 2.5. The measured single-scatter photon rate coincident with muons passing through the active veto was ~15 events/kg/keV/day, three times lower than the multiple-scatter rate, showing the advantages of self-shielding detectors. The single-scatter neutron rate was ~2 events/kg/keV/day at 20 keV.

The raw photon event rate anti-coincident with muons was lower than the coincident rate by about a factor of 10, except at low energies where the 10.4-keV Ga X-rays dominate (see Fig. 2.5d). Although some low-ionization-yield surface events appear on the detectors' outer electrodes, very few are on the inner electrodes, and all but one of these events are in the topmost detector. This rate is lower than that of previous CDMS NTD detectors by at least a factor of four, and lower than the rate for the Si QET (before risetime cut) by more than an order of magnitude. This rate is used to calculate the preliminary upper limits on the WIMP-nucleon cross section, shown in Figure 2.6. Although statistics are low, these limits are competitive with those of other experiments with much larger exposures. For instance, we have no event in the 3 bottom detectors above the 27 keV threshold of Heidelberg-Moscow, while with their background, which is the best published in the field, and our running time so far, we would expect 1 event. If subsequent running does not unveil another background contribution, our lower threshold will allow us to unequivocally test the DAMA claim within the next few months. For future data runs planned to start in the fall 1999, combining the surface-event discrimination of the QET technology with the improved background-reducing techniques used for the current NTD detectors should allow the CDMS I experiment to meet its site-limited sensitivity goals shown in Figure 1.4.

2.3. CfPA and ARI Funding.

The NSF support to CDMS I has come mainly through the Center for Particle Astrophysics at UC Berkeley, which in turn has made a subaward to CWRU for contributions to the work described above. NSF support to CDMS II has come through the ARI program in a joint award to Stanford and UC Berkeley, and a CAREER award to CWRU. The Stanford-Berkeley award provided funds for the purchase of the dilution refrigerator for the Soudan Icebox, as well as funding for related instrumentation. A recent test at the manufacturer, Oxford Instruments, indicates that the refrigerator has passed its performance specifications. The copper for the CDMS II Icebox has been purchased early enough to be stored underground and to allow for the abatement of cosmogenic activity. The Icebox is currently being fabricated at FNAL. The CWRU Career award has provided funding for a research associate whose primary activity to date has been the commissioning of a 160 microwatt refrigerator purchased on faculty startup funds. The refrigerator was successfully operated in September 1998. It is now being readied for detector operation and will be used for CDMS II detector checkout and characterization.

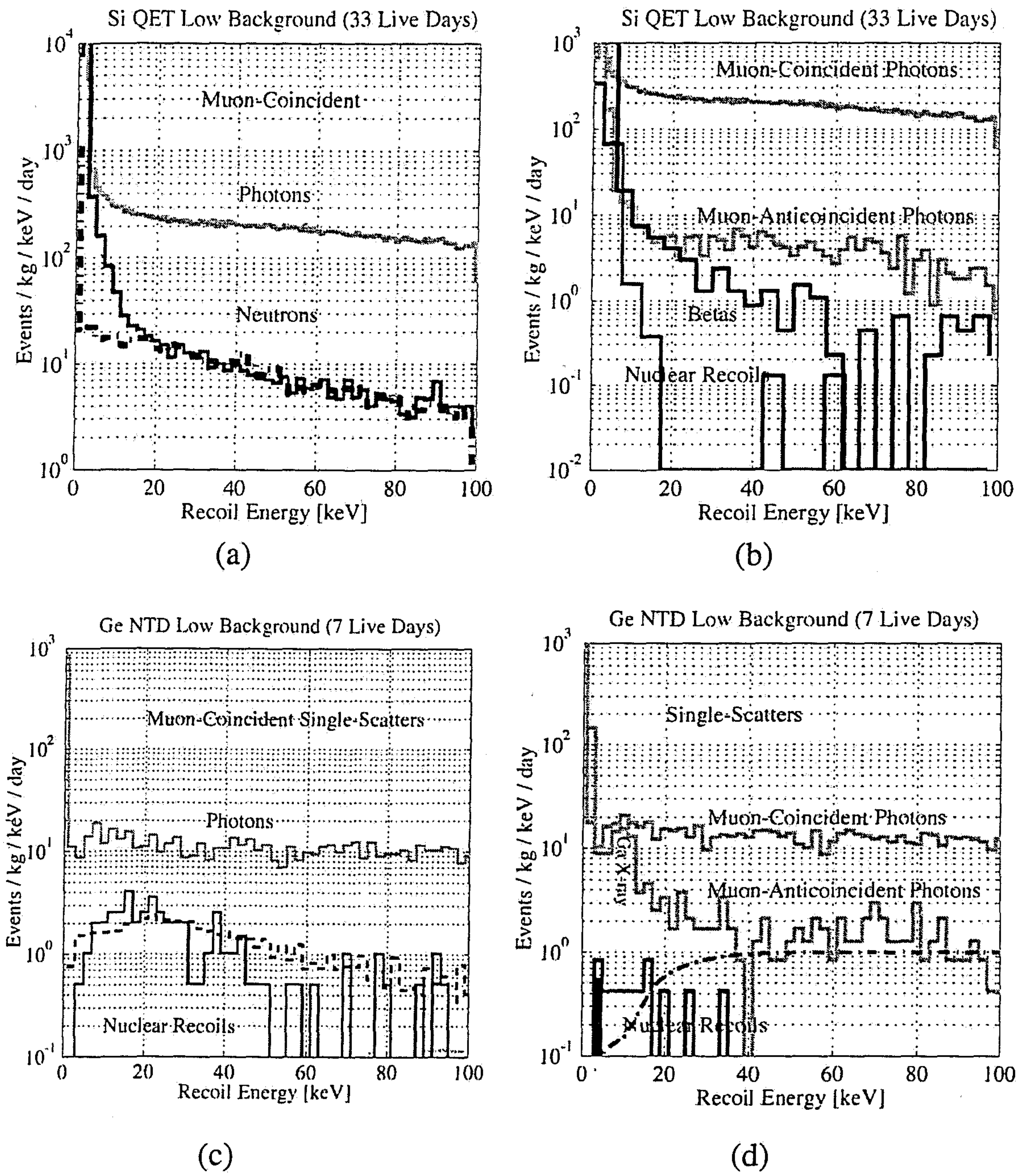


Figure 2.5: Background spectra of events in the inner electrodes of the Si QET (top) and Ge NTD (bottom) detectors at Stanford. On the left are shown the rate of photons and neutrons coincident with muons. The deviation of the measured neutron rates from the Monte Carlo predictions (black dashed lines) at low energies is due to contamination by electron-recoil events allowed by poor discrimination. On the right are the spectra of photons, betas (surface events) and potential nuclear recoils anti-coincident with muons. The filled histogram in Fig. (d) indicates the muon-anti-coincident nuclear-recoil spectrum excluding the topmost detector. The dot-dashed line indicates the efficiency for detecting nuclear-recoil events. While the surface-event discrimination of the QET removes nearly all background events >20 keV, the improved Ge detectors intrinsically have very little background.

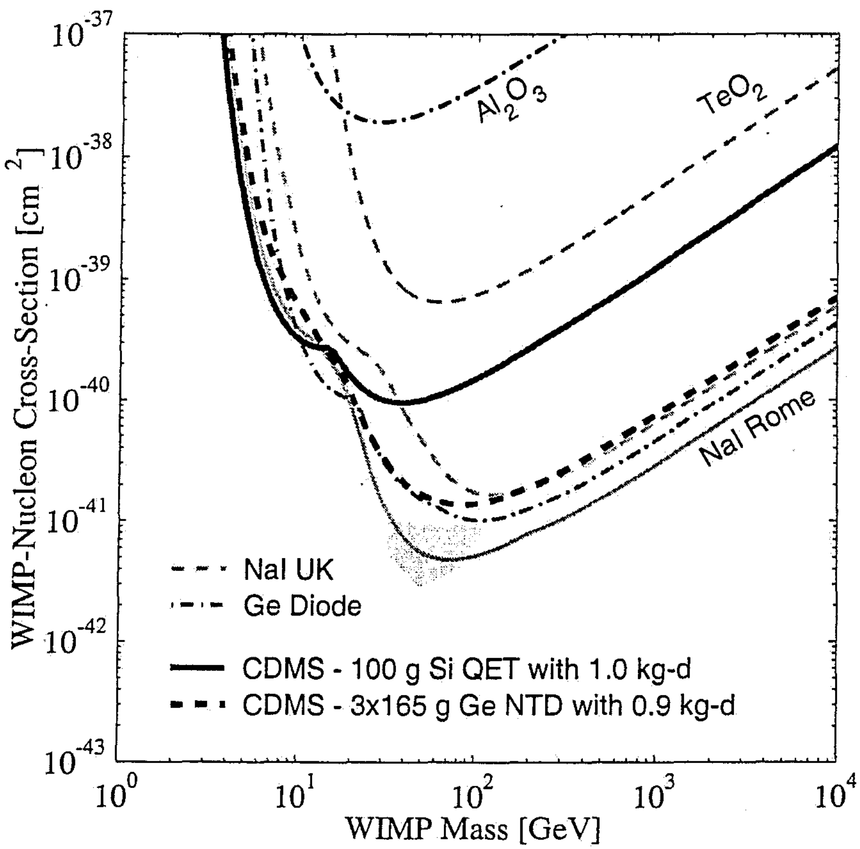


Figure 2.6: Preliminary CDMS I limits from QET detector (thick solid line) and NTD detectors (thick dashed line). Shown for comparison are published limits from other experiments described in Section 1.3. The shaded region corresponds to the modulation signal claimed by Bernabei et al.[44]

3. Project Objectives and Performance Criteria

3.1. Scientific goals and strategy

The goal of CDMS II is to increase by at least a factor 30 the WIMP sensitivity that will be reached at in CDMS I in Stanford, from a scattering rate sensitivity of 0.3 events per kilogram and per day to 0.01. The scientific motivation is to significantly extend the current WIMP searches, to explore more decisively the Supersymmetry parameter space and to perhaps discover the nature of the dark matter pervading the universe.

In order to achieve these goals we will install a second cryogenic detector system deep underground in the Soudan mine in northern Minnesota, and increase the target mass from 1 kg to approximately 5 kg of germanium and 2 kg of silicon, instrumented with an advanced detector technology. This ZIP technology (for Z-surface-rejection Ionization plus Phonon) combines our athermal phonon technology, which provides x-y positions transverse to the ionization drift direction, our improved ionization contacts, which decrease the effect of the dead layer, and our phonon pulse shape rejection of the z surfaces. The possibility of defining a fiducial volume in three dimensions, and of exploiting the information contained in the athermal phonon flux should allow us to improve our background rejection by a large factor (as large as 10). Combined with an aggressive reduction of our radioactive background, this advanced technology will result in much better use of the installed target mass, less sensitivity to systematics and much greater physics reach for our experiment.

We propose to quickly deploy a by-now fully specified technology. By technology, we should not only consider the most advanced aspects such as the detectors but also the full integrated system necessary to obtain a dark matter result: cryogenics, clean rooms, detectors, supports, cold and warm electronics, data acquisition, data reconstruction, Monte Carlos and analysis. We simply want to exploit as soon as possible the background rejection advantage that we currently have and overcome the likely limitation of our sensitivity by the residual neutron background at the shallow depth of the Stanford Underground facility. Our plans call for a focused effort involving a tight collaboration between all the groups, focused on the characterization of detectors, minimization of the background and implementation of the necessary infrastructure.

If we receive full approval from the funding agencies by 1 July 1999, we will have the new Icebox installed and tested in Soudan at the end of March 2000, start physics in Soudan in July 2000 (less than one year after approval) with detectors already tested at the Stanford Underground Facility. We will rapidly ramp up the installed mass with a completion of CDMS II construction in July 2002 (7 towers, 7 kg). Our current plans call for three years of operation in this configuration until July 2005. By that time, we should achieve an exposure of 2500kg-day on Germanium. This should allow us to surpass our sensitivity goal labeled "CDMS Soudan" in figure 1.4.

We have incorporated many strong assets in our plans:

- a robust and general infrastructure (e.g., in the warm electronics or in the towers).

- a modularity of the elements (allowing for instance the change of basements if needed to reach better background levels).

- a combination of several rejection methods (ionization versus phonon energy, pulse shape, position). In a low background experiment, there is a clear premium to improve the background rejection. An additional rejection factor of 10 that may be within reach with the ZIP technology is equivalent for a fixed detection time to an increase by the same factor of the target mass (see section 4.2.4. below)! Moreover, the sensitivity to systematics is decreased in the same proportion.

- a continuous feedback on the performance of detectors provided not only by the running at Soudan but by the performance and background tests at the Stanford Underground Facility and the full characterization of a few detectors in our four test facilities. This will allow the fine-tuning of our processing and the possibility to decrease as needed tails in distributions, which ultimately will limit our background rejection capability.

- a test of the system elements for performance and radioactivity in Stanford before implementation in Soudan, in order to save deployment time.

- a flexible and promising detector technology that, if necessary, could still be dramatically improved. Note that we have no reason from our current experience to doubt that, with its many levels of rejection, the current technology is fully adequate for the goal we advertise. If we need to fight unexpected backgrounds, it would be relatively simple to implement more complex schemes such as symmetric detectors through re-assembly of the elements of our current detector technology. We see this capability as an additional safety factor for CDMS II.

- a strong project management structure, and the technical expertise of two national laboratories.

3.2. Technical Objectives

Our overall goal is to reach a sensitivity level of 0.01 WIMP interactions/kg/day integrated or 0.0003 events/kg/keV/day differential. Running through the work breakdown structure elements, we are then led to the following objectives:

• The detector system should provide approximately 7 kg of target material, with the optimal mix of silicon and germanium to be determined from the analysis experience on CDMS I, in order to subtract the residual neutron background. Our plans are based on a 1 to 1 detector ratio. Our triggering threshold should be below 3 keV full energy deposition and the rejection of gamma interactions better than 99.5% at 15 keV. The surface electron interactions should be rejected at better than 95% at 15 keV. It is clear that we should strive for the best rejection performance within the allowed time, as this directly improves the physics reach of the experiment.

• The feedback from Stanford and Soudan operation and detector performance characterization activities is a critical component of our deployment scheme.

• The warm electronics chain serves to amplify and filter the detector signals and provides a configurable trigger which can be used to reject unwanted events and keep the trigger rate at ~ 1Hz.

• The data acquisition system must be capable of taking and logging physics triggers at 1 Hz (calibration at up to 10 Hz) with a live time greater than 80%. The analysis and logging chain must be able to keep up with the acquisition, while reducing the data volume by at least an order of magnitude.

• The active and passive shielding should reduce the rate of external γ's and neutron background to a negligible level (0.01 and 1.1 10^{-4} interactions/kg-keV-day) at 15keV.

• Our radioactive background activity strives at reducing as much as practically feasible the radioactivity contamination of the support elements close to the detectors. Our goal is to reach a γ level of 0.25 events/kg-keV-day (after multiple scattering rejection) and a surface electron flux of 5 10^{-5} electron/cm^2-keV-day at 15 keV.

• The Cryogenic System should provide a cubic foot at 10 mK with the heat loads expected from 7 towers fully equipped with the cold electronics. It is built of low activity OFC copper to limit the ambient radioactive background. It should be able to operate for several months without interruption and be remotely controllable.

• The Soudan Installation Infrastructure should provide the necessary clean room enclosure for the Icebox, the control room and all the needed elements for running the experiment.

3.3. Cost Objectives

The estimated costs are given in detail in section 9. Our overall cost objectives for CDMS II construction are:

Personnel	$10,200,000
Equipment, Supplies & Expenses, Travel	$5,900,000
Contingency	$2,300,000
Total	$18,400,000

The funds for CDMS II construction and operation will be provided by a combination of already approved NSF and DOE grants (the "base programs") and the supplementary request ("increment") included in this proposal. Of the $18.4M construction total, $10.9M is requested as an increment and $7.5M is assumed from the base program.

The CDMS II Operation annual cost is approximately $3.3M.

3.4. Project Schedule Objectives

The primary schedule objectives for the project are:

1	CDMS II full approval obtained, funding available	1-July-99
2	Start Fabrication of detectors for Towers 2-4	1-Mar-00
3	Soudan Icebox installed and tested	4-Apr-00
4	Start data run with Tower 1	10-Oct-00
5	Start Fabrication of detectors for Towers 5-7	1-Sep-01
6	Start data run with Towers 1-4	12-Sep-01
7	All construction compete, start data run with all Towers	1-July-02
8	2500 kg-day data set taken	1-July-05

4. The CDMS II Experiment Baseline Design

We propose to construct and operate a second generation CDMS experiment to search for dark matter WIMPs with a sensitivity that will be at least 30 times that of CDMS I. The new CDMS II experiment is based on the experience gained from CDMS I and will utilize the same detector technologies, with their excellent background rejection. These background rates are dominated by alpha, beta, and gamma emissions from nearby radio-nuclide contaminants, or from cosmogenic sources. All of these backgrounds produce electron recoils. In contrast, WIMPs, neutrinos, and neutrons predominantly scatter off nuclei. Therefore, an important feature of our WIMP dark matter search is the ability to discriminate between electron and nuclear recoils. The CDMS I detectors have been shown to be very effective for this purpose.

The improved sensitivity of CDMS II over CDMS I will be obtained by increasing the active detector mass by an order of magnitude (to 7 kg), and by operating in the low background environment of the Soudan mine (depth 2000 mwe), which will decrease the cosmic ray induced background rates (for both neutron, and gamma activity).

At the Soudan mine, the CDMS II experiment requires (i) two clean rooms, an electronics enclosure, and an equipment room, (ii) a second CDMS cryogenic system (Icebox + refrigerator), (iii) sufficient CDMS detectors and readout to fill the available cold volume at the center of the Icebox, and (iv) the other CDMS subsystems (DAQ, trigger, shielding, and muon veto) to complete the experimental setup.

The construction and operation of the Soudan background radiation shields and cryogenic systems are discussed in Sections 4.2 and 4.4. An overview of the cold electronics, warm electronics, triggering and data acquisition systems is outlined in Section 4.3. In Section 2 we have detailed the current status of the CDMS I experiment, including a discussion of the observed backgrounds and dark matter limits. In the next section we discuss the baseline detector specifications.

4.1. CDMS Detectors

The CDMS detectors are made of single-crystal wafers of ultra-pure germanium (Ge) and silicon (Si). The wafers (76 mm diameter, 10 mm thick) will be operated at temperatures less than 40 mK. As previously described in Section 2, when an interaction occurs in the crystal, some of the energy goes into the creation of electron-hole pairs, or ionization, while the rest appears as phonons, or vibrations in the lattice. By applying a small electric field across the crystal, the ionization can be measured with essentially standard charge-measurement electronics.

Based on the CDMS I detector design and operation, we have chosen a baseline detector design for CDMS II that incorporates the successful features of the athermal phonon sensors and the amorphous silicon ionization electrode design. The technical specifications for the detectors are summarized in Table 4.1 below.

Simultaneous determination of the ionization energy and the phonon energy deposited in the crystal makes it possible to discriminate between nuclear recoil events and electron recoil events. Discrimination is possible because nuclear recoils dissipate a significantly smaller fraction of their energy into electron-hole pairs than electron recoils. Therefore, knowledge of both the ionization energy and phonon energy for each event allows the determination of the event type. Thus, the CDMS cryogenic detectors provide detailed information on rare events, information which can be used to identify WIMP interactions and reject background events. In the CDMS I experiment these detectors have already been shown to achieve their target of >99.5% gamma background rejection efficiency, and >95% beta rejection efficiency, at energies above 20 keV. Improvements in the signal to noise ratio of detectors in the CDMS II experiment should permit us to achieve this level of discrimination above 15 keV.

The baseline design uses a large array of tungsten (W) transition edge sensors coupled with aluminum (Al) films photolithographically patterned on the surface of a Si or Ge target crystal to measure the phonons before they thermalize. These detectors provide z(depth)-sensitive information, an ionization measurement, and a phonon signal. Hence, we call them ZIP detectors.

Property	Baseline
Detector Deployment	42 ZIP (z-sensitive ionization and phonon) Detectors
Wafer Dimensions	76 mm diameter × 10 mm thickness Ge mass 250 g Si mass 100 g
Total Target Mass	7 kg (21 Ge & 21 Si detectors)
Fabrication Site	Stanford Nanofabrication Facility
Phonon Sensors	4 channel Al/W QET (quartered pattern) (Quasiparticle Trapping Assisted, Electrothermal Feedback, Transition Edge Sensors) covering top side of the wafer
Baseline Resolution (FWHM) Position Resolution (@20 keV)	<1 keV Ge&Si z (depth) identification of surface events; x&y position < 5 mm.
Cold Amplifiers Operating Temperature	NIST/U. Colorado SQUID Arrays <3 pA/√Hz (>500 Hz) Substrate <30 mK WT_c for active elements 60–90 mK
Charge Sensors Baseline Resolution (FWHM)	2 channel (inner region, and outer guard ring) Amorphous Si – Shottky Al electrodes covering both sides of the wafer <1.5 keV Ge <2.0 keV Si
Cold Amplifiers	FET Amplifiers <1 nV/√Hz (>500 Hz)
Detector Discrimination Nuclear Recoil Quenching Factor in phonons Nuclear Recoil Quenching Factor in charge	 100% (+/- 5 %) 30% in Ge (20 keV) 50% in Si (20 keV)
Gamma Rejection Factor Surface Beta Rejection Factor	>99.5% (>15 keV) >95% (>15 keV)

Table 4.1 Summary of technical specifications for CDMS II detectors.

Figure 4.1 shows a schematic, and a photograph, of the baseline ZIP detector. The CDMS II experiment will use 42 of these detectors. Half of the detectors will be Ge, and the remainder will be Si. The use of two detector materials offers different sensitivities to the various types of background (including neutrons), as well as the dark matter. The comparative information will be important in the determining the level of systematic errors in the data, as well as providing additional confirmation of, and kinematic information on, the dark matter signal. The correct management of systematics is very important in a rare event search of the type we are conducting.

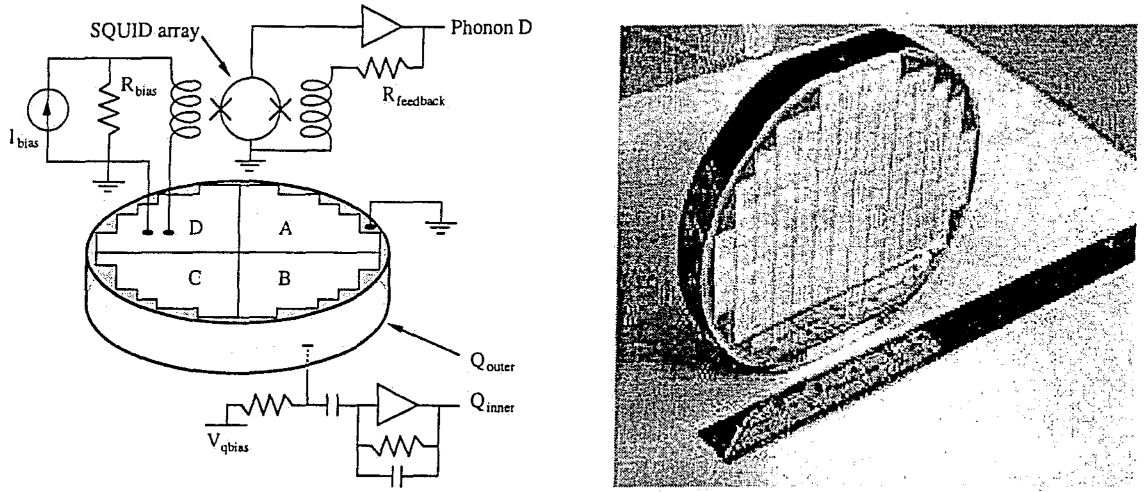


Figure 4.1. Schematic diagram (on left) of a ZIP detector, showing the four phonon W/Al QET sensors and the two ionization circuits. The phonon sensors cover 82% of the upper surface, and can be seen on the top face of a wafer in the photograph (on right) of a newly fabricated detector.

The ZIP phonon sensors are fabricated on the top surface using photolithographic processing (at the Stanford Nanofabrication Facility, see photographs in Fig. 4.2). The sensor design is also shown schematically in Fig. 4.2, at three successively higher magnifications. On the left is shown the basic layout of one of the four W/Al QET phonon sensors. Each sensor is divided into 37 units each 5 mm square (magnified in the center) which themselves contain 12 individual sensor elements (far right) connected in parallel. Aluminum quasiparticle collector fins cover 82% of the top surface of the Si and also provide the ground electrode for the charge measurement. Also shown on the far left is the W outer ionization electrode that is patterned (10% area coverage) to minimize athermal phonon absorption. These phonon sensors will be referred to by the compacted acronym QET, for Quasiparticle-trap-assisted Electro-thermal-feedback Transition-edge-sensor[68,69].The detectors are fabricated from only three separate metal layers, one of 3000 Å Al and two of W (combined thickness 700 Å). The small number of layers means that visual inspection (under microscope) can be used to confirm the integrity of the patterns throughout processing. The fabrication facility equipment is designed for mass production and so lends itself well to the production of large batches of detectors, with good batch uniformity. The chemical baths and atmosphere offer a very stable environment. The most unusual aspect of our work is that the wafers are 10 mm thick, rather than the more usual 300 μm.

The electrical readout of the phonon signals from 42 detectors will be accomplished using 168 DC SQUID Arrays, manufactured and tested by the NIST/U.Colorado group, which operate as current-sensitive amplifiers. The SQUID arrays were invented by the NIST group and allow a low-noise high-bandwidth (DC to a few MHz) amplifier design with a simplified room temperature electronics readout scheme. These amplifiers are fabricated in the NIST Cryoelectronics facilities and provide state-of-the-art current noise below ~3 $pA/\sqrt{Hz}$. The voltage bias configuration and the SQUID's electronic readout scheme are depicted in Fig. 4.1. The SQUIDs are mounted on the 600 mK stage. They are operated in a feedback mode, using custom room temperature electronics developed in collaboration with NIST, to improve linearity and allow accurate calibrations.

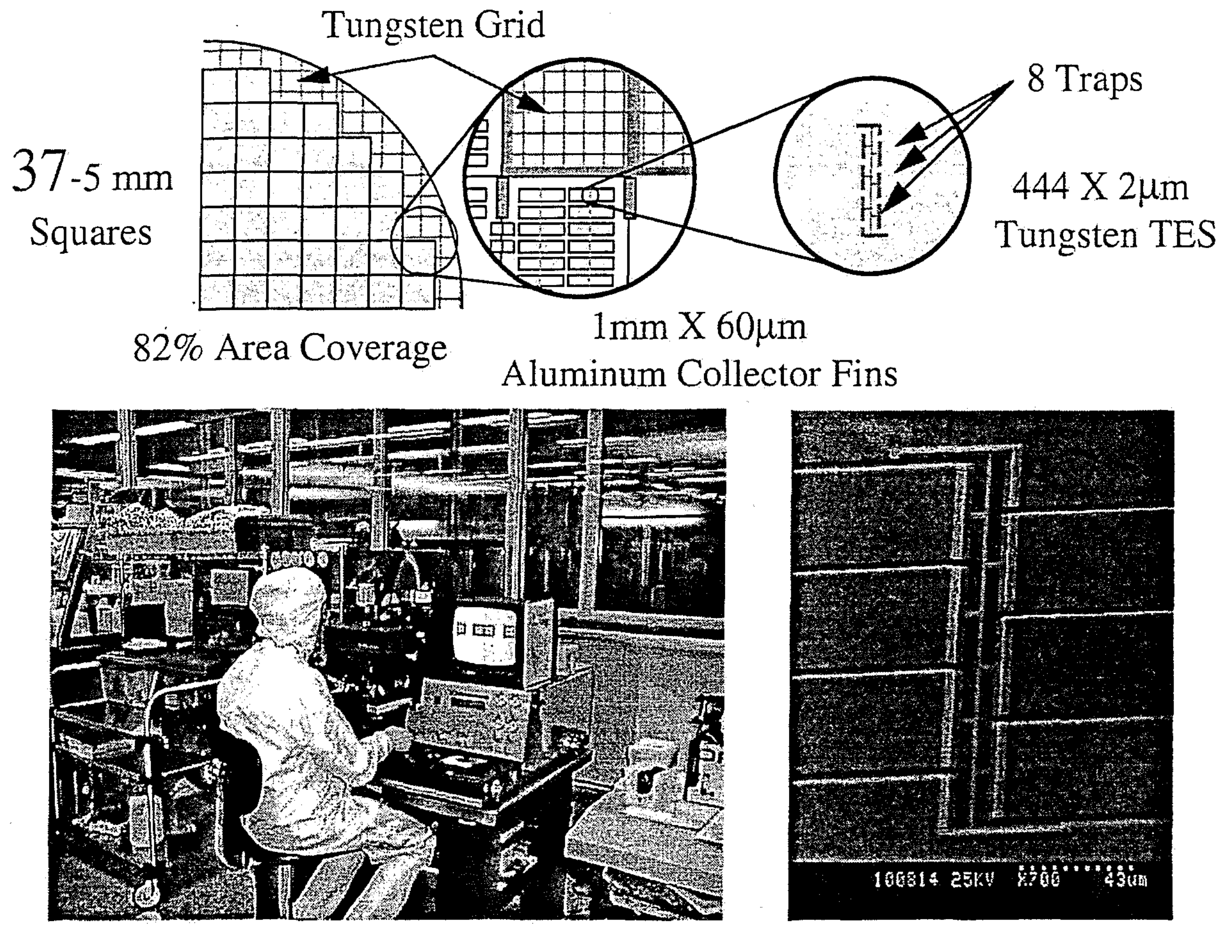


Figure 4.2: Schematic diagram of a W/Al QET phonon sensor for the ZIP detector (see the text for details). Also shown, bottom right, is an electron-micrograph of a W meander (200 μm in length, 2 μm wide), and a photograph, bottom left, of a contact mask aligner, used to pattern the thin films on the ZIP wafers at the Stanford Nanofabrication Facility.

The ionization measurement electrodes employed on the faces of the target crystal are fabricated with an amorphous Si layer with an Al thin film overcoat. This contact technology was developed under CDMS I program and can be employed on both Ge and Si. The charge collection electrode is segmented into two sections – an inner electrode and an outer electrode that are separately read out. The outer electrode allows a simple veto for events depositing all or part of their energy near the bare outer edge of the crystal where the charge collection is incomplete. The charge measurement will be made using 84 FETs operated at the 4 K stage of the assembly. The FETs are pre-screened from commercially available batches, with noise performance <1 nV/√Hz. The intrinsic baseline resolution in the charge channels for the Ge has typically been better than 1 keV FWHM, and the corresponding number in Si is 1.2 keV.[70] The design of the hardware for the cold (SQUIDs and FETs) and warm electronics are based closely on those demonstrated in CDMS I.

4.2. Shielding and Backgrounds

The goal of our shielding and background effort is to minimize the level of interactions that mimic nuclear recoils in the cryogenic detectors arising from external, conventional sources. These external sources include γ's and neutrons from radioactivity in the surrounding environment (including the shielding), γ's and neutrons produced by cosmic ray muons, and electrons from radioactivity deposited on surfaces.

Passive shielding (Pb, polyethylene, and OFHC Cu) reduces the flux from radioactive contamination and active shielding vetoes that produced by cosmic rays.

4.2.1. External Gamma Background.

The dominant external gamma backgrounds at Soudan will come from natural radioactivity in the surrounding rock, primarily the ^{238}U and ^{232}Th decay chains, with gamma ray energies up to 2.6 MeV, and the potassium isotope ^{40}K, which emits a 1.46 MeV gamma. The gamma rays scatter several times before their energies become low enough to disappear by photoelectric absorption. In rock, the relative probabilities for photoelectric absorption and Compton scattering become equal at an energy of approximately 60 keV.

Using the measured concentrations of radioisotopes in the rock, the energy spectrum of gammas leaving the rock has been computed, and is exponentially falling with energuy up to 1.8 MeV, with a small tail at higher energies. This gamma ray flux is similar in shape and intensity to the unshielded flux at the Stanford facility, where, for CDMS I, it was suppressed by a lead shield of thickness 15 cm. The same Monte Carlo calculations used to successfully design the CDMS I shield indicate that 20 cm of Pb will be sufficient for this more sensitive experiment; to be conservative, we have chosen to use 22.5 cm of Pb in our design.

Lead suppresses the most penetrating gamma radiation by about an order of magnitude every 5 cm. However, beyond a certain thickness more lead does not help, because low level activities inside the shield and in the lead of the shield itself begin to dominate the spectrum. In particular, one must beware of bremsstrahlung radiation from ^{210}Bi, a daughter of ^{210}Pb, which is present at some measurable level in all sources of recently manufactured lead. The ^{210}Pb originates in the ores from which the lead is smelted, and dies away with a 22-year half-life. Lead which was smelted more than a few hundred years ago typically has no measurable ^{210}Pb activity and is ideal for shielding purposes. The "old" lead need only be used on the inner few cm of the radiation shield since the ^{210}Bi beta bremsstrahlung (end point 1.16 MeV) does not penetrate far. We have already taken advantage of a rare opportunity to purchase sufficient old lead for the CDMS II shield from Lemer Pax in France, using money advanced to UCSB by DOE.

4.2.2. Neutron background.

Neutrons are suppressed by hydrogen-rich moderator (50 cm of polyethylene in our case) which downshifts their energy out of the region where they can be confused with 1-100 keV nuclear recoils in our detectors. At the depth of the Soudan mine most of the neutrons come from (α,n) interactions where the α originates from decays in the uranium and thorium chains. Most of the elements present in the rock, including ^{16}O and ^{28}Si, have Q-values which are too high for the relevant α energies, but Al, Na, and the less abundant isotopes of O and Mg give contributions. Feige et al.[71] have made measurements of neutron production by α's in the relevant energy range (4-8 MeV), and give production rates of neutrons for both U and Th. Using these data and the Soudan rock composition, Ruddick[72] has calculated a neutron production rate of $(2.1 \pm 0.2) \times 10^{-8}$ neutrons/(g s), most of which originate in (α,n) interactions from ^{18}O nuclei. Spontaneous fission gives an additional 2.7×10^{-9} neutrons/(g s). Based on these neutron production rates and the expected neutron energy spectrum, the GEANT program has been used together with the MICAP code to simulate neutron interactions and calculate the resulting neutron flux and energy spectrum in the CDMS II shielding configuration, consisting of 10 cm of inner polyethylene, 22.5 cm Pb, and 40 cm of outer polyethylene. The calculated energy spectrum of these neutrons is shown in Fig. 4.3. These calculations successfully reproduce the neutron rate seen in CDMS I at Stanford so it is unlikely that neutrons from radioactivity will be a problem at Soudan. In any case, the residual neutron background can be measured and subtracted, for unlike WIMPs, a significant fraction of the neutrons interact in more than one detector. The comparison between silicon and germanium provides another handle on this background.

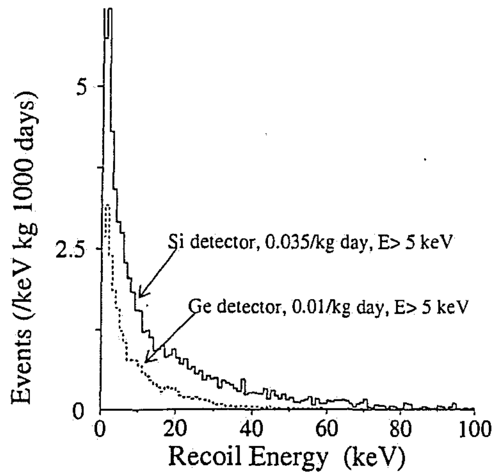


Figure 4.3: Calculated neutron spectrum from natural background sources in the Soudan mine

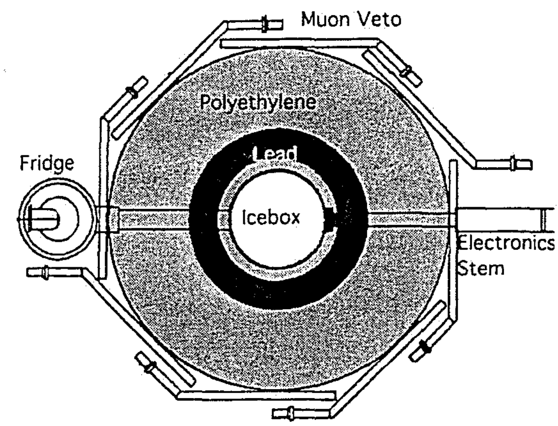


Figure 4.4: Overhead view of the shield and muon veto around the icebox and fridge

Of more concern are high-energy neutrons from interactions in the Pb shielding and the cavern rock by the residual hard cosmic ray muon flux (E~ few hundred GeV). Although the cosmic ray muon rate at Soudan is low, about 1 muon/minute would still enter the CDMS II shield. A scintillator veto, similar to that of CDMS I which has achieved an efficiency of 99.995%, will be used to suppress the effect of muons that produce neutrons in the lead shield to an very low level. However, the veto will not be able to detect all of the muons which make neutrons in the surrounding rock. A Monte Carlo simulation of these neutrons shows that their presence in our detectors can be made sufficiently small as long as we have our polyethylene moderator split between inner and outer pieces. Although there are some uncertainties in these calculations, the rate is so low that a direct measurement is not feasible before CDMS II running begins. Further simulations will be done to check the rates and kinematics of these events. There is room for some additional polyethylene and possibly an outer veto, if further reduction is needed later. Also, these neutrons can be measured and subtracted since they result in multiple interactions in the detectors and result in different spectra in the Si versus Ge detectors. Fig. 4.4 gives a overhead view of the proposed shielding.

4.2.3. Support and internal gamma and beta background.

An important limitation on the background rates is the inevitable activation of the detectors and the cryostat components by interaction with cosmic rays and their secondaries. For example, in germanium detectors, radioactive ^{68}Ga is produced via ^{70}Ge(n,3n)^{68}Ge, and its 10 keV X-ray line. Also very important are several activities produced in copper, which is the material making up the bulk of our cryostat. When components are taken into the Soudan mine, cosmogenically-induced activity will cease and activity induced at the surface will cool. To take full advantage of this effect, material for making the Icebox is being stored underground and brought to the surface only for the relatively brief periods of transportation and fabrication.

All materials used in detector supports will be carefully screened for gamma radioactivity at the LBNL Low Background Facilities, and alpha-emitting isotopes at the SUF/Princeton alpha counting setups. The goal is to make sure contamination from U/Th isotopes is < 0.1 ppb of the mass of all materials near the detectors. Radon scrubbing facilities are being prepared at Stanford and Princeton to minimize radon deposition on the detectors and surrounding materials. Additionally, all of the cleaning and handling techniques developed for CDMS I will be employed to minimize surface contamination. We will use some of our older detectors at SUF to measure the level of electron emitting isotopes in material near the detectors. Finally, the Princeton group is studying the possibility of developing, if necessary, a surface contamination proportional counter for the same purpose (funding for such a device has been planned in contingency). Using all of these techniques, we believe it is possible to improve over the current levels in CDMS I by a factor of 3-5 in the γ rate (down to about 0.5 γ/keV/kg/day at 15 keV) and a factor of 10 in surface electron flux (down to 5 x 10^{-5}β/cm^2/day or 0.02β/keV/kg/day at 15 keV). The gamma background can further be reduced by requiring a single scatter. We estimate that this brings down the internal gamma background to 0.25 events/keV/kg/day around 15 keV.

4.2.4. Detector discrimination.

Our detectors can further decrease these backgrounds. Moreover, they allow to measure the background and statistically subtract it, allowing the sensitivity to increase as the square root of the mass and of the exposure time till the experiment is limited by systematics.

The resulting statistical accuracy can be easily derived[64] in the case where a detector (with exposure MT kg–days) is assumed to have near unity acceptance of a signal (i.e. nuclear recoils), but misidentifies some small fraction, β, of the background $B\Delta EMT$. B is the background rate per unit mass and unit energy interval, ΔE is the integration interval, and β is determined from a prior calibration. Assuming that the actual signal rate, S per unit mass and unit energy interval, is very small, then we expect to see $\beta B\Delta EMT$ events pass the discrimination cut (and $(1-\beta)\ B\Delta EMT \approx B\Delta EMT$). In order to extract the underlying signal, we have to subtract the expected number of background events passing the cut from those observed. The statistical error associated with this subtraction is $\sqrt{\beta B\Delta EMT}$. For a null signal rate S, this leads to a 90% confidence level upper limit of

$$S_{90\%} = 1.6 \bullet \delta S_{stat} = 1.6\sqrt{\frac{\beta B}{M\Delta ET}}$$

In addition, the uncertainty in our determination of β, $\delta\beta$, leads to a systematic error given by

$$\delta S_{syst} = \beta B\frac{\delta\beta}{\beta}.$$

Note that the typical ΔE interval on which we need to integrate for massive WIMPs is 30keV.

The gamma backgrounds are readily discriminated by the simultaneous measurement of phonon and ionization. We conservatively assume a contamination factor $\beta = 0.5\%$ above 15 keV with a 5% relative systematic error.

The low energy betas are more difficult to reject because of the dead layer. However, we are confident that the combination of our new contacts and the phonon rise time will lead to a rejection factor better than 95%, i.e., $\beta = 5\%$ with a systematic uncertainty that we expect to bring below 10%.

We can subtract the neutrons by comparing the rates obtained in the silicon and germanium. Above 15 keV energy deposition, the neutron interaction rates are about the same in our two types of detectors: 250g of germanium, or 100g of silicon. Assuming negligible WIMP interactions and gamma contamination in silicon, one can simply subtract the number of events observed in silicon. For an equal number of germanium and silicon detector, the 90% confidence limit on the subtraction is simply

$$S_{90\%} = 1.6\sqrt{\frac{2B}{\Delta EMT}}$$

and it is probably easy to get such limit with a systematic error smaller than 0.1 B.

These numbers are conservative and do not take into account the higher rejection factors that we are likely to get with the amount of information contained in athermal phonons and from the multiple scattering events.

Table 4.2 summarizes the expected background levels in germanium at 15 keV from all external and internal conventional sources at Soudan. Note that internal γ's and β's will dominate the residual rate unless detector performance is significantly better than our goals.

Background source	Shielded	Muon Veto	After detector rejection	Background subtracted	Systematics
γ's , external radioactivity	0.01	0.01	0.00005		
γ's , cosmics in shield	0.0025	0.000025	0.0000002		
γ's, internal single scatters	0.25	0.25	0.0013		
Total γ's	0.26	0.26	0.0014	0.00022	0.00007
β's, surface contamination	0.02	0.02	0.0010	0.00018	0.00010
n's, external radioactivity	0.000005	0.000005			
n's, cosmics in shield	0.0005	0.000005			
n's, cosmics in rock	0.0001	0.0001			
Total neutrons	0.0006	0.00011		0.00009	0.00001
Total background	0.28	0.28	0.0024	0.00030	0.00012

Table 4.2: This table lists the contribution in counts/kg/keV/day at 15 keV in germanium from each background source expected in CDMS II. "Shielded" means the component that penetrates the shielding and interacts in the detectors. "Muon-Veto" refers to the subset of these that are anticoincident with a 99% efficient muon veto. "After detector rejection" is the smaller subset of events that are misidentified by the detectors as nuclear recoils. "Background subtracted" refers to the 90% C.L. limit obtained using formulae above, where MT= 2500kg days and E = 30 keV.

4.3. Electronics, Trigger, and Data Acquisition

4.3.1. Electronics and Triggers

The basic electronics for the ZIP detector front–end readout will be essentially unchanged from CDMS I. Because of the larger number of detectors, the packaging has been redesigned for higher density and efficient production. A single Eurocard 9U circuit board will instrument each detector which will provide all of the high sensitivity front-end circuitry, analog output circuitry, and digital control circuitry required for that detector. The 9U configuration is in use in CDMS I, and will be used in CDMS II. The 9U boards are housed in crates which provide separate backplanes for the front-end, analog output, and digital control sections. Each crate can house eighteen 9U boards, corresponding to three detector towers. For the full CDMS II complement of detectors, there will be a total of 42 boards housed in three 9U crates.

Each 9U board handles I/O via the digital backplane and provides digital control for setting DC levels, linear switches, and other control functions. The digital control section will occupy the bottom 1/3 of the board. The high sensitivity front-end circuits for SQUID or FET amplifiers, detector biasing, and cold-FET or SQUID control circuits will occupy the upper 1/3 of the board which will connect directly to the detector I/O cable via a board-mounted 50 pin D connector. The center section of the board will house the analog output sections which will connect to the triggering/data acquisition racks using a second board mounted connector. A combination of spatial separation on the board, careful use of internal circuit board layering, and the provision of separate grounds and power supplies will be used to maximize the shielding of the high sensitivity front-end electronics and minimize coupling between the front-end, output, and digital sections.

Great care must be taken to isolate the front-end ground from the rest of the system to minimize ground loops and AC pickup. The 9U boards will reside in crates which directly adjoin the vacuum feedthrough bulkhead of the Icebox to minimize the cable length for front-end signals. High-level analog outputs will be differentially driven across twisted pair lines to receivers located in a distant rack near the DAQ system. This rack will also contain filter and trigger cards. The ground and isolation scheme will allow for a second Faraday enclosure (the Icebox will constitute the first) between the front-end and the receiver rack. A controller board in each subrack will communicate with the 9U boards via the digital backplane and with the data-acquisition computer via a GPIB interface controlled by the DAQ system. As is the case for the CDMS I electronics, the commercial GPIB interface will be located in a separate rack from the detector electronics, and the digital controller card will be designed so that there is no digital activity in the detector electronics crate except during the execution of a control or readout function. All clock lines terminate in the remote GPIB interface.

4.3.2. Data Acquisition

The principal challenge in the CDMS II Data Acquisition system will be to reliably provide the extraordinary evidence that would be needed to support an extraordinary claim that WIMPs constitute the dark matter of our galaxy and perhaps our universe.

In terms of trigger rate, and detector complexity, the CDMS II experiment is unexceptional, when compared with modern experiments in accelerator-based particle physics. The expected trigger rate at the deep site, Soudan, is expected to be an order of magnitude less than 1 Hz, and we have specified 1 Hz as our conservative upper limit for planning purposes. There are only two types of particle detectors, as shown at the left in Fig.4.5: those for detecting the dark matter, and those for vetoing activity from unexceptional background sources such as cosmic rays and radioactivity. Information from the various detectors need not be correlated in order to reconstruct the process of interest: the signature of WIMPs will be a signal in *one* dark matter detector, and an *absence* of activity in the collateral detectors.

Reconstruction of the absence of activity in the rest of the detector presents the main challenge of the CDMS II experiment. Although the trigger rate will be low, the raw event size will be large, in the vicinity of 5-10 Megabytes. The resulting mean data flow rate of 5-10 Megabytes/s, is too large to be accommodated, with small deadtime under asynchronous operation, for transfer to the computer system that logs the raw data. The raw data must be filtered online. However, the filtering must not cause small amounts of activity in the collateral detectors to be overlooked. The extent to which small amounts of activity *are* overlooked by the filter must be monitored through the usual mechanism of pardoning a prescaled fraction of the raw events from filtering, and then using that "prescaled" sample to estimate various rates for the faking of WIMP signals.

Our baseline plan is extrapolated from the system used for CDMS I. We foresee filtering on the following levels, which are identifiable in Fig 4.5:

1. Just after the analog signal, at the discriminators; at least one phonon signal must pass a threshold.
2. In the trigger logic, where events with too many detectors above the threshold will be rejected.
3. In the digitization clock, where the time intervals between digitizations can be stretched, to reduce the amount of data on the "trailing edge" of the phonon signals.
4. In the "Fast Crate Controller," where information from the trigger will be used to restrict the amount of digitization read out, and where some compression of the raw data will occur.
5. In the "Central CPU," filtering based on all the complete event will be performed.

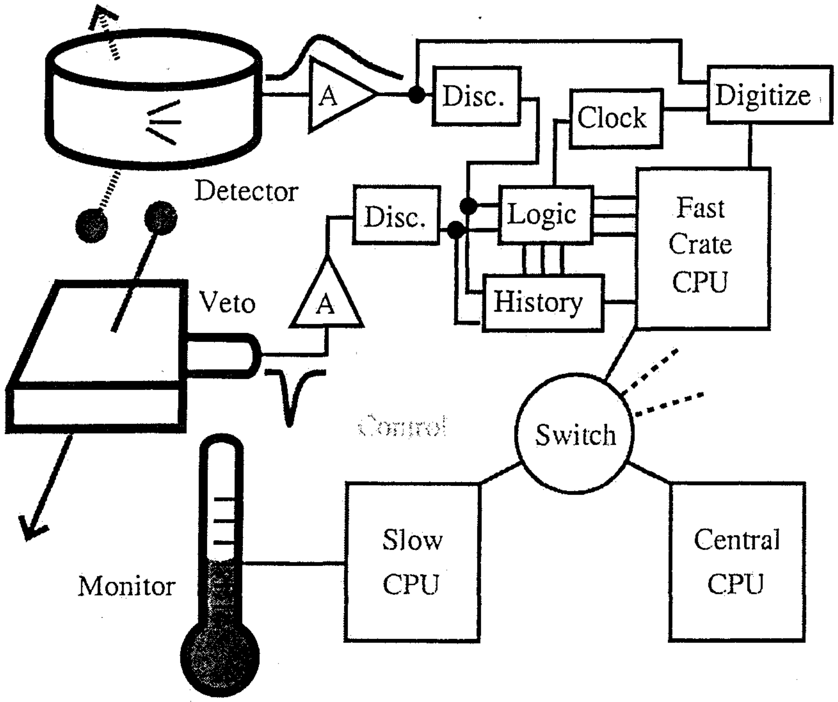


Figure 4.5: Block diagram of the Data Acquisition System

Our specification is for a livetime of at least 80%, for an expected physics trigger rate of 1 Hz asynchronous, and a calibration trigger rate of 10 Hz, also asynchronous. The tightest bottleneck appears to come from the use of fast ethernet to combine the distributed processors through the switch, as shown in the lower right of Fig.4.5 we assume that the sustained transfer rate achievable will be 1 Megabytes/s. To achieve the desired deadtime, we must then achieve a mean event size of 0.2 and 0.02 Megabytes for physics and calibration, respectively, per triggered event; that is to be compared with a raw event size of 5-10 Megabytes. This reduction appears achievable based on the ideas enumerated above, and scaling studies based on the CDMS I system.

Our studies based on scaling CDMS I indicate that substantial improvements must be achieved in various timing "overheads" in order to achieve acceptable livetime for CDMS II. Our baseline plan is to adapt the standard software tools for management of real-time data acquisition systems, including VxWorks, EPICS, and additions developed by our close colleagues in Babar, CLEO, and at FNAL, in order to arrive at timing overheads consistent with our livetime specification. Additionally, the multiple crates of digitization electronics in CDMS II, as well as the multiple types of data records needed, drive us to use of these standard tools.

The largest single cost in the data acquisition system is from the digitizers: our baseline design uses the Joerger VTR1012, which provides 12-bit resolution at up to 10 MHz sampling frequencies, and which has been successfully used in CDMS I. The rest of the baseline design is closely based upon CDMS I.

Our software plan consists of four parts:

1. **Acquisition**, including the real-time software filtering, event building, and data record structure
2. **Slow Control**, including processing of the monitor data and run configuration and control
3. **Production**, including the processing for calibration, the maintenance of calibration databases, correlation of event with monitor data records, and definition of output n-tuples
4. **Analysis**, including software packages for analysis, such as Matlab and PAW/Root

At every level, our plan is to exploit and adapt the pre-existing standard packages, including VxWorks, EPICS, LabView, to the maximum extent possible. The Production software is the most specific to CDMS, although the calibration, reconstruction, and specification of output n-tuples is again rather small in scale compared to a typical accelerator-based particle physics experiment.

4.4. Icebox and Cryogenics

The low-background cryogenic environment for the CDMS II WIMP detectors will be provided by a shielded cryostat of the type used in CDMS I, (called the "Icebox"), cooled by an Oxford Instruments Inc. 400-microwatt side-access dilution refrigerator. Although this refrigerator model is no longer generally offered, Oxford has agreed to produce this model. The CDMS I Icebox was originally designed for compatibility with deep-site operations. The basic design of the CDMS II Icebox will therefore be the same, with some minor changes to benefit from our experience with the first Icebox.

The cryogenic system is designed to accommodate the extensive shielding necessary to reduce the ambient backgrounds to acceptable levels and to minimize the amount of radioactive contamination near the detectors. Since it was impractical to make a low-radioactivity dilution refrigerator, we separate the cooling system from the cold experimental volume as shown in Fig. 4.6. We then surround the experimental volume with a nearly hermetic shield and use only pre-screened radioactively-clean construction material for everything inside the shield. When operated by itself, the dilution refrigerator has a base temperature under 5 mK.

The nested cans of the Icebox, each of which corresponds to a thermal stage in the dilution refrigerator, serve as both thermal radiation shields and heat sinks for detector wiring and support structures. The Icebox is connected to the dilution refrigerator via a copper coldfinger and a set of concentric copper tubes, collectively referred to as the cold stem. Each stem connects one can to the corresponding thermal stage in the refrigerator, with the copper coldfinger connecting the innermost can directly to the mixing chamber (~20 mK). The Icebox itself contains no cryogenic liquid; all cooling power is generated in the refrigerator, and the Icebox is cooled via conduction along the cold stem. The innermost can is 30 cm in diameter and 30 cm high, providing approximately 21 liters of experimental space at base temperature. Access to this space is obtained by removing the lid at the top of each can.

Because the reduced cosmic ray flux permits elimination of the shielding inside the cryostat, the tower capacity is increased from 3 at Stanford to 7 at Soudan. The Icebox detector package, made up of "tower" modules that each hold six detectors, does not need any modifications peculiar to the deep site. However, the Icebox-tower interface hardware must be redesigned to accommodate the increased number of detectors. To determine the expected performance of the Icebox operating with 7 fully-loaded towers, the heat load equivalent to a full complement of cold electronics has been applied to the helium layer of the Stanford Icebox and the temperature rise measured. The increase in temperature was found to be a tolerable 0.5 K. In early tests of the Stanford Icebox, we also applied heat loads to the three innermost cans to simulate the heat loads induced from the interconnecting supports within seven towers and determined that the Icebox performance is more than adequate.

4.5. Soudan Site

We propose to operate the CDMS II experiment in the Soudan Mine outside Tower, Minnesota. This facility is no longer used as a mine but is maintained for tourists as a State Park by the Minnesota Department of Natural Resources. The lowest level of the mine, at a depth of 2340 ft below the surface (~ 2090 mwe), includes a large $240 \times 45 \times 37$ ft^3 cavern which houses the SOUDAN II detector (Fig 4.7). The Soudan underground facility has been used by the University of Minnesota's Department of Physics since the early 1980s to conduct proton decay and double-beta-decay experiments. The measured flux of cosmic ray muons in the Soudan cavern is 1.8×10^{-3} muons/(m^2 s), about 10^4 times lower than in the Stanford Underground Facility.

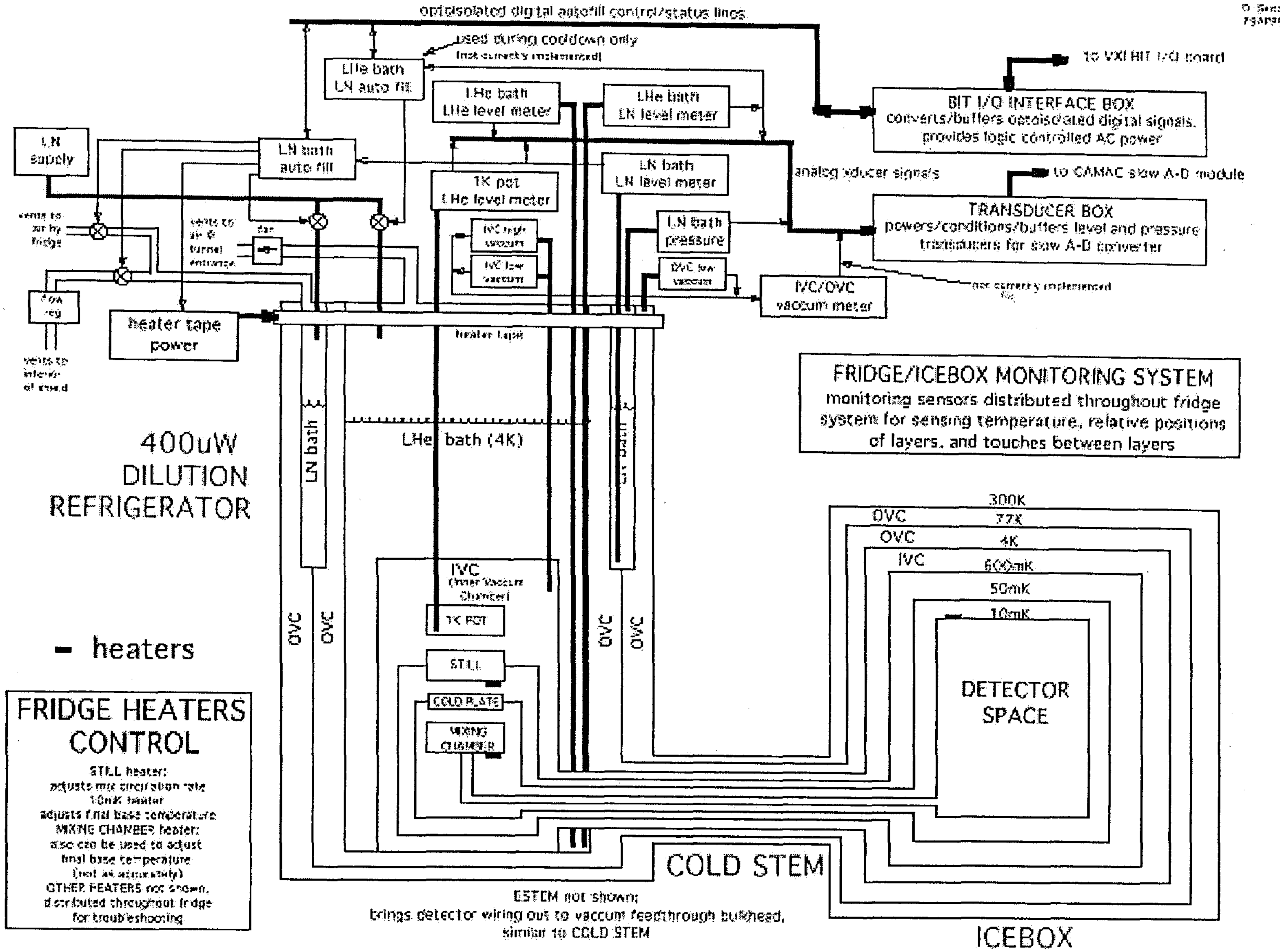


Figure 4.6: Schematic layout of the dilution refrigerator and the Icebox cryostat. The vertical section at the left is the dilution refrigerator. The set of nested cans at the right is the Icebox.

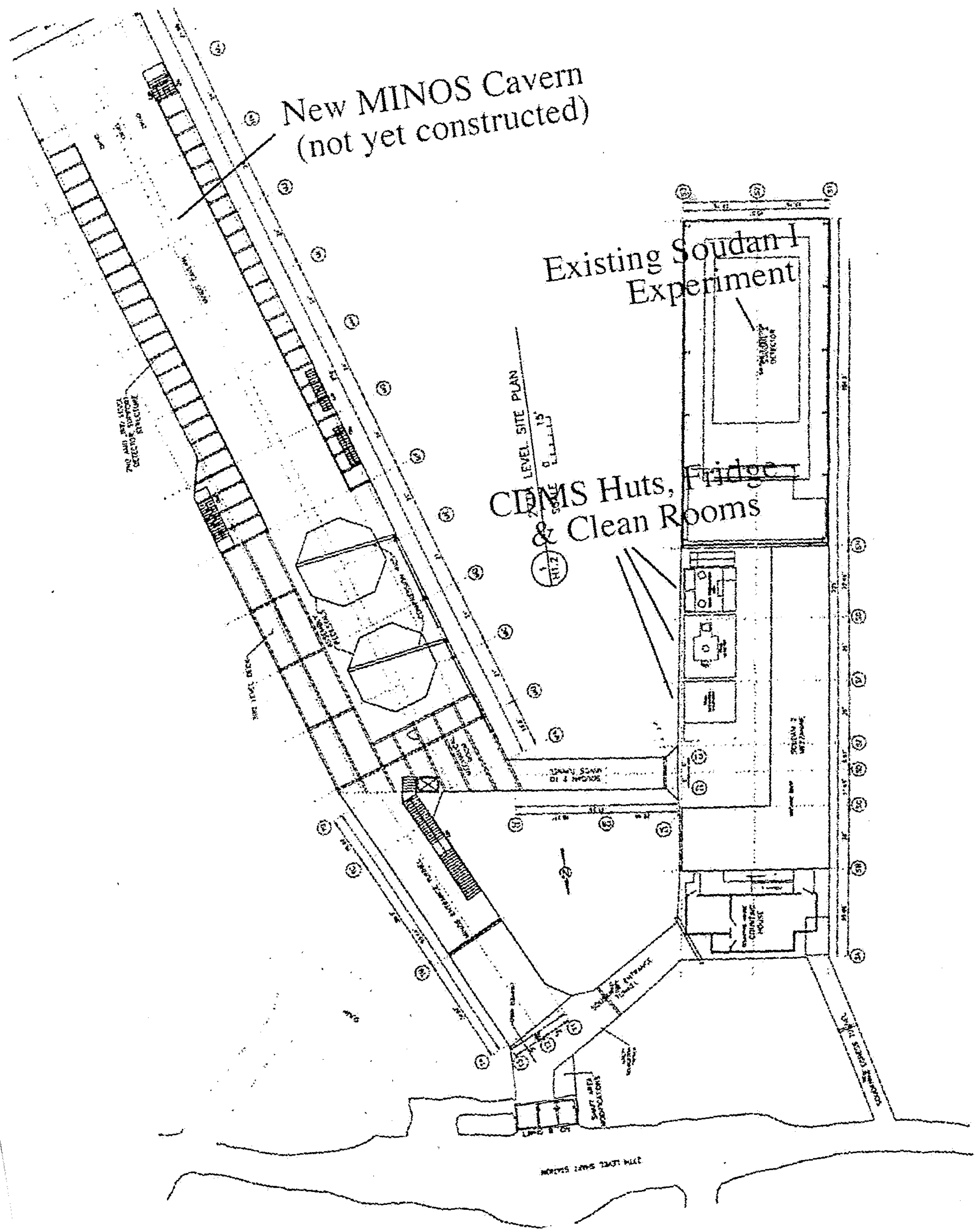


Figure 4.7: Layout of the Soudan Site

Logistical considerations are favorable at Soudan. The site combines inexpensive access without the hindrance of active mining operations. Furthermore, compared with the alternatives (Sudbury, Gran Sasso, Modane), the site is centrally located relative to the collaborating institutions. We have checked the access elevator and shaft and determined that all pieces of equipment meet the dimension and load limits. At nominal cost, extended access hours are available, e.g., during the setup phase when operations tend to be less routine. There is sufficient space for us to set up an enclosed experimental area, including clean rooms and an electronics room, within the existing cavern. Electrical power needs can be satisfied within the existing substation. Computer network access is already good and will soon be upgraded to a T1 line. Delivery and use of cryogens, which are required for the dilution refrigerator, are established at Soudan. The present technical staff already maintain machine tools and a variety of supplies and equipment at the site, and they will be available to assist us during setup and operations. Finally, the expansion planned for Fermilab's long-baseline neutrino-oscillation experiment, MINOS, will have a positive impact on further improvements to the infrastructure and scientific life at the laboratory.

5. Project Management

5.1. Overview

We propose the CDMS II Project to be funded by the National Science Foundation Physics and Astronomy Divisions and by the Department of Energy through its High Energy Physics University Program and through Fermi National Accelerator Laboratory and Lawrence Berkeley National Laboratory. It will be carried out by a collaboration of University and National Laboratory Groups. The plan for managing the CDMS project is presented and described in this Chapter.

5.2. Organizational Elements of the CDMS Project Management Plan

This subsection will tabulate the functions, responsibilities, and assignments of all the elements comprising the CDMS organizational structure. To this purpose, the organization structure will be given, and the requisite organizational relationships will be described. In addition, the lines of management responsibility necessary for successful administration of the project will be defined.

5.2.1. Organization Chart

The CDMS Organization Chart is shown in Figure 5.1. The functions and responsibilities of each of the boxes will be discussed in the following subsections. Further details concerning the subsystem structure can be found in Section 5.2.9

5.2.2. CDMS Spokesperson

The CDMS Spokesperson is responsible for the scientific success of the CDMS experiment, and as such, is accountable to the funding agencies. Consequently, the CDMS Spokesperson develops and establishes the scientific strategies and priorities necessary to ensure the success of the experiment. All decisions involving changes in the scientific scope are made by the Spokesperson. Accordingly, he or she works closely with the CDMS Co-spokesperson and the CDMS collaboration to ensure the scientific goals of the CDMS experiment are established and achieved.

Other specific duties assigned to the CDMS Spokesperson include the negotiation and assignment of CDMS Project responsibilities to the collaborating institutions. In addition, the CDMS Spokesperson is charged with the responsibility for the advancement of the educational missions of the CDMS collaborating institutions. Issues related to the educational mission include student theses, postdoc career issues, instrumentation and physics publications, and outreach activities.

Acceptance of the scientific leadership of the CDMS experiment implies that the CDMS Spokesperson will develop close working relationships with the CDMS Co-Spokesperson, the CDMS

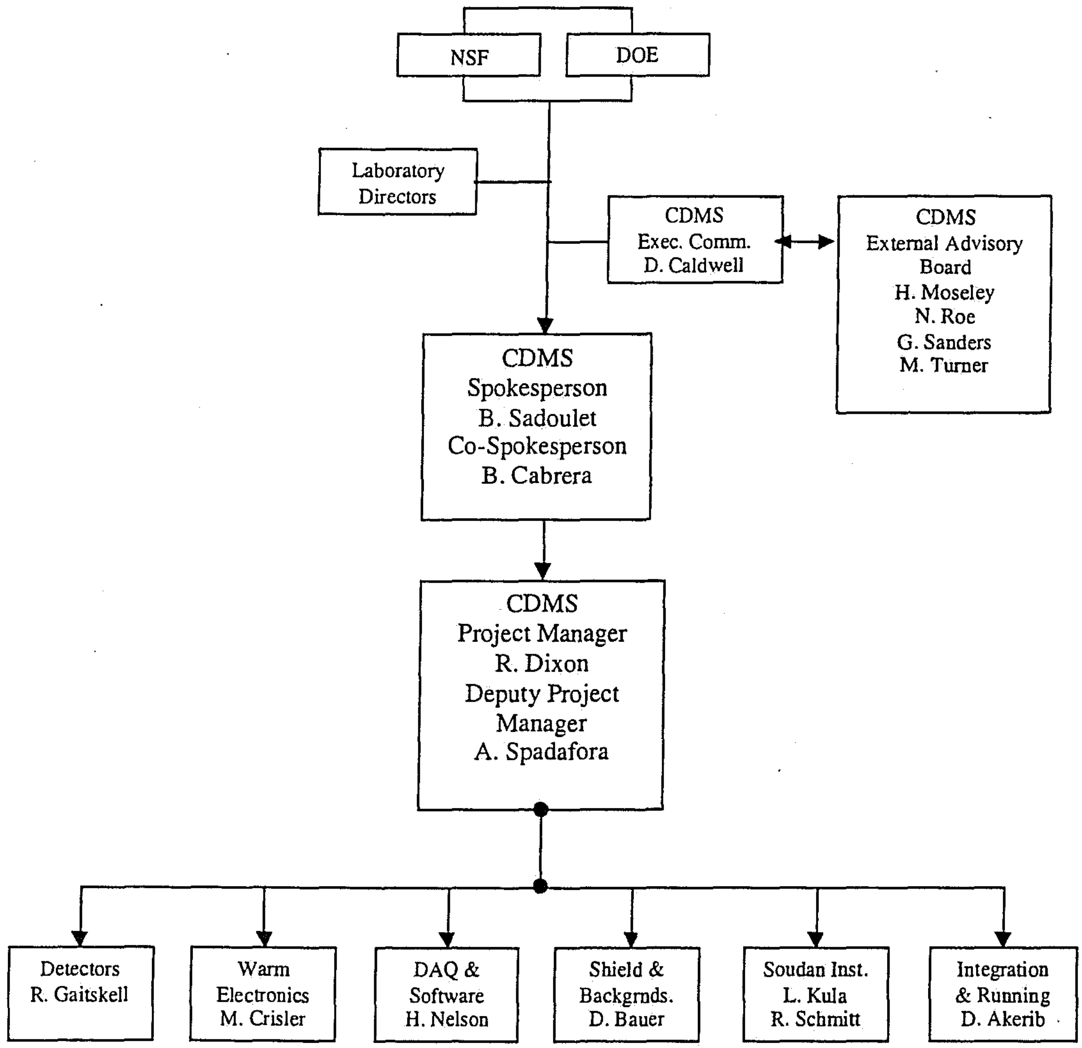


Figure 5.1: CDMS Project Organization Chart

Project management team, and the CDMS collaboration. He or she shall be responsible for organizing and calling collaboration meetings at 3 months intervals or less. These meetings will provide a forum for discussion of the scientific issues confronting the experiment. In addition, they will serve as a forum to present, review, and discuss important accomplishments. To maintain a healthy collaboration the Spokesperson must work to maximize the contribution of each collaborator and seek to recognize and reward important accomplishments through presentation at conferences, first authorship on papers, increased responsibilities and promotion. In summary, he or she is responsible for maximizing the opportunity for each institution to contribute to the overall success of the experiment.

The Spokesperson is appointed by the CDMS Executive Committee with the concurrence of the funding agencies and the Laboratory Directors. The appointment shall be made for the duration of the construction and installation period of the CDMS project. The present Spokesperson of the CDMS experiment is Bernard Sadoulet.

The CDMS Spokesperson appoints the Project Manager and the Deputy Project manager with the concurrence of the CDMS Executive Committee and the funding agencies.

5.2.3. CDMS Co-Spokesperson

The CDMS Co-Spokesperson is responsible for the technical success of the CDMS project. Accordingly, the Co-Spokesperson works closely with the CDMS Spokesperson to develop technical strategies and priorities which ensure the fulfillment of the scientific goals of the experiment. In addition, the Co-Spokesperson is charged with all of the responsibilities and duties of the CDMS Spokesperson during periods of unavailability of the Spokesperson, or whenever the Spokesperson makes such assignments.

Other specific duties assigned to the CDMS Co-Spokesperson includes setting the technical goals and priorities of the CDMS II project. Consequently, the Co-Spokesperson arranges for and organizes all technical and scientific reviews of the Project.

The CDMS Co-Spokesperson is appointed by the CDMS Executive Committee with the concurrence of the funding agencies. The appointment is made for the duration of the construction and installation period of the CDMS project. The present CDMS Co-Spokesperson is Blas Cabrera.

5.2.4. CDMS Project Manager

The CDMS Project Manager is responsible for the execution of the CDMS Construction Project. As such he or she must develop and maintain the Project Management Plan, negotiate and update the Memoranda of Understanding (MOU) between all of the collaborating institutions, and manage all the construction, installation, and related operational activities. These MOUs determine the resources which are available to the project from the collaborating institutions. Implicit in these responsibilities is the requirement that the Project Manager administer both human and financial resources available to the project through these MOUs.

Specifically, the CDMS Project Manager assigns responsibilities and resources to the Subsystem Managers. The progress of these assignments is monitored through monthly status reports generated by the Subsystem Managers, by means of monthly Subsystem Managers meetings, and through daily communications. He or she is responsible for developing, maintaining, and tracking the schedule for the project, which shall include a complete list of milestones to facilitate monitoring the progress of the project. Problems and concerns identified by this process must be corrected by the Project Manager. He or she shall react to such difficulties by making the appropriate reassignments of resources within the collaboration. Finally, it is also the responsibility of the Project Manager to provide quarterly reports summarizing the progress of the Project to the CDMS Spokespersons and to the funding agencies.

The Project Manager may delegate any or all of these responsibilities to the CDMS Deputy Project Manager as he or she deems optimal for efficient execution of the project.

The Project Manager is appointed by the CDMS Spokesperson with the concurrence of the CDMS Executive Committee and the funding agencies. The appointment is made for the duration of the CDMS Construction Project. The Project Manager position is a full-time assignment. The current Project Manager is Roger Dixon.

5.2.5. CDMS Deputy Project Manager

The CDMS Deputy Project Manager assists the CDMS Project Manager with all of the responsibilities and activities discussed in Section 5.2.4. In the absence of the CDMS Project Manager, the Deputy Project Manager performs all the duties of the Project Manager. The CDMS Project Manager may assign specific tasks to the Deputy Project Manager to facilitate execution of the Project. For example, the specific tasks currently assigned to the Deputy Project Manager include developing, maintaining, and tracking the CDMS Project schedule and budget. In addition, the Deputy Project Manager presently organizes and calls meetings of the CDMS Subsystem managers to discuss progress and problems associated with the work in the individual subsystems.

The CDMS Deputy Project Manager is appointed by the CDMS Spokesperson with the concurrence of the CDMS Executive Committee and the funding agencies. The appointment is made for the duration of the CDMS Construction Project. The current CDMS Deputy Project Manager is Anthony Spadafora.

5.2.6. CDMS Executive Committee

The CDMS Executive Committee includes a senior member from each of the collaborating institutions. The Chairperson of the Executive Committee is elected by the membership of the Executive Committee and is expected to serve for the duration of the CDMS construction period. The CDMS Spokesperson, Co-spokesperson, Project Manager, and Deputy Project Manager are ex-officio members of the CDMS Executive Committee.

The CDMS Executive Committee provides a forum to discuss scientific and technical progress of the CDMS experiment. In addition, Project execution and managerial issues are also matters for the consideration of the Executive Committee.

Specific responsibilities of the CDMS Executive Committee include the appointment of the CDMS Spokesperson and Co-Spokesperson. The Committee must also concur on the appointments of the Project Manager and the Deputy Project Manager. Furthermore, the Executive Committee must appoint an External Advisory Board (EAB) to monitor and review the execution of the CDMS Project. Meetings of the EAB are scheduled and organized by the Chairperson of the Executive Committee, and reports of the panel are made to the Executive Committee.

The Chairperson of the CDMS Executive Committee shall call, organize, and conduct the meetings of the Executive Committee. The present Chairperson of the Executive Committee is David Caldwell.

5.2.7. External Advisory Board

An external advisory board made up of four people with expertise scientific, technical, and managerial matters shall be appointed by the CDMS Executive Committee. Appointments are made for the duration of the CDMS Project. Should panel members resign, replacements will be appointed by the Executive Committee.

The External Advisory Board will meet twice per year to review the scientific and technical goals and achievements of the experiment. In addition, project execution will also be examined and evaluated by the EAB. Specifically, the EAB will review any schedule, cost, or scope variance that has to be reported to the funding agencies (see Table 5.1). Furthermore, the EAB will also be charged with reviewing the performance of the Project Management team.

Meetings of the EAB will be called and organized by the Chairperson of the CDMS Executive. Reports, including the recommendations of the Panel, will be submitted to the CDMS Executive Committee and will also be made available to the funding agencies. The current members of the EAB are: Dr. Harvey Moseley (NASA, Goddard Space Flight Center), Dr. Natalie Roe (Lawrence Berkeley National Lab), Dr. Gary Sanders (California Institute of Technology), and Prof. Michael Turner (U.Chicago).

5.2.8. CDMS Change Control Board

The CDMS Change Control Board (CCB) shall review all changes in cost or schedule which exceed the thresholds tabulated in Section 5.3.5. The Chairperson of the CCB is the CDMS Project Manager. He or she is joined on the Board by the Spokesperson, the Co-Spokesperson, the Deputy Project Manager, and the Subsystem Managers.

Items which need to be considered are brought to the attention of the CCB by the Project Manager or the Spokesperson depending on the nature of the proposed change (see Table 5.1). For the purpose of their deliberations, the CCB may organize any reviews they deem necessary. Once the CCB has examined the request for change a recommendation for appropriate actions is made to the CDMS Spokesperson and/or Project Manager, depending on the nature of the change. Recommendations are made on the basis of a majority vote of the CCB. Records of their recommendations will be kept and changes for the Project will be tracked in the accounting system.

The CCB will meet as needed. The CDMS Project Manager is responsible for calling meetings of the CCB. Meeting intervals are expected to be determined by the number of change requests and the urgency of the requests.

5.2.9. CDMS Subsystem Managers

The CDMS Subsystem Organization is shown in Figure 5.2. The CDMS Subsystem managers report to the CDMS Project Manager and to the Deputy Project Manager. They are responsible for the CDMS II activities designated in their box of the organization chart. As such they are responsible for bringing their subsystem into existence within the time and budget constraints imposed by the project schedule and goals.

The primary responsibility of the Subsystem managers is the planning and the coordination of the work for the subsystem. In close consultation with the Project Managers, they develop the work plan, schedule, and budget for their individual subsystems. They are in charge of implementing such a plan and track its progress and use of resources. They coordinate the personnel allocated by the Project Managers, and optimize the use of facilities at their disposal.

Subsystem managers must also coordinate with one another to ensure the success of the construction Project. Their subsystem must be documented in such a way as to facilitate its integration with the other subsystems. In addition, they are responsible for calling attention to technical and managerial problems and working within the CDMS Project management organization and the collaboration to find solutions.

As part of their responsibilities, Subsystem managers must provide the Project Managers with a monthly status report. The report will highlight both progress of their particular subsystem toward the project goals and difficulties encountered along the way. The report should include a short discussion of technical management relevant to their responsibilities, and should measure the progress of the subsystem effort against the specific milestones of the subproject. Furthermore, it should give an accounting of the budgetary expenditures during the monthly period, which highlights items costing more or less than expected.

Subsystem Managers are assigned by the CDMS Project Manager with the concurrence of the CDMS Spokesperson, Co-Spokesperson, and the CDMS Executive Committee. The assignments are made for the duration of the construction and installation of the project.

5.3. Project Management Systems

5.3.1. Introduction

This chapter describes the procedures and special tools which will be integrated into the project management design to create a management plan with the attributes of accountability, traceability, and flexibility. Consequently, monitoring of the technical and financial progress of the project by the Project Manager and the Deputy Project Manager, the Spokesperson and the Co-Spokesperson, and the funding agencies will be substantially enhanced. The Project Manager is responsible for implementing and using the procedures and tools described in this section.

5.3.2. Financial Plan

Prior to the beginning of each project year the Project Manager and the Deputy Project Manager in consultation with the CDMS Spokesperson and Co-Spokesperson, the Laboratory Directors, the CDMS Executive Committee, and the CDMS Level 2 managers will draft a financial plan for the coming project year. The financial plan will subsequently be submitted to the funding agencies for their concurrence and guidance. Once agreement has be reached the plan will be used by the funding agencies and the Laboratories for the allocation of Project funds to the CDMS collaborating institutions and the

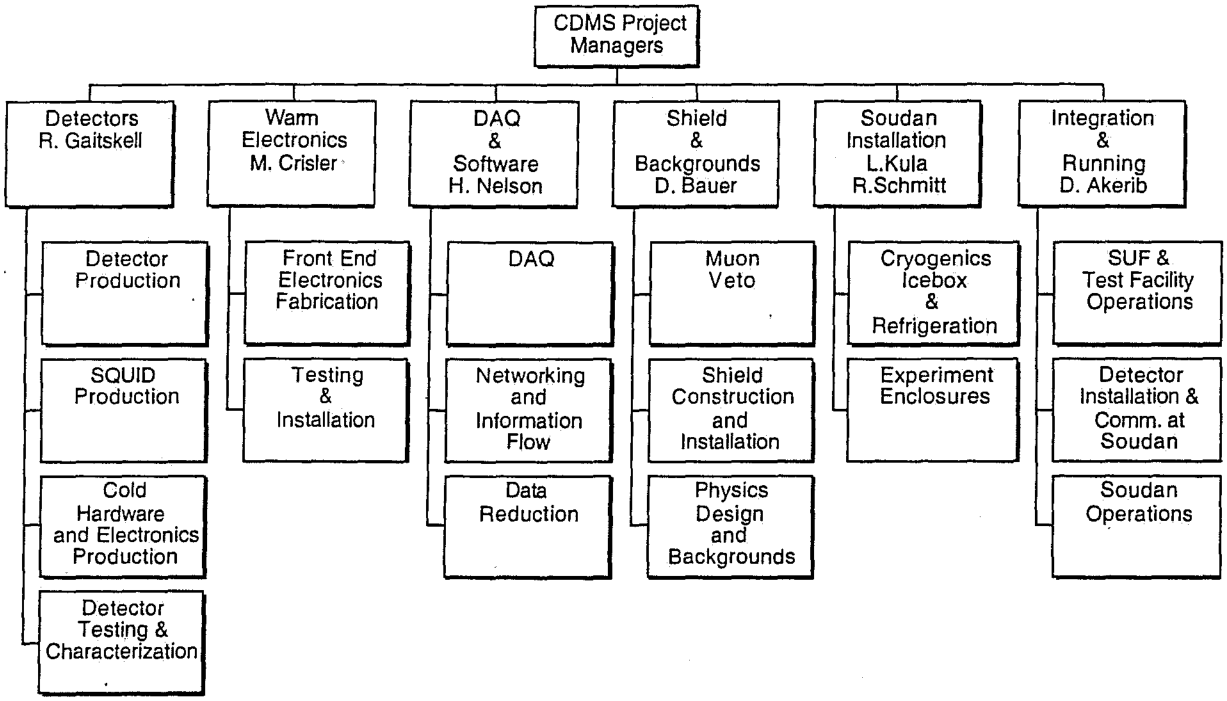


Figure 5.2: CDMS Subsystem Organization Chart

laboratory groups. This plan will summarize the status of the Project spending and contingency usage. It will also tabulate the previous years' expenditures and the current estimate of the cost to go. In addition, it will highlight all significant variances from the baseline cost estimate and the previous year's plan.

5.3.3. Spending Authorization and Cost Accounting

Funds will be allocated at the beginning of each project year to each of the WBS subtasks within the Project based on the financial plan described in the previous section. Authorization for spending is granted by the Project Manager and can be made on as block grant of authorization or item by item as deemed necessary by the Project Manager. These authorizations will be made in writing to the Subsystem Managers.

A project accounting system based on Microsoft Excel will be created and maintained by the Project Manager and his Deputy. Updates to this system will be made at least monthly by the Subsystem Managers. The Subsystem Managers are responsible for monitoring, controlling, reporting, and correcting problems with the spending for his or her subtask. Equipment spending for each subtask will be reviewed monthly by the Project Managers and the individual Subsystem Managers. Together they will initiate any appropriate corrective actions. Should the difficulties encountered exceed the thresholds delineated in Section 5.3.5, the Change Control Process must be initiated by the Project Manager.

5.3.4. Contingency Allocation

The Project Contingency is defined as the difference between the original project Total Estimated Cost and the current Estimated cost at Completion. The actual expenditure of contingency is reflected in the Estimated Cost at Completion and all changes will be traceable. A change in the Total Estimated Cost at Completion greater than the thresholds in section 5.3.5 requires the approval of the funding agencies.

Contingency for a specific project year will be held by the CDMS Project Manager, and all use of contingency must be approved by him or her. The amount of contingency held during any year by the Project Manager is determined by the approved Financial Plan and is based upon the contingency analysis submitted to the funding agencies as part of the baseline cost estimate. Subsystem managers are responsible for requesting the use of contingency funds from the Project Manager as soon as the need for such funds is discovered. These requirements will naturally arise during the monthly reviews of expenditures for each subtask. Funds not used in a subsystem are returned to the contingency.

5.3.5. Change Control Process

Schedule, cost and resource variance will be examined monthly by the Project Managers and the Subsystem Managers. When any changes occur in the cost, schedule, or scope of the CDMS project the change control process must be initiated. The particular path that the change control process takes depends on the magnitude and class of change required. For example, cost variations which result in changes of less than $5K in any specific subsystem item (Level 3 or below) require on the approval of the Subsystem Manager while changes to the scientific scope of the project require the approval of the Spokesperson, and notification of the Project Manager or his Deputy, the Change Control Board, and the funding agencies. Of course, there are many variances which fall in between these two extremes. Table 5.1 summarizes the level of approval required for all changes in cost, schedule, and scope.

Items which must be placed before the Change Control Board for a recommendation are forwarded to the Board in writing by either the CDMS Spokesperson or the Project Manager depending on the nature of the change. For example, all cost and schedule changes are submitted by the CDMS Project Manager . Alternatively, all changes to the scientific scope of the project are submitted by the Spokesperson. Should there be disagreement between the CDMS Project Manager or his Deputy and the CCB concerning a particular change, Project Management shall make the final decision. Should there be a disagreement between the Spokesperson and the CCB, the CDMS Spokesperson will make the decision. Resolution of disagreements between the Project Managers and the Spokesperson depend on the nature of the disagreement. The Project Manager or his Deputy will have the final say in all matters concerning project resources (cost and effort), and the Spokesperson will make the decisions on all matters of scientific scope.

Tracking of the schedule will be done with milestones. The primary (WBS level 1) milestones have been given in section 3.4. Agencies should be informed of any anticipated slippage of these milestones by more than 6 months. Slippage of any of the WBS level 2 milestones (subsystem milestones given in Sec. 10) by more than 3 months must be approved by the Spokesperson. Budget tracking will be accomplished as described in section 5.3.3 and 5.3.4. Normally, notifications of cost and schedule changes will be made to the funding agencies in the Project Manager's Quarterly Report.

5.3.6. Information Distribution and Reporting

In order to keep the project running smoothly it will be necessary to keep all persons working on the project informed of the current status, including problems, progress, and future plans. In addition, the funding agencies must be kept abreast of our progress. To facilitate the distribution of this information the Project Management team has adopted several standard tools to track, report, and distribute information. Microsoft Project 4.0 combined with Microsoft Excel will be used to track and monitor progress on the schedule and budget. In addition to the CDMS collaborators, it will also be necessary to implement a series of formal reports to be distributed to the stakeholders in the CDMS Project. In addition to the CDMS Collaborators, the funding agencies, the Laboratory Directors, and the External Advisory Board members are included in the group of CDMS stakeholders. For example, the Level 2 Subsystems Managers will report on the progress of their subsystem monthly. Their report will be submitted to the Project Managers, who will distribute it to the Spokespersons, the Executive Committee, and to the collaboration. Furthermore, the Project Managers will complete a quarterly report on the progress of the project and submit it all of the CDMS stakeholders. This report will summarize the recommendations of the Change Control Board in addition to giving the overall project status.

Table 5.1 Change Control Reporting Requirements

Variance	Subsystem Managers	Project Manager	Spokes-Person	CCB	EAB/Funding Agencies
Cost or effort Variance resulting in cost changes within any subsystem of ≤$5k	√				
Cost or effort Variance resulting in cost changes within any subsystem of >$5K	√	√			
Cost or effort Variance resulting in cost changes within any subsystem of ≥$25K	√	√	√	√	
Cost or effort Variance resulting in cost changes within any subsystem of ≥$50K	√	√	√	√	√
Schedule Variances within any subsystem ≤ 1 month	√				
Schedule Variances within any subsystem > 1 month	√	√			
Schedule Variances within any subsystem ≥ 3 months	√	√	√	√	
Schedule Variances within any subsystem ≥6 months	√	√	√	√	√
Technical Scope change At WBS Level 3 or below	√				
Technical Scope Change at WBS Level 2 or above	√	√	√	√	
Scientific Scope Change at any WBS Level			√	√	√

√ → Requires notification or approval of the person or group at top of column.

Other reports will be made by the External Advisory Board and the CDMS Executive Committee. These reports will be distributed as they become available.

Another means of distributing information is through the use of regular meetings. Several of these have already been discussed in this proposal. All will be summarized here.

The CDMS Spokesperson will call a meeting of all collaborators with a frequency of at least every 3 months to discuss progress, achievements, problems, and issues concerning the CDMS Project. This meeting will be open to all members of the collaboration.

A Subsystem Managers' Meeting will be held monthly between the CDMS Project Managers and the Subsystem Managers. This meetings will be used to discuss progress, achievements, and difficulties concerning cost, effort, schedule, and technical matters.

The CDMS Executive Committee will meet monthly to monitor and evaluate all aspects of the project and the corresponding scientific effort including the management team. Furthermore, the Executive Committee shall arrange to have a meeting of the External Advisory Board at least twice per year. The EAB will monitor progress and performance of the Project and give timely advice to the Executive Committee, Spokespersons, Project Managers, and funding agencies. Written reports of this panel will be distributed to the relevant people as necessary.

Finally, it is anticipated that travel funding will be limited, so many of these meetings will be teleconferenced.

6. Work Plan

6.1. General Description of Work

This project provides for the construction of the CDMS II experiment, a revised and upgraded version of CDMS I, which is now running in the Stanford Underground Facility (SUF). This section will give a brief description of the work required to build and install the CDMS II experiment. A more detailed description of the work to done for each subsystem is contained in Sec. 10.

6.2. Institutional Responsibilities

We will divide the construction responsibilities between the various institutions in the following way:

Stanford, in collaboration with the other detector groups, will carry out the optimization of the ZIP detector production process, and, together with UC Berkeley, the detector production. It will make use of its 15μW refrigerator for testing small test devices. The Stanford group will contribute to the warm electronics integration and the tower design and fabrication. In addition it will participate in the testing and calibration of full-size detectors in the cryogenics integration in 1999 and installation of the experiment in 2000.

UC Berkeley will participate in the optimization of the ZIP detector production process and, together with Stanford, in the detector production. The Berkeley group will also take responsibility for the fabrication of the towers (in association with the LBNL low background counting group) and cold electronics. It will participate together with Fermilab, LBNL, and CWRU in the installation of the Icebox in Soudan, the cryogenic and electronic integration, and the installation of the experiment. It will participate in the general trigger and electronics integration. It will also use its 75μW refrigerator for testing and calibration of detectors.

UC Santa Barbara has primary responsibility for the design, construction, and installation of the shield and muon veto. Santa Barbara will also acquire the digitizers and online computer systems and be responsible for data acquisition.

Case Western Reserve University will participate in detector checkout and characterization in its 160 microwatt refrigerator. CWRU will also contribute to the detector installation, commissioning, and operation at Soudan. In addition, CWRU will continue work on background simulations and interpretations.

Santa Clara University will participate in the optimization of the detector production process (together with Stanford and UC Berkeley) and in the detector checkout and characterization. It will be responsible for neutron response calibration in the Neutron Scattering Test Facility.

Princeton is responsible for developing methods to asses, monitor and control contamination from Radon daughters on the detectors and surrounding hardware. It is also developing a method for screening for contamination of surface by low-energy electron emitters.

LBNL is responsible for the acquisition of the detector material and its characterization. A LBNL technician will participate in fabrication of the detectors, will wire bond and mount the detectors inside the detector modules, and will participate in tower testing. Two LBNL technicians will be in charge of the assembly of the cryogenic mechanical hardware. LBNL is assuring the transfer to Fermilab of the information about the Icebox; a LBNL technician, who has coordinated the assembly of the CDMS I Icebox, will participate in the first assembly of the new Icebox at Soudan. LBNL is responsible for the low radioactivity background screening.

Fermilab will be responsible for the site preparation and the installation of the clean rooms and cryogenic systems at Soudan, the fabrication of the Icebox including the cryogenic control system, and purchase and installation of the helium liquefier. The design, construction, and deployment of the front-end "warm" electronics is also a Fermilab responsibility. In addition, the Fermilab group will equip the test facilities with the detector electronics, and participate in background measurements and simulations.

The **National Institute of Standards and Technology** and the **University of Colorado at Denver** will be responsible for fabricating and screening the SQUID arrays to be used with the ZIP detectors and will aid in the design and refinement of the detector sensors and of the SQUID electronics systems.

Regarding the operation of the experiment, as explained above, each group will be responsible for the maintenance of the hardware or software components it has provided to the experiment, taking part in the operation in Soudan, participating in the analysis and providing the necessary detector calibration (Stanford, UC Berkeley, and CWRU). In addition, we propose that we have: a full time resident support technician in Soudan (supported by Fermilab); a detector support technician (50% FTE on call) who has enough detector experience to make, if necessary, simple *in situ* repairs of detectors (e.g. wire bonding), remount them in the towers and in the Soudan Icebox (supervised by a Berkeley postdoc and supported by LBNL); an electronics technician for warm electronics support (on FNAL pay roll); and a 50% FTE electronics engineer for the small additional electronic circuits that are required by the operation in Soudan and the support of the detector characterization test facilities (requested on UC Berkeley operational grant).

6.3. Environment, Safety, and Health

The design, construction, commissioning, operation, and de-commissioning of all CDMS II subsystems will be done in such a manner as to be compliant with the Department of Natural Resources of the State of Minnesota requirements for equipment and operations to be carried out in the Soudan Laboratory. Work done on the subsystems in the individual CDMS institutions will be done safely and in such a manner as to protect the environment. All safety and environmental requirements of the individual institutions will be satisfied.

6.4. Quality Assurance

Quality Assurance will be an integral part of the design, fabrication, and construction of the CDMS II experiment. Special attention will be paid to the most critical items to the schedule and performance criteria of the experiment.

7. Work Breakdown Structure

All work required for the successful completion of the CDMS II Project is organized into a Work Breakdown Structure (WBS). The WBS contains a complete definition of the scope of the project and forms the basis for planning, execution, and control of the CDMS II Project. Specifically, the WBS provides the framework for the following activities:

Cost Estimating: The WBS supports a systematic approach to the preparation of the cost estimate for the project. The WBS structure is extended to a level sufficient to allow the definition of individual components for which a cost can be reasonably estimated.

Scheduling: The WBS also supports a systematic approach to the preparation of project schedule. The WBS is associated with tasks in the project schedule.

Support Requirements: The WBS, in conjunction with the associated schedule and cost estimates, provides the framework for projecting funding and manpower requirements over the life of the project.

Performance Measurement: The WBS supports the monitoring, control, and reporting of cost and schedule performance.

7.1. Organization of the WBS

The CDMS II Project WBS is organized with the overall project as Level 1 and the major subsystems at Level 2: Integration and Running, Detectors, Warm Electronics, Data Acquisition and Information Management, Shielding and Backgrounds, and Soudan Installation. Level 3 refers to the principal tasks for a specific subsystem. The WBS for the construction of CDMS II is shown to level 4 in following table. As described in Sec. 5, a subsystem manager is responsible for coordinating the construction and integration of the subsystem WBS.

1. Integration and Running (D.Akerib)
- 1.1. SUF and Test Facility Operations
  - 1.1.1. SUF operations
  - 1.1.2. Test facility operations
- 1.2. Detector Installation and commissioning at Soudan
  - 1.2.1. Room temperature preparation
  - 1.2.3. Cryogenic package installation
  - 1.2.4. Detector system operation
- 1.3. Soudan Operations
  - 1.3.1. Maintain infrastructure
  - 1.3.2. Experiment operations
- 1.4. Scientific Communication
  - 1.4.1. Meetings and Conferences
  - 1.4.2. Education and Outreach

2. Detectors (R. Gaitskell)
- 2.1. Detector Production
  - 2.1.1. Ge/Si Procurement
  - 2.1.2. Wafer Processing (Center for Integrated Systems)
  - 2.1.3. Radioactivity Assessment
  - 2.1.4. Production Documentation
- 2.2 SQUID Amplifier Production
  - 2.2.1. SQUID Chip production
  - 2.2.2. SQUID Card production
  - 2.2.3. Testing
- 2.3. Cold Hardware & Electronics Production
  - 2.3.1. Fabricate FET cards
  - 2.3.2. Fabricate Towers & Basements
  - 2.3.3. Materials Radioactivity Monitoring
- 2.4. Detector Testing & Characterization
  - 2.4.1. Assembly of Detector Stack with Tower
  - 2.4.2. Tower Checkout at Test Facilities/SUF
  - 2.4.3. Detector Characterization

3. Warm Electronics (M.Crisler)
- 3.1. Front End Electronics Production
- 3.2. Testing and Installation

4. DAQ and Information Management (H. Nelson)
- 4.1. DAQ
  - 4.1.1. DAQ Hardware
- 4.2. Information Management
  - 4.2.1. Run Coordination
  - 4.2.2. Event Coordination
  - 4.2.3. Slow Control
  - 4.2.4. Software Environment
  - 4.2.5. Network
  - 4.2.6. Software Integration
  - 4.2.7. Data Storage and Retrieval
  - 4.2.8. Documentation
- 4.3. Data Reduction
  - 4.3.1. Filter
  - 4.3.2. Hardware
  - 4.3.3. Software
  - 4.3.4. Documentation

5. Shielding , Muon Veto, Backgrounds (D.Bauer)
- 5.1. Muon Veto system
  - 5.1.1. Veto Design and Prototyping
  - 5.1.2. Veto construction
  - 5.1.3. Veto Electronics
  - 5.1.4. Assemble and test veto at Soudan
- 5.2. Shield Construction and Installation
  - 5.2.1. Shield design
  - 5.2.2. Shield procurement
  - 5.2.3. Shield construction
- 5.3. Physics Design and Backgrounds
  - 5.3.1. Neutron calculations and measurements
  - 5.3.2. Gamma Screening of CDMS construction materials
  - 5.3.3. Surface Contamination
  - 5.3.4. Radon Scrubbing
  - 5.3.5. Alpha Screening

6. Soudan Installation (R.Schmitt & L.Kula)
- 6.1. Cryogenic Systems (R.Schmitt)
  - 6.1.1. Dilution Fridge
  - 6.1.2. Icebox
  - 6.1.3. Liquefier
  - 6.1.4. Cryogenics Control System
- 6.2. Experiment Enclosures at Soudan (L.Kula)

	6.2.1. Preinstallation 6.2.2. Experiment Enclosures 6.2.3. Cryogenics Installation 6.2.4. Shield Installation **7. Management (R.Dixon)** 7.1. Project Management

7.2. WBS Dictionary

This section provides a short description of each WBS level 3 item.

1.1 SUF and Test Facility Operations: Includes manpower and other costs to operate the Stanford Underground Facility, the Stanford 15μW and the SC/SCU Test Facility at Stanford, and the test facilities at the University of California at Berkeley and Case Western Reserve University, for detector checkout and characterization. The Stanford Underground Facility is used to do the low background screening for the detectors and the other facilities are used to do other aspects of detector checkout and characterization. After detectors are produced and assembled into towers they will be operated in one or more of these facilities before being taken to the Soudan Laboratory for installation in the CDMS II Icebox. Other costs include cryogens and supplies.

1.2 Detector Installation and Commissioning at Soudan: This item provides for assembling the towers and making electrical connections before their installation in the CDMSII Icebox. It also includes installing assembled detectors into the CDMS II Icebox at Soudan, and commissioning the detectors after they are installed. Costs included Manpower, cryogens, travel, hoist trips, and other miscellaneous expenses associated with operations at Soudan.

1.3 Soudan Operations: Includes manpower and other costs associated with operating the CDMS II experiment at Soudan. Other costs includes cryogens, travel, hoist trips, and other miscellaneous expenses associated with operations at Soudan. In addition, costs to maintain the infrastructure at the Soudan Laboratory are also included in this WBS element.

1.4 Scientific Communication: This item covers travel to conferences and meetings to discuss and present scientific results of the CDMS II experiment. In addition, it covers the education and outreach effort and the costs associated with informing the public about the activities of the CDMS collaboration and the expected results. For example, it will include an information display at Soudan, which will describe the experiment to the visitors to the Laboratory.

2.1 Detector Production: This item contains the cost of purchasing bulk the germanium and silicon from which the individual wafers for the silicon and germanium detectors are made. It also includes the photolithography to add phonon and ionization sensors to the surface of the Ge and Si wafers. Manpower for detector checkout and characterization is also found here.

2.2 SQUID Amplifier Production: Includes the fabrication and testing of the SQUID chips used to readout the phonon sensors at the NIST facility in Boulder. It also includes the production and testing of the electronics cards which contain the SQUIDS and associated cold electronics.

2.3 Cold Hardware & Electronics Production: This item includes the manpower and other costs associated fabricating a tower to hold 6 ZIP detectors together with all their mechanical support hardware. Since the tower material resides close to the detectors, this item also includes radioactive background screening for all the materials to be used in the towers. Also included is the fabrication of the FET used in the amplifiers for the ionization measurement.

2.4 Detector Testing and Characterization: Includes manpower and associated costs for assembling and testing complete towers of detectors and cold electronics. It also includes the manpower for checkout and characterization of the completed towers at the CDMS test facilities.

3.1 Front End Electronics Production: Included are the design, prototyping, and production of the warm electronics used to readout out and control the detectors.

3.2 Testing and Installation: This item provides for the testing and installation of the warm electronics in the Soudan Laboratory.

4.1 DAQ Hardware: The hardware necessary to get the data from the Front End Electronics, decimate it, digitize it, and transfer it to disk and tape for later analysis. This item includes computers and digitizers.

4.2 Information Management: Manpower and networking hardware to do run coordination, data storage and retrieval and software management. This includes the online software necessary to retrieve the data from the detectors.

4.3 Data Reduction: Software, hardware, and documentation to perform data analysis offline.

5.1 Muon Veto System: Provides for the construction of a scintillation counter based veto system which will veto events that have a muon penetrating the detector region. Included are design, construction, and assembly of the veto at the Soudan Laboratory.

5.2 Shield Construction and Installation: This item provides for the construction of a passive shield around the Icebox to attenuate the flux of incident particles and radiation from all sources. The shield is made from Pb and polyethylene, and must be constructed so that it can be disassembled for detector installation.

5.3 Physics Design & Backgrounds: Included under this WBS item are calculations and measurement of the known backgrounds expected to be present in the Soudan Laboratory. In addition, screening of all materials to be located close to the detectors for radioactive contaminants is carried out under this WBS number. Surface contamination control and measurements is also found here as is radon scrubbing for the detector fabrication facility and the Soudan clean rooms.

6.1 Cryogenic Systems: Included here is the procurement of all the cryogenic components necessary for the Soudan installation such as the dilution refrigerator and a helium liquifier. In addition, Icebox fabrication plus all associated components of the cryogenic installation at Soudan can be found here.

6.2 Experiment Enclosures at Soudan: This item includes all the structures to be assemble at Soudan to house the experiment. Included are two clean rooms, and equipment room, and an electronics room. Additionally, shield installation and the cryogenic installation is also found in this WBS item. For example, final assembly of the Icebox appears here.

7.1 Project Management: Includes manpower and travel costs for the Project Manager, the Deputy Project Manager, the CDMS Spokesperson, and Co-Spokesperson. This item also includes administrative support for the project management team and some commercial software and computing equipment.

8. Schedule and Personnel

8.1. Schedule Methodology

In order to facilitate management of the project, we maintain a comprehensive schedule of work to finish design, construct, assemble and commission the CDMS II experiment. The schedule is assembled using Microsoft Project. It is organized by following the Work Breakdown Structure. A master schedule is maintained by the Project Managers, while detailed schedules for the subsystems are prepared and maintained by the subsystem managers.

The schedule proposed here assumes that CDMS II funding will become available in July 1999. The staffing level used in developing the schedule is given in the manpower table below. The baseline schedule for the CDMS II construction is given below as a Gantt chart timeline. For brevity, some tasks are shown here as summary tasks (dark lines). The dependencies of the detailed tasks that are rolled up into summary tasks are not shown but are used in calculating the schedule.

8.2. Critical Path and Milestones

The scheduling program identifies the critical path (or paths) to completion of the project. This feature calls attention to those tasks that have no "float" or slack time; any slippage in their finish date would result in a slippage of the project completion date. Tasks on the project critical path are shown hashed with diagonal lines on the Gantt chart (see chart legend).

Milestones for each subsystem are listed after the work plans in Sec. 10 and are shown as diamonds on the Gantt chart. The principal milestones for the CDMS construction project are:

1	CDMS II full approval obtained, funding available	1-July-99
2	Start Fabrication of detectors for Towers 2-4	1-Mar-00
3	Soudan Icebox installed and tested	4-Apr-00
4	Start data run with Tower 1	10-Oct-00
5	Start Fabrication of detectors for Towers 5-7	1-Sep-01
6	Start data run with Towers 1-4	12-Sep-01
7	All construction compete, start data run with all Towers	1-July-02

In developing this baseline schedule we have used our experience with CDMS I to estimate the duration of the CDMS II construction tasks. In particular, our experience with the time needed for debugging and testing the detectors with dilution refrigerator test facilities has led us to adopt what we believe are realistic estimates for these tasks.

Critical Path to Milestones

Milestone No. 2 (Gantt chart ID# 210) : the start of fabrication of detectors for Towers 2-4. The milestone is set for five months after the start of Run 20 at SUF to allow feedback from the low background running of the first ZIP detectors.

Milestone No. 3 (ID# 119): the completion of the installation and testing of the Icebox at Soudan. The critical path to this milestone includes the preparation of the RF Cleanroom and the equipment room, the installation of the refrigerator, and a 10-week cold test. The refrigerator has passed acceptance tests at the vendor and was delivered to Fermilab in March 1999.

Milestone No. 4 (ID# 206) the start of a data run with Tower 1 at Soudan. The critical path to this milestone includes an 11 week installation and commissioning period and, before that, a 12 week system test of the Icebox with shield and veto, warm electronics, and DAQ subsystems.

Milestone No. 5 (ID#224): the start of production of detectors for Towers 5-7. This work will start 10 months after the start of the run with the first tower at Soudan and can benefit from results obtained from this run. This start date is the latest possible to achieve the milestone No. 7 on time.

Milestone No. 6 (ID# 220): the start of data taking with Towers 1-4 . This is proceeded by a 3 month installation and commissioning period and by an 8 month checkout run of Tower 1 at Soudan. Towers 2-4 will be checked out at the test facilities and SUF while Tower 1 is running at Soudan. Detector production and testing is close to the critical path, with approximately 1 month of slack time.

Milestone No 7 (ID# 232): the completion of construction with the installation of the last three towers. This is the critical path for the completion of the CDMS II construction. This includes an 8-month run with Towers 1-4 and, before that, the 8 month run of Tower 1 only.

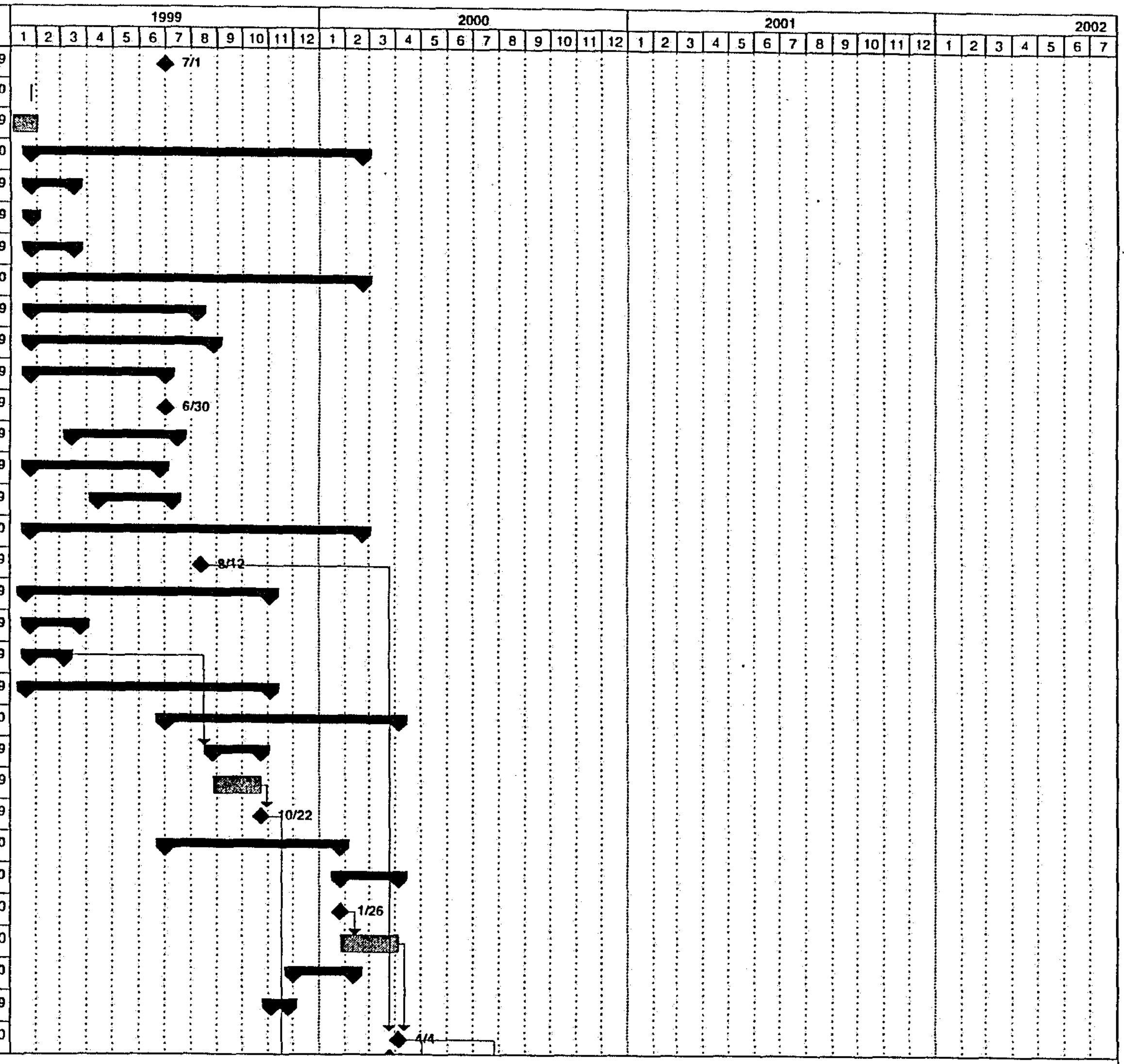
8.3. Personnel

The following table lists all the scientific and technical personnel working on the construction and operation phases of the CDMS II project. This list, with the assignments of individuals to subsystems, was used in developing the project schedule and cost estimate. A more detailed breakdown of specific tasks individuals will be working on can be found in the manpower tables of the various subsystems (Sec 10).

All individuals listed here are included in the cost estimate in Sec. 9, which also provides for 2-3 undergraduate research assistants in each group. Essentially all of the scientific staff are full time on the project as indicated by the given FTE. For faculty, FTE=1.0 implies all the person's research time is devoted to CDMS and this corresponds to two months of summer salary in the cost estimate.

The table indicates the ramp up in personnel assumed in our planning by listing generic names (e.g. "FNAL phys A") for individuals not yet identified. Graduate students and postdocs are listed as "name/generic" to indicate that the position would filled if the original person left the project. The ramp up includes two new staff physicists, six new postdocs (two of which may be filled by present graduate students, and one for which recruitment is currently underway), and seven new graduate students. New personnel are assumed to start approximately six months after the start of funding in July 1999.

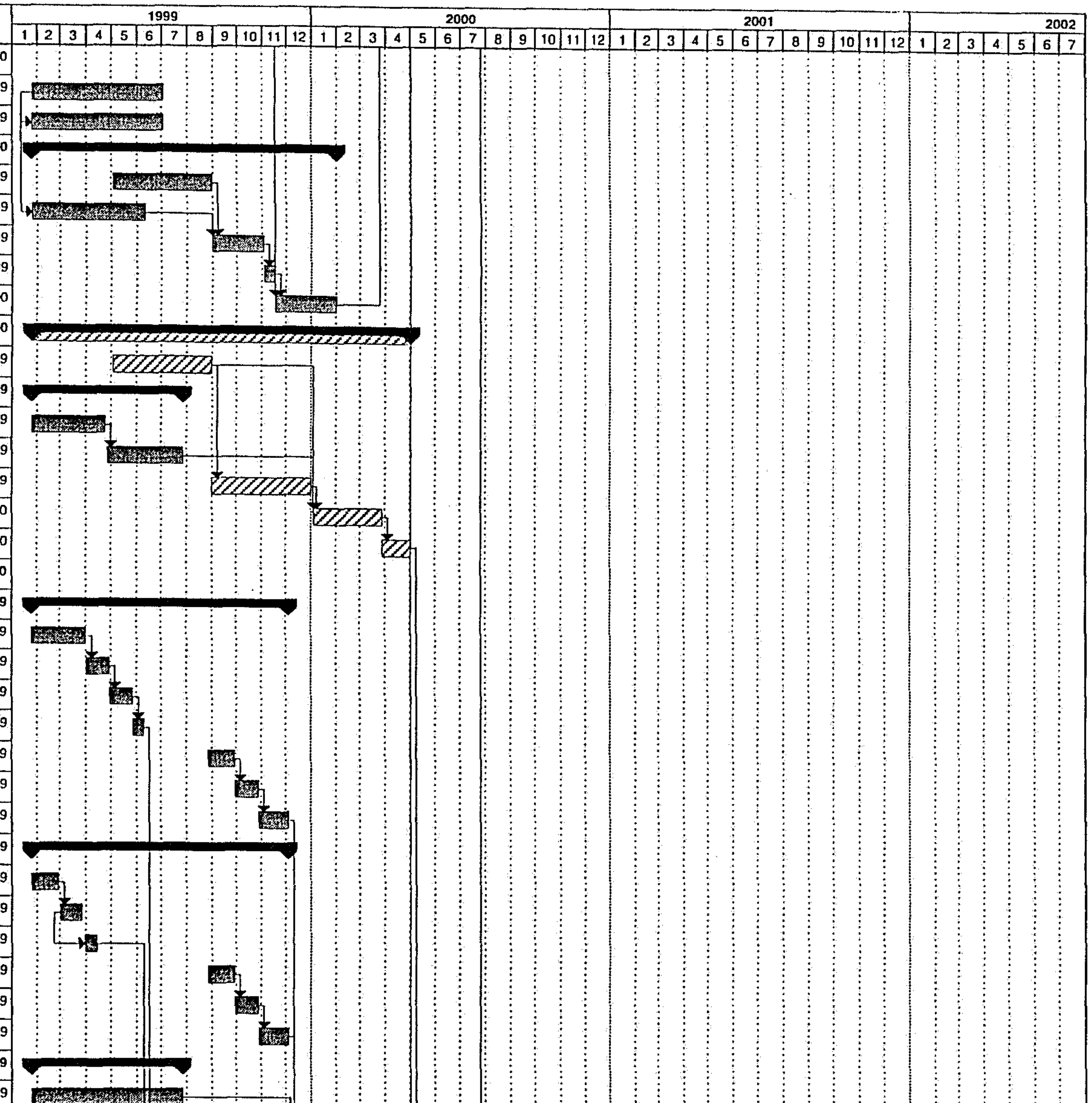
ID	Task Name	Duration	Start	Finish
1	MS#1 Project Approval/funding start	0w	7/1/99	7/1/99
2	Soudan Installation	64.2w	1/4/99	4/4/00
3	MOU FNAL/Minn.	4.3w	1/4/99	2/2/99
4	Exp. enclosures	55w	1/25/99	2/21/00
5	Preinstallation	7.2w	1/25/99	3/15/99
6	Clear Cavern Space for CDMS	0.2w	1/25/99	1/25/99
18	Concrete Pad(s)	7.2w	1/25/99	3/15/99
24	Structures	55w	1/25/99	2/21/00
25	Crane	27.8w	1/25/99	8/6/99
32	RF Clean room	30.6w	1/25/99	8/26/99
44	Equipment Room	22.6w	1/25/99	6/30/99
51	Ready for Cryogenic Installation	0d	6/30/99	6/30/99
52	Detector Prep Room	17.6w	3/15/99	7/15/99
61	Electronics Hut	21.8w	1/25/99	6/24/99
70	Mezzanine Structure	12.2w	4/15/99	7/9/99
77	HVAC System	55w	1/25/99	2/21/00
84	Enclosures Complete at Soudan	0d	8/12/99	8/12/99
85	Cryo Systems Prep	40.6w	1/20/99	11/2/99
86	Fridge	8.6w	1/25/99	3/24/99
88	Icebox	6w	1/25/99	3/5/99
95	Cryo Controls & Monitoring	40.6w	1/20/99	11/2/99
100	Cryo System Installation	38.6w	7/1/99	4/4/00
101	Icebox Installation	8w	8/27/99	10/22/99
102	Final Assembly and leak checking	8w	8/27/99	10/22/99
103	Ready for shield installation	0d	10/22/99	10/22/99
104	Dilution Refrigerator Installation	28.6w	7/1/99	1/25/00
110	Cryo System Tests	10w	1/26/00	4/4/00
111	Icebox Ready for Test Run	0d	1/26/00	1/26/00
112	Cold Test of Icebox	10w	1/26/00	4/4/00
113	Liquifier	10w	12/1/99	2/10/00
116	Cryo Control sys Installation	3w	11/4/99	11/24/99
119	MS #3 Cryo Sys Complete/Tested	0w	4/4/00	4/4/00



Project: CDMS
March 1999

Task | Progress | Summary | Rolled Up Milestone
Critical | Milestone | Rolled Up Task | Rolled Up Progress

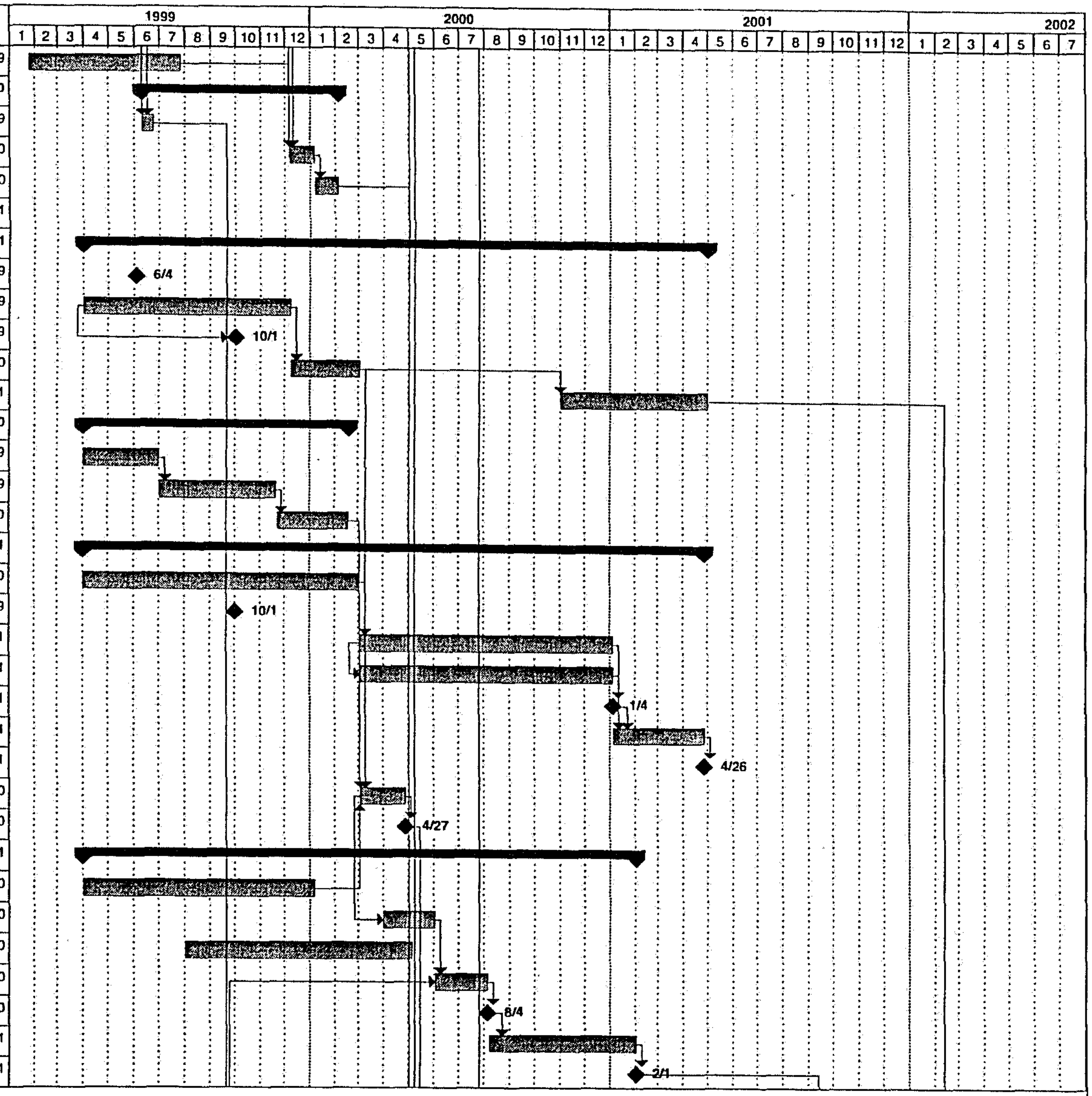
ID	Task Name	Duration	Start	Finish
120	**Shield & Veto**	65w	1/25/99	5/1/00
121	Physics Design	23w	1/25/99	7/2/99
122	Eng. Design & Prototype	23w	1/25/99	7/2/99
123	**Shield**	52w	1/25/99	1/31/00
124	Procure Shield materials	17w	5/3/99	8/30/99
125	Build frames, etc	99d	1/25/99	6/10/99
126	Test Assmbly at UCSB	9w	8/31/99	11/2/99
127	Ship to Soudan	2w	11/3/99	11/16/99
128	Shield Installation	10w	11/17/99	1/31/00
129	**Veto**	65w	1/25/99	5/1/00
130	Proc. Veto Scintillator, Tubes	17w	5/3/99	8/30/99
131	**Veto Electronics**	26w	1/25/99	7/26/99
132	Design Veto Elec	13w	1/25/99	4/23/99
133	Build Veto Elec	13w	4/26/99	7/26/99
134	Assemble Veto Counters	17w	8/31/99	12/31/99
135	Test Veto at UCSB	12w	1/4/00	3/27/00
136	Ship Veto to Soudan & Install	5w	3/28/00	5/1/00
137	**Warm Electronics**	52.8w	1/25/99	2/4/00
138	**ZIP boards**	44.2w	1/25/99	12/3/99
139	Design ZIP bds	9.6w	1/25/99	3/31/99
140	Fab prototype ZIP bds	4w	4/1/99	4/28/99
141	Stuff prototype ZIP bds	4w	4/29/99	5/26/99
142	Test prototype ZIP bds	2w	5/27/99	6/9/99
143	Fab production ZIP bds	4.3w	8/27/99	9/28/99
144	Stuff production ZIP bds	4.3w	9/28/99	10/27/99
145	Test ZIP Bds	5w	10/28/99	12/3/99
146	**RTF boards**	44.2w	1/25/99	12/3/99
147	Design RTF bds	5w	1/25/99	2/26/99
148	Fab run 20 RTF bds	4w	3/1/99	3/26/99
149	Test RTF bds	2w	3/31/99	4/13/99
150	Fab Production RTF bds	4.3w	8/27/99	9/28/99
151	Stuff production RTF bdsd	4.3w	9/28/99	10/27/99
152	Test RTF bds	5w	10/28/99	12/3/99
153	**Other components**	26w	1/25/99	7/26/99
154	Build Sub-Racks	26w	1/25/99	7/26/99



Project: CDI
March 1999

Task · Progress · Summary · Rolled Up Milestone
Critical · Milestone · Rolled Up Task · Rolled Up Progress

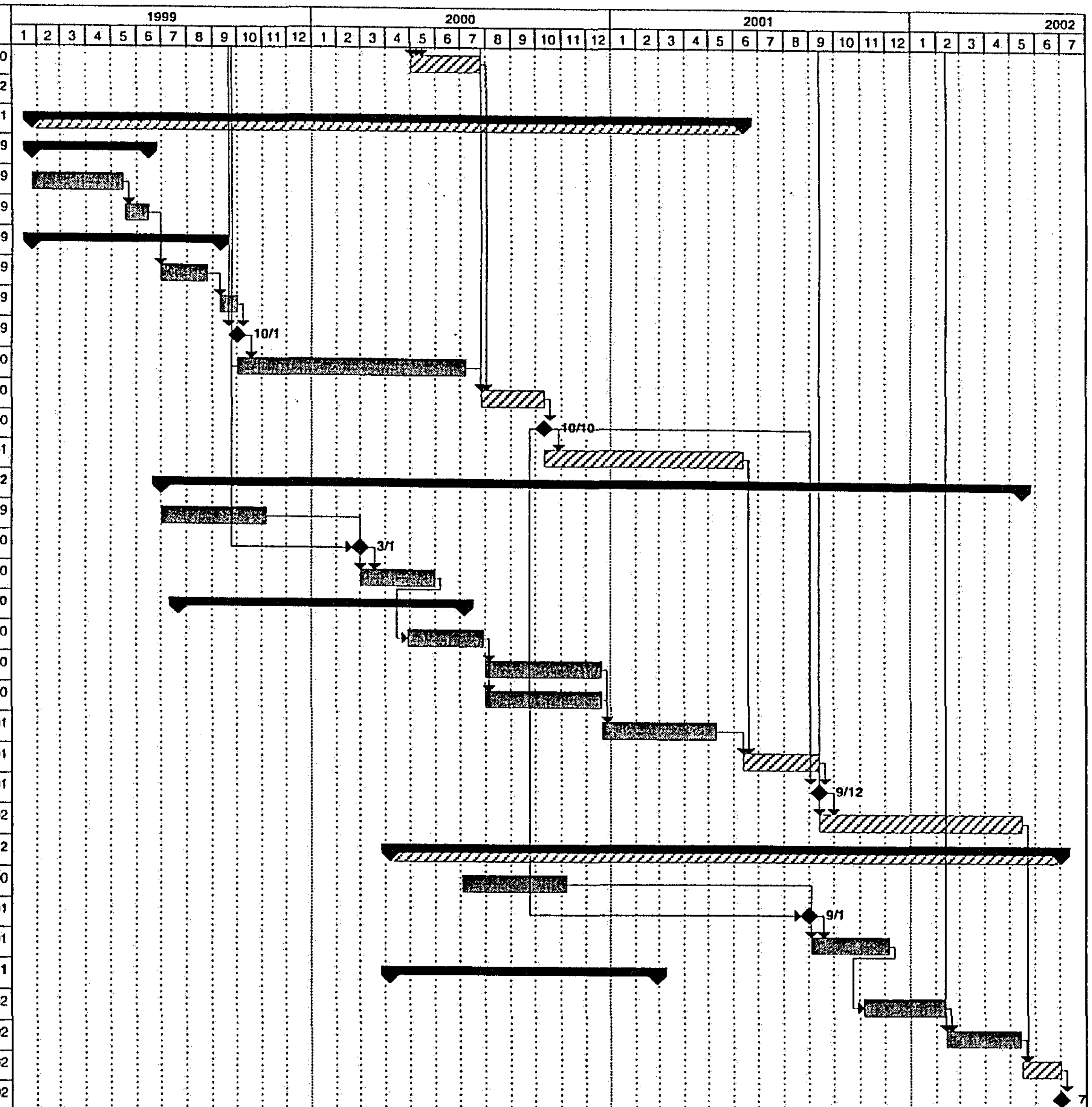
ID	Task Name	Duration	Start	Finish
155	Build Power supplies	26w	1/25/99	7/26/99
156	Test and Install W. Elec	33.2w	6/10/99	2/4/00
157	Sys test at FNAL for run 20	2w	6/10/99	6/23/99
158	Sys test at FNAL	4.3w	12/6/99	1/6/00
159	Install & test W.Elec sys at Soudan	4.3w	1/6/00	2/4/00
160	DAQ & Software	106.4w	4/1/99	4/30/01
161	Eval. Digitizers, design/test scalable DA	106.4w	4/1/99	4/30/01
162	New UCSB Postdoc hired	0w	6/4/99	6/4/99
163	System design	35w	4/1/99	12/7/99
164	Event builder: 2 crate events built	0w	10/1/99	10/1/99
165	Procure Digitizers for Twr 1-4	12w	12/8/99	3/2/00
166	Procure Digitizers for Twrs 5-7	25w	11/1/00	4/30/01
167	Trigger Design & construction	45w	4/1/99	2/17/00
168	Prototype Logic Boards	13w	4/1/99	6/30/99
169	Finalize Logic Board Design	20w	7/1/99	11/19/99
170	Board construction and testing	12w	11/22/99	2/17/00
171	Online Software	106w	4/1/99	4/26/01
172	Preliminary system design & developn	47w	4/1/99	3/2/00
173	Record Structure Defined	0w	10/1/99	10/1/99
174	Production system design & developm	43w	3/3/00	1/4/01
175	Documentation	43w	3/3/00	1/4/01
176	Production system remote test	0w	1/4/01	1/4/01
177	System finalization	16w	1/5/01	4/26/01
178	DAQ system finalized	0w	4/26/01	4/26/01
179	DAQ System test at SUF/Run 20	8w	3/3/00	4/27/00
180	Ready for system test at Soudan	0w	4/27/00	4/27/00
181	Offline Software Development	94w	4/1/99	2/1/01
182	Design Calibration Sequence	39w	4/1/99	1/6/00
183	Revise Calibration Sequence	9w	3/31/00	6/1/00
184	Design Mass Storage Logistics	39w	8/2/99	5/5/00
185	Prelimin. Prod of Yr 1 Data	9w	6/2/00	8/4/00
186	Processed run 20 data	0w	8/4/00	8/4/00
187	Design Final offline system	25w	8/7/00	2/1/01
188	Final Offline Sys Spec'd and ordered	0w	2/1/01	2/1/01



Project: CDI
March 1999

Task | Progress | Summary | Rolled Up Milestone
Critical | Milestone | Rolled Up Task | Rolled Up Progress

ID	Task Name	Duration	Start	Finish
189	Pre-Detector System Test at Soudan	12w	5/2/00	7/25/00
190	Detectors	175.6w	1/25/99	7/1/02
191	Tower Stack 1	122w	1/25/99	6/11/01
192	Fab Detectors	20.3w	1/25/99	6/15/99
193	Procure Ge/Si Batch 1	16w	1/25/99	5/14/99
194	Fab det for Twr 1	4.3w	5/17/99	6/15/99
195	Prep & assemble Tower & Elec.	32.3w	1/25/99	9/9/99
201	Detector Tests at UCB	8w	6/29/99	8/25/99
202	Twr 1 checkout at UCB	3.2w	9/9/99	10/1/99
203	Start Twr 1/Run 20 at SUF	0w	10/1/99	10/1/99
204	Twr 1/Run 20 at SUF	39w	10/1/99	7/7/00
205	Install & commission Twr 1 at Soudan	11w	7/26/00	10/10/00
206	MS#4 Start Soudan Data Run Twr 1	0w	10/10/00	10/10/00
207	Soudan Data Run Twr 1	34w	10/11/00	6/11/01
208	Tower Stacks 2-4	146.4w	7/1/99	5/15/02
209	Procure Ge/Si Batch 2	18w	7/1/99	11/5/99
210	MS#2 Start Det Production Twr 2-4	0d	3/1/00	3/1/00
211	Fab det for Twrs 2-4	13w	3/1/00	5/30/00
212	Fab Twr parts	48.8w	7/22/99	7/5/00
215	Assemble Twrs 2-4	13w	4/28/00	7/28/00
216	Twr 2-4 test at UCB	20w	7/31/00	12/19/00
217	Twr 2-4 test at CWRU	20w	7/31/00	12/19/00
218	Twr 2-4 run at SUF	20w	12/20/00	5/10/01
219	Commission Twrs 2-4	13w	6/12/01	9/12/01
220	MS #6 Start data run Twrs 1-4	0w	9/12/01	9/12/01
221	Soudan data Run Twrs 1-4	34w	9/13/01	5/15/02
222	Tower Stacks 5-7	114.2w	4/6/00	7/1/02
223	Procure Ge/Si Batch 3	18w	7/3/00	11/6/00
224	MS#5 Start Production Twr 5-7	0d	9/1/01	9/1/01
225	Fab det for Twrs 5-7	13w	9/3/01	12/5/01
226	Fab Twr parts	45.6w	4/6/00	2/26/01
229	Asmble Det in Twr 5-7	13w	11/6/01	2/11/02
230	Twr 5-7 run at SUF	13w	2/12/02	5/13/02
231	Commission Twrs 5-7	6.6w	5/16/02	7/1/02
232	MS #7 Constr. Complete/Start run Twi	0d	7/1/02	7/1/02



Project: CDI
March 1999

Task | Critical | Progress | Milestone | Summary | Rolled Up Task | Rolled Up Milestone | Rolled Up Progress

CDMS Personnel

Sum of FTE				Scientific Staff					Technical Staff				
				Project Year					Project Year				
Inst	level	Name	Subsystem	1	2	3	4	5	1	2	3	4	5
CWRU	fac	Akerib	Detectors	1.00	0.70	0.70	0.30	0.30					
			Intgr & Running		0.30	0.30	0.70	0.70					
	postd	Bolozdynya/pd B	Detectors	0.90	0.90	0.90	0.25	0.25					
			Intgr & Running	0.10	0.10	0.10	0.75	0.75					
		Schnee/pd A	Detectors	0.75			0.30	0.30					
			Intgr & Running	0.25	1.00	1.00	0.70	0.70					
	grad	Driscoll/gr B	Detectors	0.80	0.50	0.50	0.30	0.30					
			Intgr & Running	0.20	0.50	0.50	0.70	0.70					
		Perera/gr A	Detectors	0.60	0.40	0.40	0.25	0.25					
			Shield & Bkgd	0.40	0.50	0.50							
			Intgr & Running		0.10	0.10	0.75	0.75					
		Wang/gr C	Detectors		0.40		0.25	0.25					
			Intgr & Running		0.60	1.00	0.75	0.75					
	tech	Computer support	Intgr & Running						0.05	0.05	0.05	0.05	0.05
CWRU Total				5.00	6.00	6.00	6.00	6.00	0.05	0.05	0.05	0.05	0.05
FNAL	phys	Crisler	Warm Elect.	0.50	0.50								
			Intgr & Running			0.50	0.50	0.50					
		Dixon	Management	1.00	1.00	1.00	1.00	1.00					
		FNAL phys A	Soudan Infra	0.50	1.00	1.00							
			Intgr & Running				1.00	1.00					
	postd	Eichblatt/pd A	Warm Elect.	0.50	0.50								
			DAQ	0.50	0.50	0.50							
			Intgr & Running			0.50	1.00	1.00					
		FNAL postd B	Soudan Infra	0.50	1.00	1.00							
			Intgr & Running				1.00	1.00					
	eng	Haldeman	Warm Elect.						0.63	0.50			
		Kula	Soudan Infra						1.00	1.00	1.00		
		Schmitt	Soudan Infra						0.50	0.50	0.50		
		FNAL eng A	DAQ						0.50	0.50			
		FNAL eng B	Soudan Infra						0.12				
	tech	FNAL designer	Soudan Infra						0.25				
		FNAL techs	Soudan Infra						2.00				
		Johnson,W.	Warm Elect.						0.63	0.50			
		Soudan tech	Soudan Infra						0.50				
			Intgr & Running						1.00	1.00	1.00	1.00	1.00
		FNAL pcb assy tech	Warm Elect.						0.13				
		Merkel	Warm Elect.						0.63	0.13			
		Morrison/Regan	Warm Elect.						0.63	0.13			
FNAL Total				3.50	4.50	4.50	4.50	4.50	8.52	4.26	2.50	1.00	1.00
LBNL	fac	Ross	Soudan Infra	0.30	0.30	0.30							
			Intgr & Running				0.30	0.30					
	phys	Taylor,J.	Soudan Infra	0.25	0.25	0.25							
			Intgr & Running				0.25	0.25					
		McDonald	Shield & Bkgd	0.08	0.08	0.08							
	postd	LBNL postd A	Intgr & Running			1.00	1.00	1.00					
	tech	Emes	Detectors						1.00	1.00	1.00	0.50	0.50
		LBNL tech A	Detectors						1.00	1.00	0.00		
		LBNL tech B	Detectors						1.00	1.00			
LBNL Total				0.63	0.63	1.63	1.55	1.55	3.00	3.00	1.00	0.50	0.50
PU	fac	Shutt	Shield & Bkgd	0.25	0.25	0.25							
			Intgr & Running				0.25	0.25					
	postd	PU postd A	Shield & Bkgd	0.50	1.00	0.50							
			Intgr & Running			0.50	1.00	1.00					
	grad	PU grad A	Shield & Bkgd	0.50	1.00	0.50							
			Intgr & Running			0.50	1.00	1.00					
	eng	PU eng	Shield & Bkgd						0.20	0.00			
PU Total				1.25	2.25	2.25	2.25	2.25	0.20	0.00			
SCU	fac	Young	Detectors	1.00	1.00	1.00							
			Intgr & Running				1.00	1.00					
SCU Total				1.00	1.00	1.00	1.00	1.00					

Sum of FTE				Scientific Staff					Technical Staff				
				Project Year					Project Year				
SU	fac	Cabrera	Management	1.00	1.00	1.00	1.00	1.00					
	phys	SU phys	Detectors	0.75	0.40	0.20	0.30	0.30					
			Intgr & Running	0.25	0.60	0.80	0.70	0.70					
	postd	Clarke/pd A	Detectors	1.00	0.75	0.75							
			Intgr & Running		0.25	0.25	1.00	1.00					
	grad	Saab/gr A	Detectors	1.00	0.40	0.25	0.30	0.30					
			Intgr & Running		0.60	0.75	0.70	0.70					
		SU grad B	Detectors	0.50	1.00	1.50							
			Intgr & Running				1.00	1.00					
		SU grad C	Detectors	0.50	1.00	1.00	0.30	0.30					
			Intgr & Running				0.70	0.70					
	eng	Hennessy	Intgr & Running						0.50	0.50	0.50		
	tech	Abusaidi	Detectors						0.90	0.90	0.90		
		Castle	Detectors						0.50	0.50	0.50		
		Perales	Intgr & Running						0.50	0.50	0.50	0.30	0.30
SU Total				5.00	6.00	6.50	6.00	6.00	2.40	2.40	2.40	0.30	0.30
UCB	fac	Sadoulet (LBL budge	Management	1.00	1.00	1.00	1.00	1.00					
	phys	Spadafora	Management	0.75	1.00	1.00	1.00	1.00					
	postd	Gaitskell/pd A	Detectors	1.00	1.00	1.00	0.30	0.30					
			Intgr & Running				0.70	0.70					
		Hellmig/pd B	Detectors	0.90	0.65	0.90	0.25	0.25					
			Intgr & Running	0.10	0.35	0.10	0.75	0.75					
		Isaac/pd C	Detectors	0.75	0.75	0.75							
			Shield & Bkgd	0.15	0.15	0.15							
			Intgr & Running	0.10	0.10	0.10	1.00	1.00					
		Golwala/pd D	Detectors	1.00	1.00	1.00							
	grad	Mandic/gr A	Detectors	0.90	0.50		0.25	0.25					
			Intgr & Running	0.10	0.50	1.00	0.75	0.75					
		UCB grad B	Detectors	0.50	1.00	1.00							
			Intgr & Running				1.00	1.00					
		UCB grad C	Detectors	0.40	0.90	0.90	0.25	0.25					
			Intgr & Running	0.10	0.10	0.10	0.75	0.75					
	eng	Seitz	Detectors						1.00	1.00	1.00		
			Intgr & Running									0.50	0.50
		Smith,G.	Detectors						0.40	0.40	0.40		
	admin	admin asst	Management						0.50	0.50	0.50	0.50	0.50
		Esteves	Management						0.50	0.50	0.50	0.50	0.50
UCB Total				7.75	9.00	9.00	8.00	8.00	2.40	2.40	2.40	1.50	1.50
UCSB	fac	Caldwell	Management	1.00	1.00	1.00	1.00	1.00					
		Nelson	DAQ	1.00	1.00	1.00							
			Intgr & Running				1.00	1.00					
	phys	Bauer	DAQ	0.40	0.40	0.20							
			Shield & Bkgd	0.40	0.40	0.20							
			Intgr & Running	0.20	0.20	0.60	1.00	1.00					
		Yellin	Shield & Bkgd	1.00	1.00	0.50							
			Intgr & Running			0.50	1.00	1.00					
	postd	UCSB postd A	DAQ	1.00	1.00	0.50							
			Intgr & Running			0.50	1.00	1.00					
	grad	Bunker/gr A	DAQ	0.50	0.50	0.50							
			Shield & Bkgd		0.50	0.50							
			Intgr & Running				1.00	1.00					
		UCSB grad B	DAQ	0.50	1.00	0.50							
			Intgr & Running			0.50	1.00	1.00					
		UCSB grad C	DAQ	0.50	1.00	0.50							
			Intgr & Running			0.50	1.00	1.00					
	eng	Burke,S.	DAQ						0.50	0.50	0.50		
		Hale	Shield & Bkgd						0.50	0.50	0.50		
	tech	Callahan,D.	Shield & Bkgd						1.00	0.50			
UCSB Total				6.50	8.00	8.00	8.00	8.00	2.00	1.50	1.00		
NIST	fac	Huber (sabbat)	Detectors	0.40									
	phys	Martinis	Detectors	0.10	0.10	0.10							
	tech	NIST tech	Detectors						0.40	0.40	0.25		
NIST Total				0.50	0.10	0.10			0.40	0.40	0.25		
UcoID	fac	Huber	Detectors	0.50	0.50	0.33							
UcoID Total				0.50	0.50	0.33							
Grand Total				31.63	37.98	39.31	37.30	37.30	18.97	14.01	9.60	3.35	3.35

9. Financial Plan: Cost Estimate and Funding

9.1. Costing Methodology

The 5-year financial plan presented here is the result of a bottom-up estimate of the funds required for the personnel and equipment needed to build and operate the CDMS II experiment. We have attempted to provided a complete account of all the costs associated with the project, i.e. all the time and expenses of all the people working on the project. We have included funds used from existing support ("base program") as well as the additional funds requested in this proposal ("increment funds") in order to provide a complete account of the project needs.

In order to make this cost estimate, a cost database was developed by the project managers using Microsoft Excel. A detailed cost estimate was worked out for each subsystem by including all the personnel, equipment, expenses, and travel needed. A costed item is assigned to a WBS task at level 3, to a project year consistent with the schedule in Sec. 8, and to an institution's base or increment funding. Costs are estimated in 1999 dollars and a 3% inflation correction is added for future years.

This cost estimate is developed using "project years" which start on July 1 of each year, and cover the following periods:

Year 1	01-Jul-99	30-Jun-00
Year 2	01-Jul-00	30-Jun-01
Year 3	01-Jul-01	30-Jun-02
Year 4	01-Jul-02	30-Jun-03
Year 5	01-Jul-03	30-Jun-04

Funds spent on equipment for this project prior to our Year 1 are listed separately in Table 9.2.2.

We have assigned costs to our construction or operations budgets. The project schedule requires a three year construction budget. During the first three years, we include most of the costs associated with our "Integration and Running" subsystem (e.g. operating the test facilities for detector checkout) as construction costs. (Note that in previous cost estimates of this project, such costs were listed under the operating budget, resulting in an apparent lower construction total.) The operations budget contains some costs for start up of operations in years 2 and 3 and full operating cost in years 4 and 5. It consists mostly of the costs under "Integration and Running" but, as can be seen in Table 9.2.5, there are also management and some continued detector testing costs.

When assigning a budget item to an institution, we list it as under base or increment funding. For the NSF groups, "base program" refers previously approved grants, e.g. CfPA or CAREER, that will be used for CDMS II. For the DOE groups, this refers to the roughly constant level the group has been supported at and at which it is assumed to continue. The Fermilab support is listed as base program. For the NSF groups, "increment" refers to the amount requested in this proposal, and for the DOE groups, it refers to a supplement needed to build and operate CDMS II.

We have assigned a budget contingency for the construction budget using the following guidelines, which are taken from DOE cost estimating guide (DOE G 430.1-1). We assign a contingency to each particular budget item of equipment or payroll support of technicians and engineers.

Phase of Project	**Contingency Estimate**
Preliminary Estimate Based on Conceptual Design	30%--> 50%
Budget Estimate during Design work	25%--> 45%
Final Design Complete	10%--> 20%
Item in Hand	0%

In previous reviews of this project, attention has been called to the possibility of a need to deal with higher than expected background levels at Soudan. In response to this we have allowed for items such as extra shielding in our contingency estimate as they are not included in the base cost. A breakdown of the contingency estimate for each subsystem is provided in the tables in Sec. 10, with special items such as the extra shielding listed separately. This review of the contingency has resulted in a somewhat higher amount than our previous estimates.

9.2. Cost Summary Tables

The following tables provide a summary of the cost estimate indicating the funds needed for each subsystem and for each institution per year. Unless listed separately, contingency is included in the totals. (In the tables, "Cost3" includes contingency, "Cost2" does not). A detailed budget for each subsystem, listing individual items and with contingency listed separately, in given in Sec. 10.

Table 9.2.1: Five Year Project Summary (July 1999 – June 2004)

	BASE			INCREMENT			BASE + INCREMENT		
CONSTRUCTION									
	Cost	Contingency	Total	Cost	Contingency	Total	Cost	Contingency	Total
NSF	560,517	0	560,517	4,484,489	273,490	4,757,979	5,045,005	273,490	5,318,496
DOE Lab	4,228,786	599,926	4,828,712	1,186,160	215,193	1,401,352	5,414,946	815,119	6,230,064
DOE Univ	2,089,442	0	2,089,442	3,506,281	1,234,266	4,740,548	5,595,724	1,234,266	6,829,990
	6,878,745	599,926	7,478,671	9,176,930	1,722,949	10,899,879	16,055,675	2,322,875	18,378,550
OPERATIONS									
	Cost	Contingency	Total	Cost	Contingency	Total	Cost	Contingency	Total
NSF	0	0	0	3,187,925	0	3,187,925	3,187,925	0	3,187,925
DOE Lab	2,073,829	0	2,073,829	416,228	0	416,228	2,490,057	0	2,490,057
DOE Univ	1,560,368	0	1,560,368	530,892	0	530,892	2,091,260	0	2,091,260
	3,634,197	0	3,634,197	4,135,045	0	4,135,045	7,769,242	0	7,769,242
CONSTRUCTION + OPERATIONS									
	Cost	Contingency	Total	Cost	Contingency	Total	Cost	Contingency	Total
NSF	560,517	0	560,517	7,672,414	273,490	7,945,904	8,232,931	273,490	8,506,421
DOE Lab	6,302,615	599,926	6,902,541	1,602,388	215,193	1,817,580	7,905,003	815,119	8,720,121
DOE Univ	3,649,810	0	3,649,810	4,037,173	1,234,266	5,271,440	7,686,984	1,234,266	8,921,250
	10,512,942	599,926	11,112,868	13,311,975	1,722,949	15,034,924	23,824,917	2,322,875	26,147,792

Table 9.2.2: CDMS II Equipment Expenditures prior to July 1999

Sum of Cost2			
Agcy	Subsystem	Name	
NSF	Detectors	Striplines	60,500
	Soudan Infra	Icebox Cu	30,000
		Dilution fridge	220,000
NSF Total			310,500
DOE Lab	Detectors	Ge det (10) Raw Mat & pol.	33,600
	Warm Elect.	Crates (9)	20,600
		RTF Boards (25)	100,000
		Test Bnch/Diag eqpt FNAL	20,000
		Test Bnch/Diag eqpt UCB	6,700
		ZIP Boards (60)	116,000
	Soudan Infra	Concrete Pad(s)	12,000
		Crane	45,000
		Electrical System	5,000
		Machining & Welding	140,000
DOE Lab Total			498,900
DOE Univ	Shield & Bkgd	old lead	65,000
DOE Univ Total			65,000
Grand Total			874,400

Table 9.2.3: Summary by Project Year

Construction Budget		Project Year					
Agcy	fund	1	2	3	4	5	Grand Total
NSF	base	412,697	72,456	75,364			560,517
	Inc	1,635,681	1,680,496	1,441,801			4,757,979
NSF Total		2,048,378	1,752,952	1,517,166			5,318,496
DOE Lab	base	2,561,324	1,486,311	781,076			4,828,712
	Inc	594,670	556,428	250,254			1,401,352
DOE Lab Total		3,155,994	2,042,739	1,031,331			6,230,064
DOE Univ	base	729,927	706,377	653,139			2,089,442
	Inc	2,285,701	1,553,701	901,146			4,740,548
DOE Univ Total		3,015,627	2,260,079	1,554,284			6,829,990
Construction Total		8,220,000	6,055,769	4,102,781			18,378,550
Operations Budget							
NSF	Inc		125,894	233,333	1,400,521	1,428,177	3,187,925
NSF Total			125,894	233,333	1,400,521	1,428,177	3,187,925
DOE Lab	base		124,614	327,422	802,849	818,944	2,073,829
	Inc			83,296	164,006	168,926	416,228
DOE Lab Total			124,614	410,718	966,855	987,870	2,490,057
DOE Univ	base		23,627	76,823	729,981	729,937	1,560,368
	Inc		12,066	94,418	208,909	215,499	530,892
DOE Univ Total			35,693	171,241	938,890	945,435	2,091,260
Operation Total			286,201	815,292	3,306,267	3,361,482	7,769,242
Grand Total		8,220,000	6,341,971	4,918,073	3,306,267	3,361,482	26,147,792

Table 9.2.4: Summary by Subsystem

		Base Cost					Contingenc	Base+Cont.
	Subsystem	Personnel	Travel	S&E	Eqpt	Total		Total
Construction	Detectors	3,837,013	103,845	497,999	662,848	5,101,706	733,424	5,835,130
	Warm Elect.	553,820	28,826		210,010	792,656	145,301	937,957
	DAQ	917,252	32,262		683,346	1,632,859	391,850	2,024,710
	Shield & Bkgd	1,106,014	84,362	262,464	538,720	1,991,560	641,380	2,632,940
	Soudan Infra	1,381,094	183,118	32,876	555,820	2,152,908	410,919	2,563,827
	Management	1,278,957	115,643	56,395	8,120	1,459,116		1,459,116
	Intgr & Running	1,099,478	425,028	1,270,186	130,177	2,924,870		2,924,870
Construction Total		10,173,629	973,084	2,119,921	2,789,040	16,055,675	2,322,875	18,378,550
Operations	Detectors	467,692		12,127		479,819		479,819
	Management	938,892	64,811	13,345		1,017,048		1,017,048
	Intgr & Running	4,601,857	556,982	1,097,140	16,396	6,272,375		6,272,375
Operations Total		6,008,441	621,794	1,122,612	16,396	7,769,242		7,769,242
Grand Total		16,182,070	1,594,878	3,242,533	2,805,435	23,824,917	2,322,875	26,147,792

Table 9.2.5: Summary by Subsystem Task

Sum of Cost with contingency)			Project Year					
Construction Budget								
Subsystem	**WBS**	**Task**	1	2	3	4	5	**Grand Total**
Intgr & Running	1.1.	SUF/TF Running	637,497	447,856	384,821			1,470,174
	1.2.	Det. Install/commis.	111,863	458,508	420,188			990,559
	1.3.	Soudan Ops/Science	120,984					120,984
	1.4.1	Meetings/conferences	69,666	87,067	92,293			249,026
	1.4.2	Education/outreach	40,698	27,888	25,542			94,127
Intgr & Running Total			980,707	1,021,318	922,844			2,924,870
Detectors	2.1.	Det Production	683,883	536,163	354,795			1,574,841
	2.2.	SQUID amps	279,346	261,846	168,505			709,698
	2.3.	Towers & Cold Elec	754,409	547,901	361,983			1,664,293
	2.4.	Det. Testing & Char.	714,650	609,018	562,630			1,886,298
Detectors Total			2,432,288	1,954,929	1,447,913			5,835,130
Warm Elect.	3.1.	Board Production	543,827	210,868				754,695
	3.2.	Elec test/install		183,263				183,263
Warm Elect. Total			543,827	394,130				937,957
DAQ	4.1.	DAQ system	812,202	710,915	274,575			1,797,692
	4.2.	Information Mngmnt	53,750	14,806	20,555			89,111
	4.3.	Data Reduction	23,750	40,556	73,600			137,906
DAQ Total			889,702	766,277	368,730			2,024,710
Shield & Bkgd	5.1.	Muon Veto	430,401	208,610	26,949			665,959
	5.2.	Shield const/install	312,827	189,807	134,978			637,612
	5.3.1	Phys Design/Bkgds	182,494	266,532	106,562			555,587
	5.3.2	Gamma Screening	68,912	70,979	43,498			183,389
	5.3.3	Surface Contamination	117,884	78,596	63,535			260,015
	5.3.4	Radon Suppression	321,144	9,234				330,378
Shield & Bkgd Total			1,433,661	823,758	375,521			2,632,940
Soudan Infra	6.1.1	Icebox	338,986	126,115	119,589			584,690
	6.1.3	Liquefier	121,500					121,500
	6.1.4	Cryo Controls	90,043					90,043
	6.2.2	Exp Enclosures	807,242	412,515	377,945			1,597,702
	6.2.3	Cryo installation	93,245	76,648				169,893
Soudan Infra Total			1,451,016	615,277	497,534			2,563,827
Management	7.1.	Management	488,798	480,079	490,238			1,459,116
Management Total			488,798	480,079	490,238			1,459,116
Construction Total			**8,220,000**	**6,055,769**	**4,102,781**			**18,378,550**
Operations Budget								
Intgr & Running	1.1.	SUF/TF Running				165,632	168,944	334,576
	1.3.	Soudan Ops/Science		286,201	815,292	2,274,220	2,308,330	5,684,043
	1.4.1	Meetings/conferences				98,765	101,586	200,351
	1.4.2	Education/outreach				26,308	27,097	53,405
Intgr & Running Total				286,201	815,292	2,564,925	2,605,957	6,272,375
Detectors	2.4.	Det. Testing & Char.				236,397	243,422	479,819
Detectors Total						236,397	243,422	479,819
Management	7.1.	Management				504,945	512,103	1,017,048
Management Total						504,945	512,103	1,017,048
Operations Total				**286,201**	**815,292**	**3,306,267**	**3,361,482**	**7,769,242**
Grand Total			**8,220,000**	**6,341,971**	**4,918,073**	**3,306,267**	**3,361,482**	**26,147,792**

Table 9.2.6: Summary by Institution

				Project Year					
Agcy	fund	Inst	Constr	1	2	3	4	5	Grand Total
NSF	base	CWRU	Constr	100,039	72,456	75,364	0	0	247,859
		UCB	Constr	312,657	0	0	0	0	312,657
	base Total			412,697	72,456	75,364	0	0	560,517
	Inc	CWRU	Constr	387,925	346,405	334,221	0	0	1,068,552
			Oper	0	100,364	111,710	437,898	451,034	1,101,006
		CWRU Total		387,925	446,769	445,931	437,898	451,034	2,169,558
		PU	Constr	154,170	183,472	148,446	0	0	486,088
			Oper	0	0	40,299	174,988	176,886	392,172
		PU Total		154,170	183,472	188,744	174,988	176,886	878,260
		SCU	Constr	60,513	54,731	47,087	0	0	162,332
			Oper	0	0	0	36,406	37,043	73,449
		SCU Total		60,513	54,731	47,087	36,406	37,043	235,781
		UCB	Constr	837,156	1,018,314	912,047	0	0	2,767,517
			NSF contingency	195,916	77,574	0	0	0	273,490
			Constr+Cont.	1,033,073	1,095,887	912,047	0	0	3,041,007
			Oper	0	25,530	81,324	751,230	763,213	1,621,297
		UCB Total		1,033,073	1,121,418	993,371	751,230	763,213	4,662,305
	Inc Total			1,635,681	1,806,390	1,675,134	1,400,521	1,428,177	7,945,904
NSF Total				**2,048,378**	**1,878,846**	**1,750,498**	**1,400,521**	**1,428,177**	**8,506,421**
DOE Lab	base	FNAL	Constr	2,176,084	1,238,341	671,196	0	0	4,085,621
			FNAL conting.	338,922	200,263	60,741	0	0	599,926
			Constr + conting	2,515,006	1,438,603	731,937	0	0	4,685,547
			Oper	0	124,614	327,422	752,236	766,812	1,971,084
		FNAL Total		2,515,006	1,563,217	1,059,360	752,236	766,812	6,656,631
		LBNL	Constr	46,318	47,708	49,139	0	0	143,165
			Oper	0	0	0	50,613	52,132	102,745
		LBNL Total		46,318	47,708	49,139	50,613	52,132	245,910
	base Total			2,561,324	1,610,925	1,108,499	802,849	818,944	6,902,541
	Inc	LBNL	Constr	532,444	505,157	148,558	0	0	1,186,160
			LBNL conting.	62,226	51,271	101,696	0	0	215,193
			Constr+Cont.	594,670	556,428	250,254	0	0	1,401,352
			Oper	0	0	83,296	164,006	168,926	416,228
		LBNL Total		594,670	556,428	333,550	164,006	168,926	1,817,580
	Inc Total			594,670	556,428	333,550	164,006	168,926	1,817,580
DOE Lab Total				**3,155,994**	**2,167,353**	**1,442,049**	**966,855**	**987,870**	**8,720,121**
DOE Univ	base	SU	Constr	389,953	384,582	378,869	0	0	1,153,404
			Oper	0	5,406	11,136	390,013	389,980	796,535
		SU Total		389,953	389,988	390,005	390,013	389,980	1,949,938
		UCSB	Constr	339,973	321,795	274,270	0	0	936,038
			Oper	0	18,221	65,687	339,968	339,957	763,833
		UCSB Total		339,973	340,016	339,957	339,968	339,957	1,699,872
	base Total			729,927	730,004	729,962	729,981	729,937	3,649,810
	Inc	SU	Constr	500,189	357,478	293,713	0	0	1,151,380
			Oper	0	12,066	66,285	91,360	96,692	266,404
		SU Total		500,189	369,545	359,998	91,360	96,692	1,417,784
		UCSB	Constr	1,056,709	534,194	322,972	0	0	1,913,875
			Oper	0	0	28,133	117,549	118,806	264,488
		UCSB Total		1,056,709	534,194	351,105	117,549	118,806	2,178,363
		NIST	Constr	118,984	108,984	78,990	0	0	306,957
		UcolD	Constr	51,029	51,029	32,011	0	0	134,069
		FNAL	DOE Univ. conting.	558,790	502,017	173,460	0	0	1,234,266
	Inc Total			2,285,701	1,565,768	995,564	208,909	215,499	5,271,440
DOE Univ Total				**3,015,627**	**2,295,772**	**1,725,525**	**938,890**	**945,435**	**8,921,250**
Grand Total				**8,220,000**	**6,341,971**	**4,918,073**	**3,306,267**	**3,361,482**	**26,147,792**

10. Subsystem Work plans, Budgets, and Schedules

The following subsections provide the detailed work plans, the schedule milestones, and the resources needed for each subsystem. Work plans are given, followed by detail work breakdown structures. The teams working on each subsystem are shown in the manpower tables, where individuals have been identified with for all level 3 tasks. The subsystem schedule is summarized in a milestone table. A detailed breakdown of the subsystem cost is given, listing first the base cost estimate and then the associated contingency.

10.1. Cryogenic Detectors

Work Plan

Forty-two cryogenic detectors will be deployed in the low background facility at the Soudan mine, delivering a gross WIMP-target mass of around 7 kg. The detector technology is based on prototypes developed during the CDMS I experiment, and the final design is now fixed for the full deployment. Detectors will be run in Soudan beginning with 6 in July 2000, followed by 24 in June 2001, and a further 24 one year later. The detector production and testing schedules are tailored to make this comfortably possible.

The detectors are made from 76 mm diameter wafers, 10 mm thick, which have a gross weight of, either 250 g in Ge, or 100 g when made of Si. (We will deploy 21 of each target material.) Thin superconducting films are deposited on the front and back sides of the wafers to allow simultaneous measurement of athermal phonon and electron-hole excitations within the crystals which are operated at 30 mK. The detectors are mounted in enclosures fabricated from high purity materials, which provide local shielding from radioactive background. The mounts also provide electrical connections to sets of SQUID and FET amplifiers, also run inside the low background cryostat.

The full complement of detectors will be held in 7 towers, with a stack of 6 detectors per tower. The tower design was completed and implemented in CDMS I. It simultaneously meets the criteria of providing low noise, low impedance, low radioactive wiring from the detectors to the first stage of electronics situated at 600 mK and 4 K, while proving only a small heat load to the colder stages. At present the "basement" directly surrounding the detectors has been redesigned, and is being tested in the latest run of CDMS I (started Oct 1998). The changes were made in order to further reduce radioactive contamination local to the detectors. We anticipate one further design revision in order to accommodate the large detectors wafers now used (250 g) when compared to the 160 g Ge detectors currently deployed in CDMS I.

The phonon readout uses a technique know as QET (Quasiparticle trapping assisted, Electrothermal feedback, Transition edge) Sensors, which combine Al and (active) W films, on the surface of the detector, to measure the non–equilibrium phonon excitation from particle interactions. In addition, the charge readout from the detector uses a thin electrode formed from bi-layers of Al and amorphous Si to directly measure the electron-hole excitations. Both these technologies were developed under the CDMS I program, and have been optimized to make them suitable for use in a WIMP recoil search.

Fabrication of the thin superconducting films on the surfaces of the detectors is carried out at the Stanford Nanofabrication Facility (formerly Center for Integrated Systems), based at Stanford University. All fabrication equipment is directly maintained by the facility and we have a memorandum of understanding that it will continue to be maintained during lifetime of our program. A large number of QET devices have been made in the facility over the last 6 years, and the processing steps are well understood. Detectors are fabricated using conventional wafer processing techniques, with the caveat that the wafers are 1 cm, rather than the more usual 300–500 μm thick, and can be produced in batches as large as 24 which is more than adequate to meet the requirements of CDMS II.

After thin film processing the wafers are moved to the Radon Suppression Facility (a Cleanroom with radon scrubbing, located in the Varian Building, Stanford University) where they are visually inspected, and then mounted into detector modules, which have been separately manufactured at LBNL/UC Berkeley.

The SQUIDs, used to read out the phonon sensors, are designed, and fabricated, specifically, for the requirements of CDMS II. These requirements include a 0.2" square die, integrated detector bias resistor, 0.25 μH input inductance, and operation at 600 mK. The SQUIDs will be fabricated at NIST and screened for basic operation and noise performance at CU-Denver. The infrastructure for producing SQUIDs will be maintained throughout the experiment in case additional devices are required during operation. The FET electronics and SQUID/FET housings (which are located at the 600 mK and 4 K stages) are also being fabricated and tested at UC Berkeley. Theses units have been prototyped extensively, and we are now have the final design which will be replicated for the 42 channels of detectors.

Early in the overall production schedule we intend to individually check detectors in order to ensure that the production and manufacture process is well stabilized. Detector check-out will take place at a number of above ground cryogenic facilities as outlined in the Operations sub-section. As the detector package yield improves, and to obtain the lowest levels of surface contamination, the modules will be assembled into six detector towers and run directly in SUF prior to delivery to Soudan. This would minimize the time the detectors spend above ground, in environments that are less well controlled for radioactive contaminants.

Additional detectors, that are not bound for Soudan, will be studied in greater detail at the above ground cryogenic test facilities, in order to understand, in some detail, the response of the detectors to different types of background radioactivity. This information will be fed back to the data analysis, and Monte Carlo studies, of the experiment.

Work Breakdown Structure:

2. Detectors
2.1. Detector Production
2.1.1. Ge/Si Procurement
2.1.1.1. Purchasing
2.1.1.2. Cutting & Polishing
2.1.1.3. Quality Testing
2.1.2. Wafer Processing (Center for Integrated Systems)
2.1.2.1. Wafer Preparation
2.1.2.2. Thin Film Deposition Operations
2.1.2.2.1. Balzers Operation
2.1.2.2.2. Additional Mounting Hardware
2.1.2.2.3. Upgrade Balzers Gas Handling System
2.1.2.3. Photolithographic Operations
2.1.2.3.1. Ultratech Operation
2.1.2.3.2. Karl Suss Operation
2.1.2.3.3. Photolithographic Parameter Determination
2.1.2.3.4. Mask Design
2.1.2.3.5. Mask Fabrication
2.1.2.4. Chemical & Plasma Etch Operations
2.1.2.4.1. Profile Rates
2.1.2.4.2. Identify Potential Chemical Conflicts
2.1.2.5. Film / Fabrication Quality Assessment
2.1.2.5.1. Circuit Quality Checks
2.1.2.5.2. W Tc Monitoring
2.1.2.6. CIS Safety
2.1.3. Radioactivity Assessment
2.1.4. Production Documentation

2.3.2.4.3. Tower Assembly Copper and Graphite Components
2.3.2.4.4. Tower Wiring
2.3.2.4.5. Tower Testing
2.3.2.4.5.1. Warm Electrical Checks
2.3.2.4.5.2. Cold Electrical Checks
2.3.2.5. Basement Production

2.3.2.5.1. Basement Design
2.3.2.5.2. Basement Copper Machining
2.3.2.5.3. Basement Passive Shielding Production
2.3.2.5.4. Basement DIBs Production
2.3.2.5.5. Thermal Support Production
2.3.2.5.6. Component Testing
2.3.2.5.6.1. Warm Electrical Checks
2.3.2.5.6.2. Cold Electrical Checks
2.3.3. Materials Radioactivity Monitoring

2.4. Detector Testing and Characterization
2.4.1. Assembly of Detector Stack with Tower
2.4.1.1. Stock Management Needed for Assembly
2.4.1.2. Final Cleaning of Components
2.4.1.3. Assembly of Detector in Basement
2.4.1.3.1. Wire-bonding
2.4.1.4. Radioactivity Monitoring
2.4.1.4.1. Assay of Detector Contamination
2.4.1.4.2. Cleanliness of Radon Facility
2.4.1.5. Warm Electrical Checks

2.2. SQUID Amplifier Production & Testing
2.2.1. SQUID Chip Production
2.2.1.1. SQUID Fabrication Contract
2.2.1.2. SQUID Chip Quality Assessment
2.2.2. SQUID Card Production
2.2.2.1. Materials Procurement
2.2.2.2. Electronics Components Procurement
2.2.2.3. Card Design
2.2.2.4. Card Patterning
2.2.2.5. Card Assembly
2.2.3. SQUID Card Testing

2.3. Cold Hardware & Electronics Production

2.3.1. Fabricate FET Cards

2.3.1.1. FET Card Fabrication
2.3.1.1.1.1. Materials Procurement
2.3.1.1.1.2. Electronics Components Procurement
2.3.1.1.1.3. Card Design
2.3.1.1.1.4. Card Patterning

2.3.1.1.1.5. Card Assembly
2.3.1.1.1.6. Card Testing
2.3.1.2. SCAB Board Fabrication

2.3.1.2.1.1. Materials Procurement
2.3.1.2.1.2. Electronics Components Procurement
2.3.1.2.1.3. Card Design
2.3.1.2.1.4. Card Patterning
2.3.1.2.1.5. Card Assembly
2.3.1.2.1.6. Card Testing
2.3.2. Fabricate Towers & Basements
2.3.2.1. Materials Procurement
2.3.2.1.1. Copper Purchase & Storage
2.3.2.1.2. Other Materials Procurement
2.3.2.2. Production of Additional Tooling/Jigs needed for assembly
2.3.2.3. Purchase of Hardware for Warm/Cold Electrical Testing
2.3.2.3.1. Electrical Meters

2.3.2.3.2. IR Dewars
2.3.2.4. Tower Production
2.3.2.4.1. Tower Design
2.3.2.4.2. Tower Copper/Graphite Machining
2.3.2.4.2.1. Monitoring of Machine Shop Production

2.4.1.6. Cold Electrical Checks
2.4.1.7. Tower/Stack Assembly
2.4.1.7.1. Final Cleaning of Components
2.4.1.7.1.1. Assembly
2.4.1.7.2. Radioactivity Monitoring
2.4.1.7.2.1. Assay of Stack Contamination
2.4.1.7.2.2. Cleanliness of Radon Facility
2.4.1.7.3. Warm Electrical Checks
2.4.1.7.4. Cold Electrical Checks
2.4.2. Tower Checkout at Test Facilities/SUF
2.4.2.1. Establish and Monitor Testing Criteria
2.4.2.2. Cryogenic Test Facility Scheduling Requests
2.4.2.3. Liaison for Warm Electronics Systems Performance
2.4.2.4. Liaison for DAQ/Off-line Analysis Systems Performance
2.4.2.5. Management of Operating Crews when at Test Facilities
2.4.2.6. Establish Standard Detector Operating Procedures
2.4.2.7. Front End Data Analysis
2.4.2.8. Data Comparison Between Separate Runs
2.4.2.8.1. Detector Uniformity Assessment
2.4.2.9. Documentation & Distribution of Detector Test Information
2.4.3. Detector Characterization
2.4.3.1. Test Facility Scheduling Requests
2.4.3.2. Management of Operating Crews when at Test Facilities
2.4.3.3. Calibrate Detector Response and Discrimination
2.4.3.3.1. Fabrication of Additional Test Hardware
2.4.3.3.2. Detailed Response Determination
2.4.3.3.2.1. Radioactivity Sources
2.4.3.3.2.1.1. Gamma
2.4.3.3.2.1.2. Beta
2.4.3.3.2.1.3. Alpha
2.4.3.3.2.1.4. Neutron
2.4.3.3.2.1.5. Muon
2.4.3.3.2.2. Other parameters
2.4.3.3.2.2.1. Position Dependence & Fiducial Volume Cuts

2.4.3.3.2.2.2. Energy Dependence

2.4.3.3.2.3. Signal/Background Discrimination Performance Assessment
2.4.3.4. Measure Detector Performance & Simulate
2.4.3.4.1. Assess Performance of Phonon and Charge Signals
2.4.3.4.2. Test Device Fabrication
2.4.3.4.3. Detector Run Scheduling
2.4.3.4.4. Detector Run Operations
2.4.3.4.5. Analysis of Detector Data
2.4.3.4.6. Modeling of Phonon and Electron-hole Systems in Detectors

Manpower Plan

Sum of FTE					Yr					
WBS	Task	Inst	level	Name	1	2	3	4	5	Grand Total
2.1.	Det Production	LBNL	tech	Emes	0.5	0.5	0.5			1.5
		SU	postd	Clarke/pd A	0.5	0.5	0.5			1.5
			grad	SU grad B	0.5	1.0	1.5			3.0
			tech	Abusaidi	0.9	0.9	0.9			2.7
				Castle	0.5	0.5	0.5			1.5
	Det Production Total				2.9	3.4	3.9			10.2
2.2.	SQUID amps	NIST	fac	Huber (sabbat)	0.4					0.4
			phys	Martinis	0.1	0.1	0.1			0.3
			tech	NIST tech	0.4	0.4	0.3			1.1
		UcolD	fac	Huber	0.5	0.5	0.3			1.3
	SQUID amps Total				1.4	1.0	0.7			3.1
2.3.	Towers & Cold Elec	LBNL	tech	LBNL tech A	1.0	1.0	0.0			2.0
				LBNL tech B	1.0	1.0				2.0
		UCB	postd	Isaac/pd C	0.8	0.8	0.8			2.3
			grad	UCB grad B	0.5	1.0	1.0			2.5
			eng	Seitz	1.0	1.0	1.0			3.0
				Smith.G.	0.4	0.4	0.4			1.2
	Towers & Cold Elec Total				4.7	5.2	3.2			13.0
2.4.	Det. Testing & Char.	CWRU	fac	Akerib	1.0	0.7	0.7	0.3	0.3	3.0
			postd	Bolozdynya/pd B	0.9	0.9	0.9	0.3	0.3	3.2
				Schnee/pd A	0.8			0.3	0.3	1.4
			grad	Driscoll/gr B	0.8	0.5	0.5	0.3	0.3	2.4
				Perera/gr A	0.6	0.4	0.4	0.3	0.3	1.9
				Wang/gr C		0.4		0.3	0.3	0.9
		LBNL	tech	Emes	0.5	0.5	0.5	0.5	0.5	2.5
		SCU	fac	Young	1.0	1.0	1.0			3.0
		SU	phys	SU phys	0.8	0.4	0.2	0.3	0.3	2.0
			postd	Clarke/pd A	0.5	0.3	0.3			1.0
			grad	Saab/gr A	1.0	0.4	0.3	0.3	0.3	2.3
				SU grad C	0.5	1.0	1.0	0.3	0.3	3.1
		UCB	postd	Gaitskell/pd A	1.0	1.0	1.0	0.3	0.3	3.6
				Hellmig/pd B	0.9	0.7	0.9	0.3	0.3	3.0
				Golwala/pd D	1.0	1.0	1.0			3.0
			grad	Mandic/gr A	0.9	0.5		0.3	0.3	1.9
				UCB grad C	0.4	0.9	0.9	0.3	0.3	2.7
	Det. Testing & Char. Total				12.5	10.5	9.5	4.1	4.1	40.7
Grand Total					21.5	20.1	17.2	4.1	4.1	66.9

Detector Schedule Milestones

Milestone	Date
Procured Ge/Si Batch 1	5/14/99
Detectors for Run 20 fabricated	6/15/99
Tower & Cold Elec. Ready	9/9/99
Start Twr 1/Run 20 at SUF	10/1/99
Start Soudan Data Run Twr 1	10/6/00
Procured Ge/Si Batch 2	11/5/99
Start Det Production Twr 2-4	3/1/00
Detectors for Twrs 2-4 fabricated	5/30/00
Twr 2-4 run at SUF done	5/10/01
Start data run Twrs 1-4	9/10/01
Procured Ge/Si Batch 3	11/6/00
Start Det Production Twr 5-7	9/1/01
Detectors for Twrs 5-7 fabricated	12/5/01
Twr 5-7 run at SUF done	5/13/02
All towers done and commissioned	7/1/02

Detector Budget:

Sum of Cost2					Yr					
categ	WBS	Task	Inst	Name	1	2	3	4	5	Grand Total
pers Total					1,398,800	1,325,478	1,112,736	230,423	237,269	4,304,706
Travel	2.4.	Det. Testing & Char.	CWRU	travel		9,298	8,197			17,495
			SU	travel to UCB	7,810	8,044	8,286			24,140
			UCB	travel to CWRU		7,746	7,978			15,724
				travel to SU	15,040	15,491	15,956			46,487
		Det. Testing & Char. Total			22,850	40,579	40,417			103,845
Travel Total					22,850	40,579	40,417			103,845
S&E	2.1.	Det Production	SU	Aligner Masks	7,810	8,044	8,286			24,140
				Balzers mod	3,905					3,905
				CIS personnel chrges	44,986	46,335	23,863			115,183
				CIS supplies	781	804	829			2,414
				Spinner/Dryer in CIS		6,435	3,314			9,750
				SU machine shop	7,029					7,029
				SU/RF Adhesive Mats	781	804	829			2,414
				SU/RF Gowns, gloves, boots&hoods	2,343	2,413	2,486			7,242
				SU/RF HEPA Filters	2,343	2,413	2,486			7,242
			UCB	UCB/CR Adhesive Mats	752	775	798			2,324
				UCB/CR gas supplies	3,008	3,098	3,191			9,297
				UCB/CR Gowns,Boots,Gloves,Hoods	2,256	2,324	2,393			6,973
				UCB/CR HEPA Filters	2,256	2,324	2,393			6,973
		Det Production Total			78,250	75,771	50,867			204,887
	2.2.	SQUID amps	NIST	NIST clean room OH	18,000	18,000	11,000			47,000
				NIST S&E/travel	8,000	8,000	5,000			21,000
			UcolD	UCD S&E/travel	16,000	16,000	10,000			42,000
		SQUID amps Total			42,000	42,000	26,000			110,000
	2.3.	Towers & Cold Elec	UCB	software licenses	3,008	3,098	3,191			9,297
				Twr fixtures shops	8,158					8,158
				Twr parts shops	84,781	58,217				142,998
				Twr welding	1,408					1,408
		Towers & Cold Elec Total			97,355	61,315	3,191			161,861
	2.4.	Det. Testing & Char.	CWRU	detector transport	3,060	3,152				6,212
			SU	SU/RF Adhesive Mats				853	879	1,732
				SU/RF Gowns, gloves, boots&hoods				2,560	2,637	5,197
				SU/RF HEPA Filters				2,560	2,637	5,197
			UCB	Twr transport cases shops2	15,040					15,040
		Det. Testing & Char. Total			18,100	3,152		5,974	6,153	33,379
S&E Total					235,704	182,237	80,058	5,974	6,153	510,127
eqpt	2.1.	Det Production	LBNL	Ge det (50) polish	35,000	36,050				71,050
				Ge det (50) Raw Mat	43,750	45,063				88,813
				Ge test wafers 300 um	5,600	5,768	5,941			17,309
				Ge test wafers 4mm polish	28,000					28,000
				Ge test wafers 4mm raw	14,000					14,000
				Si det (50) polish	15,000	15,450				30,450
				Si det (50) raw	30,000	30,900				60,900
			SCU	materials analyses	3,000	3,090				6,090
				IICO ion implantation	5,000	5,150				10,150
			SU	Karl Suss New Wafer Stage	15,530					15,530
				Si sputtering target	2,000	2,060				4,060
				Si test wafers 300 um	500	515	530			1,545
				SU/RF computer	2,000					2,000
				SU/RF lam flow bench(2)	14,605					14,605
				SU/RF Class 100 chairs (5)	2,133					2,133
				SU/RF cleanroom waste cans	1,160					1,160
				SU/RF Desicator	2,645					2,645
				SU/RF DI water and nitrogen gas spray noozle	736					736
				SU/RF Dump rinser, tubing, & controller	7,951					7,951
				SU/RF Garment Storage/Shelve	1,779					1,779
				SU/RF Gas cylinder cart	397					397
				SU/RF Gas regulators, tubing, fittings, clamp	1,223					1,223
				SU/RF Low Rad Soldering Stn	500					500
				SU/RF Mechnical pump	1,282					1,282
				SU/RF microscope	13,500					13,500
				SU/RF Microtemp controller	1,862					1,862
				SU/RF Polypropylene shelves, stand	403					403
				SU/RF Secondary containers for acid &rinse di	1,150					1,150
				SU/RF Shelving & al sleeves & stand	1,258					1,258
				SU/RF Shoe dust vacuum	1,439					1,439
				SU/RF spinner/dryer	14,605					14,605
				SU/RF Storage containers and holders	5,000					5,000
				SU/RF Thermal impulse sealer & drypack	917					917
				SU/RF Vacuum flanges, valves	836					836
				SU/RF wirebonder	20,400					20,400
				SU/RFThermocouple gauge	230					230
				W sputtering target		8,240				8,240
		Det Production Total			295,390	152,286	6,471			454,147

Detector Budget: (cont)

Sum of Cost2					Yr					
categ	WBS	Task	Inst	Name	1	2	3	4	5	Grand Total
	2.3.	Towers & Cold Elec	LBNL	CE sputtering at LBL	22,800	23,484				46,284
			UCB	CE SQUID boards	3,600					3,600
				CE SQUID ribbon cable	1,280					1,280
				CE stripline clamps	1,080					1,080
				CE DIB	2,100					2,100
				CE DIB components	1,500					1,500
				CE FET components	1,500					1,500
				CE FET PCB	9,440					9,440
				CE SCAB	5,700					5,700
				CE Test Equipment	5,000					5,000
				computer for CE testing	2,000					2,000
				computer for twr autocad	4,000					4,000
				HP Function generator	3,025					3,025
				N2 Purge Twr storage	1,000					1,000
				New Oscilloscope	5,500					5,500
				Spectrum Analyser	25,000					25,000
				SRS amplifiers (2)	3,990					3,990
				Twr parts material	5,000					5,000
				Twr Pb shield	1,080					1,080
				Twr shielding Cu	500					500
				Twr stock items	14,460	9,929				24,389
				UCB/CR Lam Flow bench	10,000					10,000
				UCB/CR microscope	5,000					5,000
				UCB/CR New Wet Bench	35,300					35,300
		Towers & Cold Elec Total			169,855	33,413				203,268
	2.4.	Det. Testing & Char.	UCB	Twr transport cases (mat)	5,432					5,432
		Det. Testing & Char. Total			5,432					5,432
eqpt Total					470,677	185,699	6,471			662,848
Grand Total					2,128,031	1,733,992	1,239,682	236,397	243,422	5,581,525

Contingency

Sum of Cont			Yr			
WBS	Task	categ	1	2	3	Grand Total
2.1.	Det Production	pers	50,538	52,054	53,616	156,208
		S&E	15,745	16,217	8,352	40,314
		eqpt	49,426	25,951	1,268	76,645
	Det Production Total		115,709	94,222	63,235	273,167
2.2.	SQUID amps	pers	93,334	85,834	47,671	226,838
		S&E	16,000	16,000	9,833	41,833
	SQUID amps Total		109,334	101,834	57,504	268,671
2.3.	Towers & Cold Elec	pers			74,475	74,475
		S&E	42,662			42,662
		eqpt	22,382	2,979		25,361
	Towers & Cold Elec Total		65,044	2,979	74,475	142,498
2.4.	Det. Testing & Char.	pers	12,269	21,902	13,016	47,187
		eqpt	1,901			1,901
	Det. Testing & Char. Total		14,170	21,902	13,016	49,088
Grand Total			304,257	220,936	208,231	733,424

Contingency Detail Note:

				Yr			
WBS	Task	Name	categ	1	2	3	Grand Total
2.3.	Towers & Cold Elec	LBNL	pers			74,475	74,475
		Twr fi	S&E	42,240			42,240

10.2. Warm Electronics

Work Plan

The development of electronics for the simultaneous read–out of 42 detectors at Soudan is already well advanced, thanks to the prototyping that has taken place in CDMS I. The requirement for automated, ultra-low noise and low cross–interference read–out, for a large number of cryogenic detectors led naturally to the adoption of high density surface mount, multilayer board technology. The boards combine both digital control circuitry (for automatic configuration of circuits and detector diagnostics), and more traditional low noise amplifier chains. The digital circuits can be silenced during low noise operations.

The board design has taken place at UCB, Stanford and Fermilab. In the future all board manufacture will take place at Fermilab, with outsourcing of units and assembly, where cost effectiveness and quality control have been established. Design revision and documentation will be the responsibility of UCB and Fermilab. We have begun using the first versions of 9U units (one Front End board per detector). In 1998 we finished the revisions to the 9U cards for both FE crate operation and also Receiver-Trigger–Filter (RTF) crates. The latter set of cards (one RTF board per detector) are located just prior to digitization of the detector signals, and as the name suggest, complete analogue signal processing and create analogue trigger signals. Production of 65 detector's worth of electronics (which includes FE and RTF) will begin in Q1 1999 and extend to Q4. The sets will ultimately be split 50 at Soudan and 15 at the various above ground detector test locations. 9U crate infrastructure will also be supplied to the various sites, as will the necessary low level board control software to allow ready access to reconfigure detector operation and automate detector diagnostics.

Work Breakdown Structure:

3. Warm Electronics (M.Crisler)
3.1. Front End Electronics Fab
3.1.1. Front End Electronics
3.1.1.1. Frt End Elec design
3.1.1.2. Frt End Elec rev/doc
3.1.1.3. Frt End Elec prod (Soudan Site)
3.1.1.4. Frt End Elec prod (Test Sites)
3.1.1.5. Frt End Elec Software
3.1.2. RTF
3.1.2.1. RTF Elec design
3.1.2.2. RTF Elec rev/doc
3.1.2.3. RTF Elec prod (Soudan Site)
3.1.2.4. RTF Elec prod (Test Sites)
3.1.2.5. RTF Elec Software
3.2. Testing and Installation

Manpower Plan

Sum of FTE					Yr		
WBS	Task	Inst	level	Name	1	2	Grand Total
3.1.	Board Production	FNAL	phys	Crisler	0.5	0.1	0.6
			postd	Eichblatt/pd A	0.5	0.1	0.6
			eng	Haldeman	0.6	0.1	0.8
			tech	Johnson,W.	0.6	0.1	0.8
				FNAL pcb assy tech	0.1		0.1
				Merkel	0.6	0.1	0.8
				Morrison/Regan	0.6	0.1	0.8
	Board Production Total				3.7	0.7	4.4
3.2.	Elec test/install	FNAL	phys	Crisler		0.4	0.4
			postd	Eichblatt/pd A		0.4	0.4
			eng	Haldeman		0.4	0.4
			tech	Johnson.W.		0.4	0.4
	Elec test/install Total					1.6	1.6
Grand Total					3.7	2.3	5.9

Warm Electronics Schedule Milestones

Milestone	Date
Place RTF board pcb fab order	3/1/99
Place ZIP board prototype pcb fab order	4/1/99
Place ZIP board stuffing order	5/1/99
Receive stuffed ZIP boards at FNAL	6/25/99
Place production ZIP & RTF pcb orders	8/27/99
RTF & ZIP board test/debug complete	11/30/99

Warm Electronics Budget:

Sum of Cost2					Yr		
categ	WBS	Task	Inst	Name	1	2	Grand Total
pers Total					330,815	223,006	553,820
Travel	3.1.	Board Production	FNAL	travel	14,200	14,626	28,826
		Board Production Total			14,200	14,626	28,826
Travel Total					14,200	14,626	28,826
eqpt	3.1.	Board Production	FNAL	Crates (9)	33,217	0	33,217
				RTF Boards (25)	40,020	0	40,020
				ZIP Boards (60)	80,173	0	80,173
				FE Cables		22,660	22,660
				Test Bnch/Diag eqpt Sdn		20,600	20,600
				Test Bnch/Diag eqpt UCB	13,340		13,340
		Board Production Total			166,750	43,260	210,010
eqpt Total					166,750	43,260	210,010
Grand Total					511,765	280,892	792,656

Contingency

Sum of Cont			Yr		
WBS	Task	categ	1	2	Grand Total
3.1.	Board Production	pers	32,062	17,063	49,125
		eqpt		71,932	71,932
	Board Production Total		32,062	88,995	121,057
3.2.	Elec test/install	pers		24,244	24,244
	Elec test/install Total			24,244	24,244
Grand Total			32,062	113,239	145,301

Contingency Detail Note:

				Yr			
WBS	Task	Name	categ	1	2	3	Grand Total
3.1.	Board Production	Crates (9)	eqpt		5,600		5,600
		RTF Boards (25)	eqpt		19,200		19,200
		ZIP Boards (60)	eqpt		30,600		30,600
		Test Bnch/Diag eqpt Sdn	eqpt		12,000		12,000
	Board Production Total				67,400		67,400

Note that $263K will have been spent prior to July 1999 on this subsystem (see Table 9.2.2.)

10.3. Data Acquisition and Software

Work Plan

The present data acquisition system for CDMS I at the Stanford Underground Facility is based on waveform digitizers in VXI crates, communicating with LabVIEW software running on a Macintosh computer. Monitoring is done on a separate computer using a combination of NIM,CAMAC, and GPIB devices. Offline analysis is written in Matlab on Unix workstations. The system is flexible and fast enough to handle up to two towers of detectors with reasonable live time for physics trigger rates < 1 Hz.

However, physics triggers will occur in CDMS II at a rate of at least 1 Hz, and this may well increase to 10 Hz during calibration. Furthermore, the event size of CDMS II will be significantly larger than in CDMS I. Data transfer rates may be as large as 10 MB/s from the digitizers and logged data may exceed 20 GB/day. We must take a fresh look at data acquisition, monitoring, storage and offline analysis for CDMS II, guided by our CDMS I experience.

During the first half of 1999, the DAQ effort is concentrated on trying to optimize data flow from digitizers through to tape. We must first speed up data transfer from VXI crates or consider alternative platforms such as PCI (which may also be less expensive). This involves prototyping of an in-crate VXI processor to filter the data before the data is shipped to the data acquisition CPU. That is occurring at UCSB, where a VxWorks, an environment for the development of real-time data acquisition, is maintained for the UCSB effort on the BaBar experiment. Work is continuing on optimizing data flow from the DAQ computer to offline analysis workstations via Fast Ethernet or FDDI. Alternative software packages for both DAQ and offline analysis are evaluated for speed and ease of use; here we are relying heavily on discussions with other groups who have used such packages. Finally, we are learning from

CDMS data taken at SUF how to implement intelligent triggers which can reduce trigger rate with little loss of information, and study better ways to filter raw data to achieve manageable volumes.

Non-event based monitoring of the experiment and detectors, as well as the environment, is an ongoing activity at CDMS I and at the detector production sites. Significant needs are for tighter integration of monitoring information with the data acquisition and a database system to provide easy access to monitoring data, so that various environmental quantities can be studied over time scales longer than a few runs. In the first half of 1999 we are researching alternatives to our LabView-based monitoring and run control systems, including the popular EPICS software.

Starting in July 1999 we will summarize all we have learned and begin the full design of the hardware and software system for CDMS II data acquisition. We expect this effort to take six months and to be split over several sites, with UCSB playing the lead role. During this time, we will procure sufficient waveform digitizers, crates, hardware, and software to allow data acquisition and analysis for one CDMS detector tower.

In March 2000, the new DAQ and offline analysis system will be commissioned at SUF and tested for two months. This should be sufficient time to debug the system and get it running smoothly. As soon as the tower moves to Soudan, the working DAQ/offline will go with it. During the rest of the year 2000, procurement will proceed for the remainder of the DAQ hardware needed to take data with seven towers of detectors. Work will also undoubtedly continue on optimizing the DAQ and refining the analysis software.

Work Breakdown Structure:

4. DAQ and Information Management (H. Nelson)

4.1. DAQ Hardware

4.1.1. Digitizers (VXI/PCI)
4.1.2. Crates (VXI/PCI)
4.1.3. Trigger
4.1.4. NIM
4.1.5. GPIB
4.1.6. Diagnostic Equipment
4.1.7. Fridge Monitoring
4.1.8. Environmental Monitoring
4.1.9. CPUs (in-crate/external)
4.1.10. Misc. Hardware
4.1.11. SUF Testing
4.1.12. Soudan Integration
4.1.13. Networking (Ethernet, FDDI,...)
4.1.14. Documentation

4.2. Information Management

4.2.1. Run Coordination
4.2.1.1. Run Types
4.2.1.2. Record Types
4.2.1.3. Interventions
4.2.1.4. Scoreboards
4.2.2. Event Coordination
4.2.2.1. Event Types
4.2.2.2. Record Types
4.2.2.3. Crate Filter
4.2.2.4. Event Builder
4.2.3. Slow Control
4.2.3.1. Records
4.2.3.2. Alarms
4.2.3.3. Displays
4.2.4. Software Environment
4.2.4.1. LabView
4.2.4.2. Unix/c/VxWorks
4.2.4.3. Matlab
4.2.4.4. Databases
4.2.5. Network
4.2.5.1. Protocols
4.2.5.2. WWW
4.2.5.3. Miscellaneous
4.2.6. Software Integration
4.2.6.1. SUF
4.2.6.2. Detector Testing Sites
4.2.6.3. Data Analysis Sites
4.2.7. Data Storage and Retrieval
4.2.8. Documentation

4.3. Data Reduction

4.3.1. Filter
4.3.1.1. Standard Data
4.3.1.2. Calibrations
4.3.1.3. Reprocessing
4.3.2. Hardware
4.3.2.1. CPU/Memory
4.3.2.2. Disk
4.3.2.3. Operating System
4.3.2.4. Monitors
4.3.2.5. Long Term Storage
4.3.3. Software
4.3.4. Documentation

Manpower Plan

Sum of FTE					Yr			
WBS	Task	Inst	level	Name	1	2	3	Grand Total
4.1.	DAQ system	FNAL	postd	Eichblatt/pd A	0.5	0.5	0.5	1.5
			eng	FNAL eng A	0.5	0.5		1.0
		UCSB	fac	Nelson	1.0	1.0	1.0	3.0
			phys	Bauer	0.4	0.4	0.2	1.0
			postd	UCSB postd A	1.0	1.0	0.5	2.5
			grad	Bunker/gr A	0.5	0.5	0.5	1.5
				UCSB grad B	0.5	1.0	0.5	2.0
				UCSB grad C	0.5	1.0	0.5	2.0
			eng	Burke,S.	0.5	0.5	0.5	1.5
	DAQ system Total				5.4	6.4	4.2	16.0
Grand Total					5.4	6.4	4.2	16.0

Data Acquisition Schedule Milestones

Milestone	Date
New UCSB Postdoc hired	6/4/99
Event builder: 2 crate events built	10/1/99
Record Structure Defined	10/1/99
Ready for system test at Soudan	4/27/00
Processed run 20 data	8/4/00
Production system remote test	1/4/01
Final Offline Sys Spec'd and ordered	2/1/01
DAQ system finalized	4/26/01

Data Acquisition Budget

Sum of Cost2					Yr			
categ	WBS	Task	Inst	Name	1	2	3	Grand Total
pers Total					321,379	359,691	236,183	917,252
Travel	4.1.	DAQ system	UCSB	travel	12,600	12,978	6,684	32,262
		DAQ system Total			12,600	12,978	6,684	32,262
Travel Total					12,600	12,978	6,684	32,262
eqpt	4.1.	DAQ system	UCSB	Diagnostic Equipment	25,000			25,000
				Veto Electronics	10,000			10,000
				Crates (3)	36,000	0		36,000
				Environmental Monitorin	10,000			10,000
				External Processors (1)	10,000	0		10,000
				Fridge Monitoring	10,000			10,000
				GPIB	10,000			10,000
				Grand Trigger Bds. (3)	7,200	3,708		10,908
				In Crate Processors (6)	32,000	16,480		48,480
				Linear Fan In (10)	15,160			15,160
				Scalers (12)	5,700	17,613		23,313
				Switch	3,000			3,000
				Time History Units	10,000	10,300		20,300
				Trig CPU Forw. (6)	8,000	4,120		12,120
				Trigger Logic Bds. (9)	6,000	20,600	7,851	34,451
				Waveform Digitiz. (36)	100,000	103,000		203,000
				Server CPU	10,000			10,000
				Detector Monitoring	10,000			10,000
		DAQ system Total			318,060	175,821	7,851	501,732
	4.2.	Information Mngmnt	SU	Run Time Licenses (5)	1,500			1,500
			UCSB	Database	10,000			10,000
				Disks	4,000	8,240	12,731	24,971
				DLT Drive	3,500	3,605	3,713	10,818
				Software/Licenses (6)	12,000			12,000
				Development Environment	12,000			12,000
		Information Mngmnt Total			43,000	11,845	16,444	71,289
	4.3.	Data Reduction	SU	Run Time Licences (5)	1,500			1,500
			UCSB	CPUs	10,000	20,600	42,436	73,036
				Disks	4,000	8,240	12,731	24,971
				DLT Drive	3,500	3,605	3,713	10,818
		Data Reduction Total			19,000	32,445	58,880	110,325
eqpt Total					380,060	220,111	83,175	683,346
Grand Total					714,039	592,780	326,041	1,632,859

Contingency

Sum of Cont			Yr			
WBS	Task	categ	1	2	3	Grand Total
4.1.	DAQ system	pers	39,724	40,915	21,896	102,535
		eqpt	120,440	121,510	1,963	243,912
	DAQ system Total		160,164	162,425	23,858	346,447
4.2.	Information Mngmnt	eqpt	10,750	2,961	4,111	17,822
	Information Mngmnt Total		10,750	2,961	4,111	17,822
4.3.	Data Reduction	eqpt	4,750	8,111	14,720	27,581
	Data Reduction Total		4,750	8,111	14,720	27,581
Grand Total			175,664	173,497	42,689	391,850

10.4. Shield and Backgrounds

Work Plan

It is generally the case that ultra-low background experiments are ultimately limited by radioactivity of the detector or nearby components. This is because one can calculate or measure, and hence control, external sources due to radioactivity or cosmic rays. Using our experience with previous dark matter and double beta decay searches, we have successfully designed, built, and operated active and passive shielding for the CDMS-I experiment at Stanford. The task for CDMS-II is to fashion a similar shield for the environment at Soudan. Once again, the shielding will consist of passive components to reduce the fluxes of photons and neutrons, and an active scintillator veto to allow rejection of events correlated with cosmic ray interactions.

During the period January through June of 1999, we intend to complete the physics and engineering design of both the shield and veto. This involves testing materials for radioactive contamination and prototyping scintillation counter designs. In addition, we will procure bids for all of the main materials for both shield and veto. Finally, we are evaluating whether it is desirable to purchase electronics to power and read out the veto commercially, or whether an "in-house" design would serve our needs better. Particularly important is the module which keeps a time history of veto hits for each detector trigger.

Procurement should take place during the summer of 1999. Major procurement items are 1) polyethylene, 2) lead, 3) scintillator, 4) light guides, 5) photomultipliers and 6) electronics. We have already successfully purchased sufficient low-activity lead to produce the inner layers of the shield. Most of the forming of the lead and polyethylene pieces for the shield can be contracted out at this time. Mechanical supports, tooling, and lifting fixtures will be built in the UCSB machine shops. During the summer of 1999, the veto electronics should be either procured or the design finalized and prototypes tested.

Construction of the shielding will occur in the period from September through December 1999. The passive shielding will be assembled and tested for fit at UCSB, before being shipped to Soudan. Scintillation counter construction will involve gluing the preformed light guides to scintillator paddles, wrapping, and attaching photomultiplier tubes and bases. In addition, mechanical supports for the counters will be constructed and tested. If we have decided to produce the veto electronics ourselves, it will be built and tested during this time period. Most of this work will be done by the excellent engineering and technical staff at UCSB.

During the first three months of the year 2000, the scintillation counters and electronics will undergo extensive tests at UCSB to characterize their response. They will then be shipped to Soudan and assembled together with the passive shielding around the detector volume. Considerable travel by both physicists and engineers will be required during this phase. After assembly, the shield and veto will be thoroughly evaluated together with the first tower of detectors. If external backgrounds prove to be higher than expected, we would use contingency funding to purchase and install additional polyethylene and/or an outer veto counter optimized to detector particles coincident with neutrons coming from the cavern walls.

Radon Handling

The primary line of defense against Rn is to limit exposure to Rn in air. This must happen during the detector production, and during subsequent transportation, storage and handling at various facilities.

During 1999, we plan to measure the efficiency with which airborne Rn decay products (Bi, Po and Pb) adhere to the surfaces of the detector and their immediately surrounding materials such as Cu under clean-room conditions. Materials will be exposed to Rn-laden air in a small sealed clean-room at Princeton, and the amount of ^{210}Pb on the surface monitored by measuring alphas from the decay of ^{210}Po in the CDMS alpha screening setup in SUF. The effect of a variety of typical clean-room conditions such as humidity and static charge state will be explored.

Exposure during assembly of the detectors and hardware is minimized by a Rn scrubbing system installed at Stanford, whose target is reduction of Rn by a factor of 100 from normal air. Princeton is developing techniques to monitor Rn concentration at least as low as a factor of 100 below normal background levels. Such monitors will be deployed at the SUF detector facilities during 1999. If the Stanford detector preparation facility is measured to fail its radon reduction target, there is a contingency to add additional elements during fall 1999. This will give sufficient information to insure that the Rn scrubbing planned for our Soudan installation will be successful. Finally, the tower and detector packages will be kept in Rn-tight containers, with a localized flow of bottled clean air, during storage, transportation and handling. This system will be developed as part of the towers and cryogenic hardware package.

Surface contamination

The Princeton group is studying the feasibility of building a low-mass, large area gas-proportional counter to screen the surfaces of detectors and other material for contamination by beta emitters. The goal is to be able to quickly measure very low levels of surface contamination which will allow us to find methods to remove it. Currently the only methods of measuring surface beta-emitter contamination are running test detectors at SUF or the full running of the experiment in Soudan. This would be developed at Princeton, either to be run at Princeton with a muon veto or at Gran Sasso. Personnel also working on Borexino would be supported to operate the screening station at Gran Sasso in the later case. We have included this project as a contingency within CDMS II.

Material selection and characterization

Naturally occurring radioactive isotopes are often the main source of background in low count rate experiments. Thus it is necessary to select and control all the materials being used in the experimental set-up. LBNL's Low Background Facility (LBF) has been an extremely valuable resource to CDMS, assisting in the selection and control of the materials being used in the experiment. The LBF consists of laboratories specifically designed to provide ultra-low background radiation environments for gamma-ray spectroscopy. The Berkeley site consists of a 4m x 6m x 4m low-activity concrete-shielded room with a minimum wall thickness of 1.5m. The Oroville site is located in the powerhouse of the Oroville Dam, 180 meters below ground. These facilities are used for the sensitive measurement of extremely small quantities of gamma-ray-emitting radionuclides. Calibrated and lead-shielded gamma-ray spectrometers in these facilities measure sub-picocurie activities in samples ranging in size from milligrams to kilograms and over an energy range of 10 to 3000 keV. Both sites have computer-based data acquisition and analysis equipment. A 115% n-type Germanium detector provides sub-parts-per-billion sensitivity to uranium and thorium in kg-sized samples as well as the capability to measure cosmic-ray activity or sub-parts-per-trillion sensitivity to trace elements in neutron-activated silicon wafers.

During the construction phase of CDMSII, the UCB group will work closely with the LBF in measuring and analyzing samples. The material selection process is interactive, and often requires a rapid feedback in order to avoid delays in construction or assembly. The components that require strict material selection analysis are the components close to the detectors: housings, cold electronics and towers. The

LBF will also collaborate with the UCB and the Princeton group in studying mitigation techniques for surface contamination.

Work Breakdown Structure

5. Shielding , Muon Veto, Backgrounds (D.Bauer)

5.1. Muon Veto system

5.1.1. Veto Design and Prototyping
5.1.1.1. Physics design
5.1.1.2. Engineering design
5.1.1.3. Build/evaluate prototypes
5.1.2. Veto construction
5.1.2.1. Order light guides
5.1.2.2. Order scintillator
5.1.2.3. Join scintillator and light guides
5.1.2.4. Order PM tubes
5.1.2.5. Order bases & magnetic shields
5.1.2.6. Order cables
5.1.2.7. Order High Voltage Supply
5.1.2.8. Assemble paddles with PMTs, bases, shields
5.1.2.9. Test assembled paddles
5.1.2.10. Fabricate mechanical supports, storage racks
5.1.2.11. Ship to Soudan
5.1.3. Veto Electronics

5.1.3.1. Decide on design
5.1.3.2. Prototype design
5.1.3.3. Build or procure
5.1.3.4. Test
5.1.3.5. Integrate with DAQ
5.1.4. Assemble and test veto at Soudan

5.2. Shield Construction and Installation

5.2.1. Shield design
5.2.1.1. Physics design
5.2.1.2. Engineering design
5.2.2. Shield procurement
5.2.2.1. Order lead
5.2.2.2. Contract lead shaping
5.2.2.3. Order polyethylene
5.2.2.4. Contract polyethylene shaping
5.2.2.5. Contract low-activity lead shaping
5.2.3. Shield construction
5.2.3.1. Build mechanical support structures
5.2.3.2. Test assembly at UCSB
5.2.3.3. Build lifting fixtures, storage racks
5.2.3.4. Assembly at Soudan

5.3. Backgrounds

5.3.1. Neutron calculations and measurements
5.3.1.1. Neutrons from radioactivity
5.3.1.2. Neutrons from cosmic ray interactions
5.3.1.3. Measurements at Soudan
5.3.2. Gamma Screening of CDMS construction materials
5.3.2.1. Test detector materials
5.3.2.2. Test icebox materials
5.3.2.3. Test inner shield materials
5.3.3. Surface Contamination
5.3.3.1. Screening in Borexino CTF
5.3.3.2. Surface contamination analysis
5.3.4. Radon Scrubbing
5.3.4.1. Install SU Clean Room
5.3.4.2. Prep PU Radon facility
5.3.4.3. Establish test procedures
5.3.4.4. Implement scrubbing
5.3.5. Alpha Screening
5.3.5.1. Upgrade to proportional counter system
5.3.5.2. Ongoing screening of materials

Manpower Plan

Sum of FTE					Yr			
WBS	Task	Inst	level	Name	1	2	3	Grand Total
5.1.	Muon Veto	UCSB	phys	Bauer	0.4	0.4	0.2	1.0
			tech	Callahan,D.	1.0	0.5		1.5
	Muon Veto Total				1.4	0.9	0.2	2.5
5.2.	Shield const/install	UCSB	grad	Bunker/gr A		0.5	0.5	1.0
			eng	Hale	0.5	0.5	0.5	1.5
	Shield const/install Total				0.5	1.0	1.0	2.5
5.3.1	Phys Design/Bkgds	CWRU	grad	Perera/gr A	0.4	0.5	0.5	1.4
		PU	postd	PU postd A	0.5	1.0		1.5
			grad	PU grad A	0.4	0.8	0.5	1.7
		UCSB	phys	Yellin	1.0	1.0	0.5	2.5
	Phys Design/Bkgds Total				2.3	3.3	1.5	7.1
5.3.2	Gamma Screening	LBNL	phys	McDonald	0.1	0.1	0.1	0.2
		UCB	postd	Isaac/pd C	0.2	0.2	0.2	0.5
	Gamma Screening Total				0.2	0.2	0.2	0.7
5.3.3	Surface Contamination	PU	fac	Shutt	0.3	0.3	0.3	0.8
			postd	PU postd A			0.5	0.5
			eng	PU eng	0.0	0.0		0.0
	Surface Contamination Total				0.3	0.3	0.8	1.3
5.3.4	Radon Suppression	PU	grad	PU grad A	0.1	0.2		0.3
			eng	PU eng	0.2			0.2
	Radon Suppression Total				0.3	0.2		0.5
Grand Total					5.0	5.9	3.7	14.5

Shield and Background Schedule Milestones

Milestone	Date
Shield and Veto Eng. design done	6/30/99
Shield and veto materials procured	8/31/99
Shield Test Assembly at UCSB done	10/31/99
Radon plateout measured	11/30/99
Veto counters assembled	12/31/99
Shield Installed at Soudan	1/31/00
Veto counters tested	3/31/00
Veto installed at Soudan	4/30/00

Shield and Background Budget:

Sum of Cost2					Yr			
categ	WBS	Task	Inst	Name	1	2	3	Grand Total
pers Total					405,199	434,393	266,421	1,106,014
Travel	5.2.	Shield const/install	UCSB	travel	25,200	12,978	6,684	44,862
		Shield const/install Total			25,200	12,978	6,684	44,862
	5.3.1	Phys Design/Bkgds	PU	travel bkgd studies	7,900	15,800	15,800	39,500
		Phys Design/Bkgds Total			7,900	15,800	15,800	39,500
Travel Total					33,100	28,778	22,484	84,362
S&E	5.1.	Muon Veto	UCSB	S&E	12,600	12,978		25,578
		Muon Veto Total			12,600	12,978		25,578
	5.2.	Shield const/install	UCSB	S&E	25,200	25,956	26,735	77,891
		Shield const/install Total			25,200	25,956	26,735	77,891
	5.3.1	Phys Design/Bkgds	PU	S&E bkgd studies	7,900	7,900		15,800
		Phys Design/Bkgds Total			7,900	7,900		15,800
	5.3.2	Gamma Screening	LBNL	low bkgd fac	37,414	38,536	19,846	95,796
		Gamma Screening Total			37,414	38,536	19,846	95,796
	5.3.3	Surface Contamination	PU	S&E	15,800	15,800	15,800	47,400
		Surface Contamination Total			15,800	15,800	15,800	47,400
S&E Total					98,914	101,170	62,381	262,464
eqpt	5.1.	Muon Veto	UCSB	HV cables	2,000			2,000
				HV PS	8,000			8,000
				light guides & WLS	40,000			40,000
				LV cables	2,000			2,000
				mag shields	4,000			4,000
				NIM crates	20,000			20,000
				PHA & scope	10,000			10,000
				PM bases	4,000			4,000
				PM tubes	32,000			32,000
				scintillator	100,000			100,000
				Veto support	10,000			10,000
				Outer veto		0		0
		Muon Veto Total			232,000	0		232,000
	5.2.	Shield const/install	UCSB	Doe run lead	55,000			55,000
				polyethylene	50,000			50,000
				shield support	15,000			15,000
				extra shielding		0		0
				Shield Asmbly,tooling	25,000			25,000
		Shield const/install Total			145,000	0		145,000
	5.3.1	Phys Design/Bkgds	PU	computer	5,000	5,000		10,000
		Phys Design/Bkgds Total			5,000	5,000		10,000
	5.3.3	Surface Contamination	PU	Prop. ctr	0			0
				Prop. ctr electronics	0			0
				Prop. ctr shield		0		0
				Prop. ctr veto		0		0
		Surface Contamination Total			0	0		0
	5.3.4	Radon Suppression	FNAL	Rn monitor	5,000			5,000
				Soudan Radon scrubbing	113,000			113,000
			PU	Rn mon (alpha counter)	23,000			23,000
			SU	SU/RF Rn scrubbing	0			0
				SU/RF Radon mon	10,720			10,720
		Radon Suppression Total			151,720			151,720
eqpt Total					533,720	5,000		538,720
Grand Total					1,070,933	569,341	351,286	1,991,560

Contingency

Sum of Cont			Yr			
WBS	Task	categ	1	2	3	Grand Total
5.1.	Muon Veto	pers	25,799	13,286		39,085
		eqpt	43,200	100,000		143,200
	Muon Veto Total		68,999	113,286		182,285
5.2.	Shield const/install	pers	20,639	21,258	21,896	63,792
		Travel	8,820	4,542	2,339	15,702
		eqpt	29,000	50,000		79,000
	Shield const/install Total		58,459	75,800	24,235	158,494
5.3.1	Phys Design/Bkgds	pers		9,265		9,265
	Phys Design/Bkgds Total			9,265		9,265
5.3.3	Surface Contamination	pers	50,614	26,066		76,680
		eqpt	45,000	30,000		75,000
	Surface Contamination Total		95,614	56,066		151,680
5.3.4	Radon Suppression	pers	25,307			25,307
		eqpt	114,350			114,350
	Radon Suppression Total		139,657			139,657
Grand Total			362,728	254,417	24,235	641,380

Contingency Detail Note

				Yr			
WBS	Task	Name	categ	1	2	3	Grand Total
5.1.	Muon Veto	Outer veto	eqpt		100,000		100,000
5.2.	Shield const/install	extra shielding	eqpt		50,000		50,000
5.3.3	Surface Contamination	PU eng	pers	50,699	26,110		76,809
		Prop. ctr	eqpt	25,000			25,000
		Prop. ctr electronics	eqpt	20,000			20,000
		Prop. ctr shield	eqpt		12,000		12,000
		Prop. ctr veto	eqpt		18,000		18,000
5.3.4	Radon	SU/RF Rn scrubbing	eqpt	89,000			89,000
		SU/RF Radon mon	eqpt	5,000			5,000

10.5. Soudan Installation

Work Plan

In preparation for the CDMS II experiment, two clean rooms, one of them RF shielded, must be constructed in the Soudan Laboratory. In addition, an electronics hut, an equipment room and a mezzanine structure must also be built in the Laboratory. The space has already been cleared in the Soudan Laboratory to make room for the CDMS II experiment.

The new structures are being specified by a Fermilab engineer and will be constructed by a suitable vendor with support from the Soudan Laboratory crew. Each of the clean rooms will be class 10,000 with a sub-area at class 100. The RF shielded clean room will contain a crane for assembly of the Icebox shielding and installation of the dilution refrigerator. Air for the clean room will be passed through HEPA to remove particulate matter. This air handling system will be included in the clean room contract and installed by the appropriate vendor.

A second clean room will be used to prepare cryogenic detectors for installation in the CDMS II Icebox. It will contain two clean, class 100 work benches and a small amount of storage.

The electronics hut will contain racks for the electronics and data acquisition system. Ambient air from the mine will be ducted into the room for cooling the electronics.

The equipment room will contain the HVAC system for the clean rooms as well as the compressors, dewars, and other components for the cryogenic systems. All of the CDMS II structures must have fire protection equipment installed in addition to ordinary power. Furthermore, a chiller system for cooling electronics will be installed in case it is needed when all the experiments envisaged for the Soudan Laboratory are up and running. The CDMS II Soudan infrastructure will be completed in the fall of 1999.

The cryogenic system for the CDMS II experiment includes a second dilution refrigerator, a helium liquefier, a nitrogen system and a second Icebox all to be installed in the Soudan Laboratory. Work to install this system can begin before all of the structures are in place. Only the RF clean room is required to be structurally present.

System design and construction is being supervised by a Fermilab cryogenic engineer. The dilution refrigerator has been purchased from Oxford Instruments and delivered to Fermilab in March 1999. The helium liquefier which will provide helium to the dilution refrigerator will also be purchased from a suitable vendor. The Icebox for the CDMS II experiment is being fabricated by the Fermilab group following the design of the CDMS I Icebox with only minor changes. Machining and welding has been contracted to and outside vendor and the work is nearing completion. Some initial fit up and assembly is being done at Fermilab by cryogenic technicians with help from CDMS I experts. This work will be completed in the spring of 1999. At that time the Icebox will be delivered to the Soudan Laboratory along with all the other components of the cryogenic system. Final assembly of the Icebox at Soudan will begin in the fall of 1999. Note that the base of the shield must be in place before final assembly can begin. The remainder of the shielding will be put in place after the Icebox assembly is completed.

The cryogenic plumbing, instrumentation, and the cryogenic control system must also be installed. This can begin once the equipment room is in place. Assembly and installation will be accomplished with a combination of Fermilab and Soudan technicians as well as experts from the CDMS II collaboration. It is expected that this work will be completed in the fall of 1999 allowing CDMS II to enter an extensive program of testing and commissioning in preparation for receiving the first cryogenic detectors.

A cryogenic control system and instrumentation must also be specified and purchased for CDMS II. The system will be specified by the Fermilab cryogenic engineer with input from experts in the CDMS I collaboration.

Work Breakdown Structure:

6. Soudan Installation (R.Dixon)
6.1. Cryogenic Systems (R.Schmitt)
6.1.1. Dilution Fridge
6.1.1.1. EDIA
6.1.1.2. Procurement
6.1.2. Icebox
6.1.2.1. EDIA
6.1.2.2. Copper Procurement
6.1.2.3. All Icebox Materials in Hand
6.1.2.4. Icebox Assembly
6.1.2.4.1. Machining & Welding
6.1.2.4.2. Fitting and leak checking at Fermilab
6.1.2.5. Icebox Ready to go to Soudan
6.1.3. Liquefier
6.1.3.1. EDIA
6.1.4. Cryogenics Control System
6.1.4.1. EDIA
6.1.4.2. Computer
6.1.4.3. UPS
6.1.4.4. Software

6.2. Soudan Installation (L.Kula)
6.2.1. Preinstallation
6.2.1.1. EDIA
6.2.1.2. Clear Cavern Space for CDMS
6.2.1.2.1. Move and Stack Tasso Tubes

6.2.2.3.8. Ready to Begin Icebox Installation
6.2.2.3.9. Soft Wall Clean Room
6.2.2.4. Equipment Room
6.2.2.4.1. Acquire DNR Approval
6.2.2.4.2. Bid Period
6.2.2.4.3. Notice to Proceed
6.2.2.4.4. Prefabrication
6.2.2.4.5. Install
6.2.2.4.6. Power
6.2.2.5. Ready for Cryogenic Installation
6.2.2.6. Detector Preparation Room
6.2.2.6.1. Acquire DNR Approval
6.2.2.6.2. Bid Period
6.2.2.6.3. Notice to Proceed
6.2.2.6.4. Prefabrication
6.2.2.6.5. Install
6.2.2.6.6. Power
6.2.2.6.7. Air shower installation
6.2.2.6.8. Work Bench installation
6.2.2.7. Electronics Hut
6.2.2.7.1. Acquire DNR Approval
6.2.2.7.2. Bid Period
6.2.2.7.3. Notice to Proceed
6.2.2.7.4. Prefabrication
6.2.2.7.5. Install

6.2.1.2.2. Check and Sort Tubes
6.2.1.2.3. Move Communications Cable Tray to West Wall
6.2.1.2.4. Move Gas Lines to West Wall
6.2.1.2.5. Move 30 ft. of Long Work Bench & Store Stuff
6.2.1.2.6. Move Steel Frame
6.2.1.2.7. Re-set Steel Frame
6.2.1.2.8. Move and Sort Veto Shield land stuff under frame
6.2.1.2.9. Clean up Double Beta Bldg. and other storage
6.2.1.2.10. Survey floor for Clean Room Installation
6.2.1.2.11. Ready to begin Installation at Soudan

6.2.1.3. Electrical System
6.2.1.4. Concrete Pad(s)
6.2.1.4.1. EDIA
6.2.1.4.2. Obtain DNR Approval
6.2.1.4.3. Bid Period
6.2.1.4.4. Notice to Proceed
6.2.1.4.5. Construction
6.2.2. Experiment Enclosures
6.2.2.1. EDIA
6.2.2.2. Crane
6.2.2.2.1. EDIA
6.2.2.2.2. Obtain DNR Approval
6.2.2.2.3. Bid Period
6.2.2.2.4. Notice to Proceed
6.2.2.2.5. Construct
6.2.2.2.6. Install Crane
6.2.2.3. RF Clean room
6.2.2.3.1. Acquire DNR Approval
6.2.2.3.2. Bid Period
6.2.2.3.3. Notice to Proceed
6.2.2.3.4. Pre-Fabricate
6.2.2.3.5. Install
6.2.2.3.6. Power
6.2.2.3.7. Shield Base Assembly

6.2.2.7.6. Power
6.2.2.8. Mezzanine Structure

6.2.2.8.1. Acquire DNR Approval
6.2.2.8.2. Bid Period
6.2.2.8.3. Notice to Proceed
6.2.2.8.4. Prefabrication
6.2.2.8.5. Install

6.2.2.8.6. Power
6.2.2.9. HVAC System
6.2.2.9.1. Main Clean Room Filter and air circulation system
6.2.2.9.2. Radon Filter
6.2.2.10. Vibration Isolation
6.2.2.11. Fire Protection System
6.2.2.12. Chiller System
6.2.2.13. Enclosures Complete at Soudan
6.2.3. Cryogenics Installation
6.2.3.1. Icebox Installation
6.2.3.1.1. Final Assembly and leak checking at Soudan
6.2.3.1.2. Ready for shield installation
6.2.3.2. Dilution Refrigerator
6.2.3.2.1. Pre-installation of piping & pumps
6.2.3.2.2. Fridge Installation
6.2.3.2.3. Wiring & Instrumentation Hookup
6.2.3.2.4. Test Run without Icebox
6.2.3.2.5. Hookup to Icebox assembly
6.2.3.2.6. Icebox Ready to Run
6.2.3.2.7. Testing with Icebox
6.2.3.3. Liquifier
6.2.3.3.1. Installation
6.2.3.3.2. Testing
6.2.3.4. Cryogenic Control System Installation
6.2.3.4.1. Installation
6.2.3.4.2. Checkout
6.2.3.5. Cryogenic System Complete and Tested
6.2.4. Shield Installation

Manpower Plan

Sum of FTE					Yr			
WBS	Task	Inst	level	Name	1	2	3	Grand Total
6.1.1	Icebox	FNAL	eng	Schmitt	0.5	0.5	0.5	1.5
			tech	FNAL techs	2.0			2.0
		LBNL	fac	Ross	0.3	0.3	0.3	0.9
			phys	Taylor,J.	0.3	0.3	0.3	0.8
	Icebox Total				3.1	1.1	1.1	5.2
6.2.2	Exp Enclosures	FNAL	phys	FNAL phys A	0.5	1.0	1.0	2.5
			postd	FNAL postd B	0.5	1.0	1.0	2.5
			eng	Kula	1.0	1.0	1.0	3.0
				FNAL eng B	0.1			0.1
			tech	FNAL designer	0.3			0.3
				Soudan tech	0.5			0.5
	Exp Enclosures Total				2.9	3.0	3.0	8.9
Grand Total					5.9	4.1	4.1	14.0

Soudan Installation Schedule Milestones

Milestone	Date
Clear Cavern Space for CDMS	1/25/99
FNAL/Minnesota MOU signed	2/2/99
Concrete pad ready	3/15/99
Enclosures complete at Soudan	8/10/99
Ready to begin Icebox Assembly	8/24/99
Icebox Assembly Complete	10/19/99
Cryo system ready for test run	1/19/00
Ready for Detector Installation	3/28/99

Soudan Infrastructure Budget:

Sum of Cost2					Yr			
categ	WBS	Task	Inst	Name	1	2	3	Grand Total
pers Total					520,230	424,071	436,793	1,381,094
Travel	6.1.1	Icebox	LBNL	travel	8,098	8,341		16,438
		Icebox Total			8,098	8,341		16,438
	6.2.2	Exp Enclosures	FNAL	phys travel	7,100	7,313		14,413
		Exp Enclosures Total			7,100	7,313		14,413
	6.2.3	Cryo installation	FNAL	Eng travel	21,300	14,626		35,926
				phys travel	21,300	14,626		35,926
				Tech Travel	49,700	30,715		80,415
		Cryo installation Total			92,300	59,967		152,267
Travel Total					107,498	75,620		183,118
S&E	6.1.1	Icebox	LBNL	general	16,195			16,195
		Icebox Total			16,195			16,195
	6.2.3	Cryo installation	LBNL	general		16,681		16,681
		Cryo installation Total				16,681		16,681
S&E Total					16,195	16,681		32,876
eqpt	6.1.3	Liquefier	FNAL	Liquefier	90,000			90,000
		Liquefier Total			90,000			90,000
	6.1.4	Cryo Controls	FNAL	Amp/Driver Board	6,400			6,400
				Comp.(1)/GPIB	10,000			10,000
				Computer	5,000			5,000
				Connects/Filters	2,000			2,000
				Display Board	3,300			3,300
				GPIB iface	1,200			1,200
				Instrumentation	24,000			24,000
				Mplex Board	3,400			3,400
				PSU	250			250
				Software	2,000			2,000
				UPS	1,000			1,000
			UCB	Thermometers	11,000			11,000
		Cryo Controls Total			69,550			69,550
	6.2.2	Exp Enclosures	FNAL	Air shower installation		9,270		9,270
				Chiller System		20,600		20,600
				Decking	35,000			35,000
				Fire Protection System	4,000			4,000
				Ladders and Stairs	1,000			1,000
				Link to Soudan Control Room	5,000			5,000
				Main Clean Room Filter and air circulation s	50,000			50,000
				Mods. for Clean Room	5,000			5,000
				Power	8,000			8,000
				Racks	2,000			2,000
				RF Structure, penetrations, and electrical filte	100,000			100,000
				Shield Assembly fixtures	5,000			5,000
				Soft Wall Clean Room	7,000			7,000
				Sound proofing	2,500			2,500
				Vibration Isolation	5,000			5,000
				Work Bench installation	10,000			10,000
				Structure (Det Prep room)	44,000			44,000
				Structure (Elec Hut)	33,600			33,600
				Structure (Eqpt room)	33,600			33,600
				Link to Surface Control Room	10,000			10,000
				Link to World	5,000			5,000
		Exp Enclosures Total			365,700	29,870		395,570
	6.2.3	Cryo installation	FNAL	Dilution Refrigerator	700			700
		Cryo installation Total			700			700
eqpt Total					525,950	29,870		555,820
Grand Total					1,169,873	546,242	436,793	2,152,908

Contingency

Sum of Cont			Yr			
WBS	Task	categ	1	2	3	Grand Total
6.1.1	Icebox	pers	69,978	19,657	20,247	109,882
		Travel	1,620	1,668		3,288
		S&E	4,049			4,049
	Icebox Total		75,646	21,325	20,247	117,218
6.1.3	Liquefier	eqpt	31,500			31,500
	Liquefier Total		31,500			31,500
6.1.4	Cryo Controls	eqpt	20,493			20,493
	Cryo Controls Total		20,493			20,493
6.2.2	Exp Enclosures	pers	61,835	39,315	40,494	141,644
		eqpt	91,425	8,395		99,820
	Exp Enclosures Total		153,260	47,709	40,494	241,463
6.2.3	Cryo installation	eqpt	245			245
	Cryo installation Total		245			245
Grand Total			281,143	69,035	60,741	410,919

10.6. Integration and Running

Work Plan

This section of the work plan covers operations of the CDMS II experiment at Soudan as well as test facilities at Stanford, UC Berkeley and Case Western Reserve. The goal of Integration and Running as defined by our organizational structure is to maintain and operate all the facilities where cryogenic detector operation is to take place. The primary facility is of course the Icebox and related systems at Soudan where the physics data will be taken. In addition, our plan is to use three other facilities, including the Stanford Icebox, to test and prescreen all detectors prior to installation at Soudan. Detector calibration and characterization will also be carried out at these test facilities, although at a reduced level in years 4 and 5 when CDMS II is smoothly operating. Because of practical limitations in personnel we have devised a strategy that does not require us to simultaneously operate all four facilities. Rather, we will temporarily interrupt operations at a given facility to allow the critical path tasks to proceed as rapidly as possible at the appropriate site.

We plan to operate the original icebox and shield systems at the Stanford Underground Facility in the first year of this proposal to complete the data runs for CDMS I physics goals. Following that we will use the SUF to prescreen all tower/detector assemblies prior to installation at Soudan. This important step will serve to minimize the cycling of the icebox at Soudan that might otherwise result from radiocontaminants. In addition, depending on what we see in the data at Soudan, some aspects of detector response may require a low background environment. To allow for this, we have included the necessary resources for a four month run in each of years 4 and 5. These detector operations will therefore require that we maintain the infrastructure at the SUF, including the cryogenic systems, shield, veto, readout electronics and data acquisition, along with an appropriate supply of cryogens and basic diagnostic equipment. This facility will also be used to debug and test the readout and DAQ systems prior to installation at Soudan.

Owing to the large number of detectors that we need to test to fill the Soudan icebox and the need to develop a detailed knowledge of detector response to various types of radiation, we will maintain and operate detector test facilities at UC Berkeley and Case Western Reserve University. The UCB facility is centered around the 75 microwatt dilution refrigerator in use since the mid-1980s. This refrigerator has been used for all of the CDMS large-detector development and testing, to date, and requires only modest upgrades to auxiliary systems to serve our needs for CDMS II. The facility at CWRU is based on a new 160 microwatt dilution refrigerator purchased on faculty startup funds. Installed last summer in newly renovated lab space, it underwent a successful system test in September 1998. It is currently being instrumented for CDMS tower operation and diagnostic measurements. Both test facilities, as well as the SUF, will utilize the same production 9U electronics being prepared for Soudan. During the construction phase (years 1-3) the test facilities at UCB and CWRU will be fully dedicated to CDMS II, dropping to a 50% duty cycle in the last 2 years when the demands for detector response work will be reduced; cryogens, personnel and supplies are budgeted accordingly.

The test facility at Stanford (SU/SCU) is headed by Prof. Betty Young, our collaborator from Santa Clara University, and has been designed at the end of a proton beam line from a 3 MeV Van de Graaff. During the first project year, the facility will be used for detector testing, particularly rapid turn around checks of W Tc and of W/Al QET phonon collection efficiency. During the second and third years, the facility will use the proton beam to produce a calibrated flux of neutrons for a detailed calibration of the Si and Ge ZIP response for nuclear recoils.

Detector operation at Soudan will begin with a single tower at the end of year 1. The tower will have been running at SUF for a minimum of 6 months, and will be brought to Soudan following the successful testing of the icebox and a brief period of preparation work by the detector team. The installation and commissioning of this tower will drive a full system integration for one-towers worth of electronics and DAQ, and serve to check the noise environment, on-site analysis tools and background level early in year 2 of the project. Although additional channels of electronics and DAQ will be installed later to keep pace with two additional phases of detector installation, the essential infrastructure and first set of read out will be in place by this time, so the focus in early year 2 will be on systems integration. We plan to operate this tower for up to 7 months, at which time towers 2-4 will be ready for installation. Following a 3 month installation and commissioning of 2-4, we will operate for a maximum of 8 months. The end of this run is timed for the completion of the SUF pre-screening of towers 5-7. These last three towers will be installed during the last two months of year three and will represent the completion of the construction phase.

During tower installation and commissioning periods, detector teams consisting of 4-5 detector experts will travel to Soudan. Once smooth operation is achieved the on-site detector personnel can fall back to a rotation at a reduced level of typically two individuals. While back at their home institution, detector experts will support the efforts of those on site with data handling, diagnostics, and other tasks that can be handled remotely. Once construction is complete and 7-tower operation has been achieved, we will organize a rotation of interleaved two-week shifts with two physicists on site at a time. Their efforts will be assisted by a member of the resident technical staff assigned to the project to maintain cryogens, mount tapes, and assist with other day to day aspects of running. The subsystem manager for Integration and Running will also establish a rotation of a "physicist in charge" who is responsible for operations during a 3 month period. He or she would not necessarily spend full time at the mine, but would be "on call" for this period. They would be ready to travel to the mine on short notice to coordinate a response to problems that can arise in the operation of a complex experiment. To bring in the necessary experts, we also allow for several longer stays for members of each institution.

In order to contain the cost of cryogens we plan to install a closed-cycle helium liquifier. Due to limitations on the heat load generated by this unit, we may need a chilled water system to be installed in the mine in order to use the liquifier. This unit will result in a significant cost saving of approximately $100,000 per year of operation (starting at the end of year 3) for a capital investment of $90,000.

Work Breakdown Structure:

1. Integration and Running (D.Akerib)

1.1. SUF and Test Facility Operations
1.1.1. SUF operations
1.1.1.1. Maintain infrastructure
1.1.1.1.1. DAQ/computers
1.1.1.1.2. Detector "warm" electronics
1.1.1.1.3. Shield & veto
1.1.1.1.4. Cryogenic systems
1.1.1.1.5. Environment/Fridge Monitoring
1.1.1.1.6. Tunnel infrastructure
1.1.1.1.6.1. Computer network
1.1.1.1.6.2. Computer peripherals

1.2.3.4. Thermal links
1.2.3.5. Striplines
1.2.3.6. Room temperature electrical checks
1.2.4. Detector system operation
1.2.4.1. Icebox cooldown
1.2.4.2. Detector pulsing
1.2.4.3. Calibration data
1.2.4.4. Low-background data
1.2.4.5. Online diagnostics
1.2.4.6. Offline reduction and analysis

1.1.1.1.7. Cryogens
1.1.1.1.8. Supplies
1.1.1.1.9. Diagnostic equipment
1.1.1.2. CDMS I Physics
1.1.1.2.1. Detector deployment
1.1.1.2.2. Data runs
1.1.1.2.3. Calibration runs
1.1.1.2.4. Data reduction and analysis
1.1.1.3. Detector Operations
1.1.1.3.1. Detector deployment
1.1.1.3.2. Data runs
1.1.1.3.3. Data reduction and analysis
1.1.2. Test facility operations
1.1.2.1. Maintain infrastructure
1.1.2.1.1. DAQ & computers
1.1.2.1.2. Warm electronics
1.1.2.1.3. Cryogenic systems
1.1.2.1.4. Cryogens
1.1.2.1.5. Supplies
1.1.2.2. Detector operations
1.1.2.2.1. Detector deployment
1.1.2.2.2. Data runs
1.1.2.2.3. Data reduction and analysis

1.2. Detector Installation and commissioning at Soudan
1.2.1. Room temperature preparation
1.2.1.1. Detector package final assembly
1.2.1.2. Electrical checks
1.2.1.3. Auxiliary parts
1.2.2. Experimental volume access
1.2.2.1. Open/close veto and shield
1.2.2.2. Open/close icebox lids
1.2.3. Cryogenic package installation
1.2.3.1. Detectors/towers
1.2.3.2. Cold electronics
1.2.3.3. Radiation shields

1.3. Soudan Operations
1.3.1. Maintain infrastructure
1.3.1.1. Experimental apparatus
1.3.1.1.1. Icebox & dilution refrigerator system
1.3.1.1.2. Environment/fridge monitoring
1.3.1.1.3. Shield & veto system
1.3.1.1.4. Detector "warm" electronics
1.3.1.1.5. Daq/computers
1.3.1.2. Auxiliary systems
1.3.1.2.1. Liquefier
1.3.1.2.2. Vacuum systems
1.3.1.2.3. Radon system
1.3.1.2.4. Clean room
1.3.1.2.4.1. Clean room
1.3.1.2.4.2. Detector work area
1.3.1.2.5. Cryogens
1.3.1.2.6. Supplies
1.3.1.2.7. Diagnostic equipment
1.3.1.2.8. Computer network
1.3.2. Experiment operations
1.3.2.1. Run initiation
1.3.2.1.1. Icebox cooldown
1.3.2.1.2. Liquefier changeover
1.3.2.1.3. Shield/veto diagnostics
1.3.2.1.4. Cryogenic detector diagnostics
1.3.2.2. Steady-state running
1.3.2.2.1. Physics data acquisition
1.3.2.2.2. Calibration data
1.3.2.2.3. Detector pulsing
1.3.2.2.4. Online diagnostics and response
1.3.2.2.5. Offline data handling
1.3.2.2.5.1. Reduction
1.3.2.2.5.2. Archiving
1.3.2.2.5.3. Distribution

Manpower plan

Sum of FTE					Yr					
WBS	Task	Inst	level	Name	1	2	3	4	5	Grand Total
1.1.	SUF/TF Running	CWRU	postd	Bolozdvnya/pd B	0.1	0.1	0.1	0.1	0.1	0.4
			grad	Driscoll/gr B	0.2					0.2
				Perera/gr A		0.1	0.1	0.1	0.1	0.3
				Wang/gr C		0.1	0.1	0.1	0.1	0.3
			tech	Computer support	0.1	0.1				0.1
		SU	phys	SU phys		0.2	0.2			0.4
			eng	Hennessy	0.5	0.5	0.5			1.5
			tech	Perales	0.5	0.5	0.5	0.3	0.3	2.1
		UCB	postd	Hellmig/pd B	0.1	0.1	0.1	0.1	0.1	0.4
			grad	Mandic/gr A	0.1	0.1	0.1	0.1	0.1	0.4
				UCB grad C	0.1	0.1	0.1	0.1	0.1	0.4
		UCSB	phys	Bauer	0.2					0.2
	SUF/TF Running Total				1.9	1.9	1.8	0.6	0.6	6.7
1.2.	Det. Install/commis.	CWRU	fac	Akerib		0.3	0.2			0.5
			postd	Schnee/pd A	0.3	0.5	0.5			1.3
			grad	Driscoll/gr B			0.3			0.3
				Wang/gr C		0.2	0.3			0.5
		FNAL	postd	Eichblatt/pd A			0.3			0.3
			tech	Soudan tech			0.5			0.5
		PU	postd	PU postd A			0.3			0.3
			grad	PU grad A			0.3			0.3
		SU	phys	SU phys	0.3	0.4	0.3			1.0
			postd	Clarke/pd A		0.3	0.3			0.5
			grad	Saab/gr A		0.4	0.4			0.8
		UCB	postd	Hellmig/pd B		0.3				0.3
			grad	Mandic/gr A		0.1				0.1
		UCSB	phys	Bauer			0.3			0.3
				Yellin			0.3			0.3
			postd	UCSB postd A			0.3			0.3
			grad	UCSB grad B			0.3			0.3
				UCSB grad C			0.3			0.3
	Det. Install/commis. Total				0.5	2.4	4.7			7.6
1.3.	Soudan Ops/Science	CWRU	fac	Akerib			0.2	0.7	0.7	1.6
			postd	Bolozdynya/pd B				0.7	0.7	1.4
				Schnee/pd A		0.5	0.5	0.7	0.7	2.4
			grad	Driscoll/gr B		0.5	0.3	0.7	0.7	2.2
				Perera/gr A				0.7	0.7	1.4
				Wang/gr C		0.3	0.6	0.7	0.7	2.3
			tech	Computer support			0.1	0.1	0.1	0.2
		FNAL	phys	Crisler			0.5	0.5	0.5	1.5
				FNAL phys A				1.0	1.0	2.0
			postd	Eichblatt/pd A			0.3	1.0	1.0	2.3
				FNAL postd B				1.0	1.0	2.0
			tech	Soudan tech	1.0	1.0	0.5	1.0	1.0	4.5
		LBNL	fac	Ross				0.3	0.3	0.6
			phys	Taylor,J.				0.3	0.3	0.5
			postd	LBNL postd A			1.0	1.0	1.0	3.0
		PU	fac	Shutt				0.3	0.3	0.5
			postd	PU postd A			0.3	1.0	1.0	2.3
			grad	PU grad A			0.3	1.0	1.0	2.3
		SCU	fac	Young				1.0	1.0	2.0
		SU	phys	SU phys			0.3	0.7	0.7	1.7
			postd	Clarke/pd A				1.0	1.0	2.0
			grad	Saab/gr A		0.2	0.4	0.7	0.7	2.0
				SU grad B				1.0	1.0	2.0
				SU grad C				0.7	0.7	1.4
		UCB	postd	Gaitskell/pd A				0.7	0.7	1.4
				Hellmig/pd B				0.7	0.7	1.4
				Isaac/pd C				0.9	0.9	1.8
			grad	Mandic/gr A		0.3	0.9	0.7	0.7	2.6
				UCB grad B				1.0	1.0	2.0
				UCB grad C				0.7	0.7	1.4
			eng	Seitz				0.5	0.5	1.0
		UCSB	fac	Nelson				1.0	1.0	2.0
			phys	Bauer		0.2	0.3	1.0	1.0	2.5
				Yellin			0.3	1.0	1.0	2.3
			postd	UCSB postd A			0.3	1.0	1.0	2.3
			grad	Bunker/gr A				1.0	1.0	2.0
				UCSB grad B			0.3	1.0	1.0	2.3
				UCSB grad C			0.3	1.0	1.0	2.3
	Soudan Ops/Science Total				1.0	3.0	7.2	29.9	29.9	70.9
1.4.2	Education/outreach	UCB	postd	Isaac/pd C	0.1	0.1	0.1	0.1	0.1	0.5
	Education/outreach Total				0.1	0.1	0.1	0.1	0.1	0.5
Grand Total					3.5	7.4	13.8	30.6	30.6	85.7

Integration and Running Budget:

Sum of Cost2					Yr					
categ	WBS	Task	Inst	Name	1	2	3	4	5	Grand Total
pers Total					293,655	497,398	962,692	1,945,976	2,001,615	5,701,336
Travel	1.1.	SUF/TF Running	CWRU	travel	28,703					28,703
			FNAL	travel	7,100					7,100
			UCB	travel to CWRU	7,520					7,520
		SUF/TF Running Total			43,323					43,323
	1.2.	Det. Install/commis.	CWRU	travel	13,599	20,575	20,640			54,814
			FNAL	travel		7,313				7,313
			SU	travel	7,810	23,972	8,286			40,068
			UCB	travel		18,744	18,030			36,775
		Det. Install/commis. Total			21,409	70,604	46,956			138,969
	1.3.	Soudan Ops/Science	CWRU	travel		22,572	22,059	21,318	21,958	87,906
			FNAL	travel			7,532	15,517	15,982	39,031
			LBNL	travel			2,337	2,407	2,479	7,222
			PU	travel				15,800	15,800	31,600
			SCU	travel				2,720	2,720	5,440
			SU	travel			16,571	25,603	26,371	68,545
			UCB	travel		16,266	20,264	27,446	18,113	82,088
			UCSB	travel				26,298	15,174	41,472
		Soudan Ops/Science Total				38,837	68,763	137,108	118,596	363,304
	1.4.1	Meetings/conferences	CWRU	Foreign conferences	8,262	2,837	5,843	6,019	6,199	29,160
				Domestic conferences	5,279	3,625	3,733	7,691	7,921	28,248
				Meetings	13,433	28,634	29,493	30,378	31,289	133,228
			PU	Foreign conferences		2,370	2,370	2,370	2,370	9,480
				Domestic conferences		2,370	2,370	2,370	2,370	9,480
			SU	Foreign conferences	7,810	8,044	8,286	8,534	8,790	41,464
				Domestic conferences	7,810	8,205	8,286	8,534	8,790	41,625
			UCB	Foreign conferences	13,536	13,942	14,360	14,791	15,235	71,864
				Domestic conferences	13,536	13,942	14,360	14,791	15,235	71,864
		Meetings/conferences Total			69,666	83,969	89,102	95,478	98,200	436,415
Travel Total					134,397	193,411	204,821	232,585	216,796	982,011
S&E	1.1.	SUF/TF Running	CWRU	cryogens	39,015	40,185	41,391	21,734	22,386	164,712
				shops	15,300	15,759	16,232	8,359	8,610	64,260
				DLT tape drive	1,836					1,836
				Geiger counter	765					765
				HEPA Filter w/Blower	1,019					1,019
				lab computer	3,825					3,825
				lab supplies	7,650	15,759	16,232	8,359	8,610	56,610
				laser printer for lab	1,224					1,224
				LN trap for diff pump	1,530					1,530
				magnetic shield	4,590					4,590
				phone/office supplies	1,530	1,576	1,623	1,672	1,722	8,123
				Radioactive sources	3,060					3,060
				SRS 760 spectrum analyzer	7,574					7,574
				SRS function generator	2,586					2,586
				Stereo Microscope Setup	3,130					3,130
				VXI adapters	1,622					1,622
			FNAL	lab supplies	14,200	14,626				28,826
			SCU	SU/SCU Test Facility	15,000	15,000	15,000	7,500	7,500	60,000
			SU	cryogens	105,103	34,223	26,799	31,621	32,570	230,315
				15 uW	15,620	16,089	16,571			48,280
				lab supplies	15,620	16,089	16,571	6,315	5,274	59,869
				SU/SCU Test Facility	15,620	16,089	16,571	8,534	8,790	65,604
			UCB	cryogens	24,816	25,560	26,327	13,559	13,965	104,228
				75 uW	0	0				0
				shops	4,512	4,647	4,787	2,465	2,539	18,950
				Computer support	5,198	5,354				10,552
				lab supplies	18,048	18,589	19,147	9,861	10,157	75,802
			UCSB	S&E	25,074					25,074
				lab supplies		25,956				25,956
		SUF/TF Running Total			355,066	265,501	217,252	119,980	122,124	1,079,922
	1.2.	Det. Install/commis.	CWRU	lab supplies		11,819	12,174			23,993
			FNAL	cryogens	44,049	196,747				240,796
				lab supplies			11,299			11,299
			LBNL	lab supplies			8,591			8,591
			PU	lab supplies			7,900			7,900
			SU	lab supplies		12,066	12,428			24,495
			UCB	lab supplies			11,967			11,967
			UCSB	lab supplies			13,367			13,367
		Det. Install/commis. Total			44,049	220,633	77,726			342,408
	1.3.	Soudan Ops/Science	CWRU	lab supplies		11,819	12,174	25,078	25,830	74,902
			FNAL	cryogens			126,247	24,688	25,429	176,364
				lab supplies			11,299	23,275	23,973	58,547
				Soudan hoist	31,240	32,177	33,143	34,137	35,161	165,857
				Soudan space	17,040	17,551	18,078	18,620	19,179	90,468
			LBNL	lab supplies			8,591	17,697	18,228	44,516
			PU	lab supplies			7,900	15,800	15,800	39,500
			SU	lab supplies		12,066	12,428	33,283	26,371	84,149
			UCB	Computer support			5,514	5,680	5,850	17,044
				lab supplies			11,967	24,652	25,391	62,010
			UCSB	lab supplies			13,367	28,087	28,363	69,818
		Soudan Ops/Science Total			48,280	73,614	260,708	250,998	249,575	883,175
	1.4.1	Meetings/conferences	UCB	publication costs		3,098	3,191	3,287	3,386	12,962
		Meetings/conferences Total				3,098	3,191	3,287	3,386	12,962
	1.4.2	Education/outreach	CWRU	teacher stipends	3,672	3,782	3,896	4,012	4,133	19,495
				supplies for prototypes	4,590					4,590
			UCB	Ed. Supplies	4,512					4,512
				Ed display @ Sdn	7,520					7,520
				teacher stipends	2,400	2,472	2,546	2,623	2,701	12,742
		Education/outreach Total			22,694	6,254	6,442	6,635	6,834	48,859
S&E Total					470,089	569,100	565,319	380,899	381,918	2,367,326

Integration and Running Budget: (cont.)

Sum of Cost2					Yr					
categ	WBS	Task	Inst	Name	1	2	3	4	5	Grand Total
eqpt	1.1.	SUF/TF Running	CWRU	AC Resistance Bridge	8,280					8,280
				Digital Oscilloscope	5,605					5,605
				HEPA-Filtered Clean Bench	5,191					5,191
				VXI Waveform Digitizer (qty 4)	10,000	10,300				20,300
				computer (linux clust. MC/anal.)	12,615					12,615
			SCU	Tex TDS420 scope	6,600					6,600
			SU	Computer for SU/SCU TF	3,000					3,000
				Joerger digitizers for SU/SCU TF	11,500					11,500
				Nat'l Inst. VXI crate for SU/SCU TF	3,500					3,500
				Nat'l Inst. VXI interface for SU/SCU TF	4,200					4,200
			UCB	Rotary Pump for 75	4,388					4,388
				Vac. gauge & controller	2,687					2,687
				computer for 75 lab (PC)	5,000	5,150				10,150
		SUF/TF Running Total			82,566	15,450				98,016
	1.2.	Det. Install/commis.	UCB	Digital Oscilloscope (2)		13,843				13,843
				SRS 760 Spec Analyzer		6,118				6,118
				SRS Amplifier (2)		4,932				4,932
				SRS Func. Gen. (2)		4,178				4,178
		Det. Install/commis. Total				29,071				29,071
	1.3.	Soudan Ops/Science	UCB	computers/data analysis			5,305	5,464	5,628	16,396
		Soudan Ops/Science Total					5,305	5,464	5,628	16,396
	1.4.2	Education/outreach	UCB	computer for edu prgmr		3,090				3,090
		Education/outreach Total				3,090				3,090
eqpt Total					82,566	47,611	5,305	5,464	5,628	146,572
Grand Total					980,707	1,307,520	1,738,136	2,564,925	2,605,957	9,197,245

10.7. Management

The Management of the CDMS II project is described above in Sec 5. The associated resources are listed below.

Management Manpower Plan

Sum of FTE					Yr					
WBS	Task	Inst	level	Name	1	2	3	4	5	Grand Total
7.1.	Management	FNAL	phys	Dixon	1.0	1.0	1.0	1.0	1.0	5.0
		LBNL	fac	Sadoulet	1.0	1.0	1.0	1.0	1.0	5.0
		SU	fac	Cabrera	1.0	1.0	1.0	1.0	1.0	5.0
		UCB	phys	Spadafora	0.8	1.0	1.0	1.0	1.0	4.8
			admin	admin asst	0.5	0.5	0.5	0.5	0.5	2.5
				Esteves	0.5	0.5	0.5	0.5	0.5	2.5
		UCSB	fac	Caldwell	1.0	1.0	1.0	1.0	1.0	5.0
	Management Total				5.8	6.0	6.0	6.0	6.0	29.8
Grand Total					5.8	6.0	6.0	6.0	6.0	29.8

Management Budget

Sum of Cost2					Yr					
categ	WBS	Task	Inst	Name	1	2	3	4	5	Grand Total
pers Total					393,962	435,958	449,037	462,508	476,384	2,217,849
Travel	7.1.	Management	FNAL	travel	35,500	21,939	22,597	23,275	15,982	119,293
			UCB	travel	7,520	7,746	7,978	8,217	8,464	39,925
				EAB meetings	4,000	4,120	4,244	4,371	4,502	21,237
		Management Total			47,020	33,805	34,819	35,863	28,948	180,455
Travel Total					47,020	33,805	34,819	35,863	28,948	180,455
S&E	7.1.	Management	UCB	EAB meetings	3,008	3,098	3,191	3,287	3,386	15,970
				teleconferences	3,008	3,098	3,191	3,287	3,386	15,970
				UCB OH on CWRU subaward	12,600					12,600
				UCB OH on SCU subaward	12,600					12,600
				UCB OH on PU subaward	12,600					12,600
		Management Total			43,816	6,196	6,382	6,574	6,771	69,740
S&E Total					43,816	6,196	6,382	6,574	6,771	69,740
eqpt	7.1.	Management	UCB	computer mngemnt (Mac)	4,000	4,120				8,120
		Management Total			4,000	4,120				8,120
eqpt Total					4,000	4,120				8,120
Grand Total					488,798	480,079	490,238	504,945	512,103	2,476,164

11.Education and Outreach

The CDMS collaboration has always been committed to science education and outreach at the K-12 level, in addition to its tradition to provide outstanding training for graduate and undergraduate students.

At the academic level, the CDMS experiments are marvelous multidisciplinary training grounds for our undergraduates, graduate students, and postdocs. Our WIMP search involves particle physics, cosmology, condensed matter, and low temperature physics. It should also be noted that the thin film development efforts at Stanford provide exceptional training opportunities for graduate and undergraduate students.

During the funding period of this proposal, our activities in education and outreach will focus on the development of materials based on the science and technology of the experiment, to be used both in the formal and the informal education settings.

For the formal classroom setting, we will develop classroom activities based on Dark Matter and Cosmology that will help teachers to present complex concepts to their classroom in a meaningful way. Two sites will be receiving intern teachers and intern students during the summer: UCB and CWRU. At UCB, we will take advantage of the existing relationship developed between programs from the Interactive University at Berkeley and the Oakland and the San Francisco Unified School district for the selection of teachers and students for these internships. Our objective is to start to develop materials for grades 10-12 at first, expanding to middle school later on. Our goal is to develop standard-linked materials that will help teachers at all grade levels to explain to their students the concepts revolving around cosmology, dark matter, and the technical challenge encountered in our experiments. By engaging teachers, students and scientists in this endeavor we will be able to develop "learning modules" that will be available online for teachers and students. Each learning module will be based on a theme, such as dark matter and coordinated with grade level standards. The participation of teachers in the development of the learning modules will ensure that the material is adequate for classroom use.

For the informal science education setting, as part of an NSF CAREER program, the CWRU group is developing astrophysics exhibits in collaboration with the Great Lakes Science Center in Cleveland. Astrophysics is somewhat underrepresented at the GLSC and they were quite enthusiastic to develop these exhibits in a joint program with CWRU. Our idea is to take advantage of the public's fascination with astronomy and astrophysics by bringing it down to a human scale that can be explored with interactive mechanical and optical exhibits. These exhibits will be designed to illustrate the physical principles at play in the cosmos and will be tied in with appropriate graphical descriptions of the related astrophysical phenomena. We have begun regular meetings with the directors of the exhibits and public programs groups and have submitted preliminary plans for five exhibit concepts for their consideration. The CWRU group will emphasize the conceptual and prototyping phase of the development, while the GLSC will focus on final design, presentation and fabrication. The common theme of these exhibits is the Big Bang Model of the Cosmos. The range of the phenomena include the warping of spacetime, weighing the galaxy, Doppler shifts in the expanding universe, supernovae as standard candles, and the finite age and size of the universe. The intended audience for these exhibits is GLSC members and visitors. They could also become part of a traveling exhibit produced by the GLSC for use at public or community events, or at other science centers and museums across the nation.

We also plan to work closely with the Department of Parks and Recreation of the State of Minnesota, that manages the Soudan mine, to develop interactive displays on site. The Soudan Mine State Park receives more 60,000 visitors a year. Again we will focus on the science and technology around the CDMS experiment.

In the long term we expect to develop a closer relationship with the native American communities in Northern Minnesota. We want to work with them exploring the parallels between science and the Native American culture, and eventually develop common education programs.

Education and Outreach Budget

Sum of Cost2		Yr					
categ	Name	1	2	3	4	5	Grand Total
pers (M.Isaac, web Programmer)		18,004	18,544	19,100	19,673	20,263	95,583
S&E	Ed display @ Sdn	7,520					7,520
	Ed. Supplies	4,512					4,512
	supplies for prototypes	4,590					4,590
	teacher stipends	6,072	6,254	6,442	6,635	6,834	32,237
S&E Total		22,694	6,254	6,442	6,635	6,834	48,859
eqpt	computer for edu prgmr		3,090				3,090
eqpt Total			3,090				3,090
Grand Total		40,698	27,888	25,542	26,308	27,097	147,533

---

[1] See, e.g., the reviews by V. Trimble, Ann. Rev. Astron. Astrophys., 25 (1987) 425; J.R. Primack, D. Seckel and B. Sadoulet, Ann. Rev. Nucl. Part. Sci., 38 (1988) 751; S. Tremaine, Physics Today 45 (1992) 28.

[2] A. Sandage, Physics Today, 34 (1990); E. Loh and E. Spillar, Astrophys. J., 303 (1986) 154; E. Loh and E. Spillar, Astrophys. J. Lett., 307 (1988) L1; E. Loh, Astrophys. J., 329 (1988) 24.

[3] S. Perlmutter et al., Astrophys. J., 483 (1997) 565; S. Perlmutter et al., Nature, 391 (1998) 51; P.M. Garnavich et al., Astrophys. J. Lett., 493 (1998) L53; S. Perlmutter et al., Preprint 1998: Astro-ph 9812473.

[4] G. Efstathiou et al., Preprint 1998: Astro-ph 981226.

[5] J. Yang et al., Astrophys. J., 281 (1984) 493; K.A. Olive, D.N. Schramm, G. Steigman and T. Walker, Phys. Lett. B, 426 (1990); D.N. Schramm and M. Turner, Rev. of Modern Phys., 70 (1998) 303.

[6] D. Tytler, X.-M. Fan and S. Burles, Nature, 381 (1996) 207.

[7] C. Fisher, M. Davis, M.A. Strauss, A. Yahil et al., Astrophys. J., 389 (1992) 188.

[8] D. Scott, J. Silk and M. White, Science, 268 (1995) 829

[9] M. Spiro, in Neutrino 98, Proc. of the XVIII International Conference on Neutrino Physics and Astrophysics, Takayama, Japan, 4–9 June 1998, edited by Y. Suzuki and Y. Totsuka.

[10] C. Afonso et al., submitted to Astron. and Astrophys. Lett., Astro-ph/98121173

[11] E.I. Gates, G. Gyuk, M.S. Turner, Phys. Rev. D, 53 (1996) 4138.

[12] M. Fich and S. Tremaine, Ann. Rev. Astron. Astrophys., 29 (1991) 409.

[13] E. Witten, Phys. Rev. D, 30 (1984) 272; A. De Rujula and S. Glashow, Nature, 312 (1984) 734.

[14] A. de Rujula, S.L. Glashow and U. Sarid, Nucl. Phys. B, 333 (1990) 173.

[15] C. Hagmann et al., Phys. Rev. Lett., 80 (1998) 2043.

[16] J.E. Kim, Phys. Rev. Lett., 43 (1979) 103; M.A. Shifman, A.I. Vainshtein and V.I. Zakharov, Nucl. Phys. B, 166 (1980) 493.

[17] P. Sikivie, Phys. Rev. Lett., 51 (1983) 1415.

[18] R. Cowsik and J. McClelland, Astrophys. J., 180 (1973) 7.

[19] T. Kajita, et al., in Neutrino 98, Proc. of the XVIII International Conference on Neutrino Physics and Astrophysics, Takayama, Japan, 4–9 June 1998, edited by Y. Suzuki and Y. Totsuka.

[20] M. Davis, F. Summers and D. Schlegel, Nature, 359 (1992) 393; D. Pogosyan and A.A. Starobinsky, Astrophys. J., 447 (1995) 465; J.R. Primack et al., Phys. Rev. Lett., 74 (1995) 2160; A. Klypin, R. Nolthenius and J.R. Primack, Astrophys. J., 474 (1997) 533.

[21] S.D. Tremaine and J.E. Gunn, Phys. Rev. Lett., 42 (1979) 407; J. Madsen, Phys. Rev. D, 44 (1991) 999.

[22] B. Lee and S. Weinberg, Phys. Rev. Lett., 39 (1977) 165; J. Silk and M. Srednicki, Phys. Rev. Lett., 53 (1984) 624.

[23] M.W. Goodman and E. Witten, Phys. Rev. D, 31 (1985) 3059; J.R. Primack, D. Seckel and B. Sadoulet, Ann. Rev. Nucl. Part. Sci., 38 (1988) 751; J.D. Lewin and P.F. Smith, Astropart. Phys., 6 (1996) 87.

[24] J.R. Primack, D. Seckel and B. Sadoulet, Ann. Rev. Nucl. Part. Sci., 38 (1988) 751..

[25] L. Bergstrom, Nucl. Phys. B 325 (1989)647.

[26] J.Silk and M. Srednicki, Phys. Rev. Lett. 53 (1984)624.
[27] W.H.Press and D.N. Spergel, Astrophys. J. 296 (1985)679.
[28] J. Silk, K. Olive and M. Srednicki, Phys. Rev. Lett. 55 (1985)257.
[29] K. Freese, Phys. Lett. B 187(1986)295.
[30] L. Krauss, M. Srednicki and F. Wilczek, Phys. Rev. D 33 (1986)2079.
[31] T. Gaisser, G. Steigman and S. Tilav, Phys. Rev. D 34 (1986) 2206.
[32] M. Kamionkowski, K. Griest, G. Jungman and B. Sadoulet, *Phys. Rev. Lett.* 74 (1995) 5174.
[33] L. Bergstrom, J. Edsjo and P. Gondolo, hep-ph/9806293; Phys. Rev. D 55 (1997) 1765.
[34] G. Jungman, M. Kamionkowski and K. Griest, Phys. Rep., 267 (1996) 195.
[35] R. Bernabei et al., Phys. Lett. B, 389 (1996) 757.
[36] P.F. Smith et al., Phys. Lett. B, 379 (1996) 299; J.J. Quenby et al., Astropart. Phys., 5 (1996) 249.
[37] A. Alessandrello et al., Nucl. Instr. and Methods, A370 (1996) 241.
[38] A. de Bellefon, et al., Nucl. Instr. and Methods, A370 (1996) 230.
[39] S.P. Ahlen et al., Phys. Lett. B, 195 (1987) 603.
[40] D.O. Caldwell et al., Phys. Rev. Lett., 61 (1988) 510.
[41] D. Reusser et al., Phys. Lett. B, 235 (1991) 143
[42] M. Beck et al., Phys. Rev. Lett., 70 (1993) 2853; L. Baudis et al., Preprint 1998: hep-ex/9811045.
[43] A. Morales, private communication (1997).
[44] R. Bernabei et al., Rome II preprints, 1998, INFN/AE-8/23 and ROM2F/98/34.
[45] A. Bottino et al., Phys. Lett. B, 402 (1997) 113.
[46] D.N. Spergel, Phys. Rev. D, 37 (1988) 353.
[47] A.K. Drukier, K. Freese and D.N. Spergel, Phys. Rev., 33 (1986) 3495; K. Freese, J. Frieman and A. Gould, Phys. Rev. D, 37 (1987) 3388.
[48] D.P. Snowden-Ifft, E.S. Freeman and P.B. Price, Phys. Rev. Lett., 74 (1995) 4133.
[49] J.I. Collar, Phys. Rev. D, 54 (1996) R1247.
[50] K.N. Buckland, M.J. Lehner, G.E. Masek and M. Mojaver, Phys. Rev. Lett., 73 (1994) 1067; M.J. Lehner, K.N. Buckland and G.E. Masek, Astropart. Phys., 8 (1997) 43.
[51] A.A. Klimenko et al., JETP Lett. 67 (1998) 875.
[52] J. Hellmig and H.V. Klapdor-Kleingrothaus, Zeit. fur Phys. A, 359 (1997) 351.
[53] R.J. Gaitskell et al., Nucl. Phys. B (Proc. Suppl.), 51B (1996) 279.
[54] S.W. Nam et al., Proc. of the VIIth International Workshop on Low Temperature Detectors, Munich, 1997, published by the Max Planck Institute of Physics, p. 217, and Web site: http://avmp01.mppmu.mpg.de/ltd7.
[55] M. Sisti et al., Proc. of the VIIth International Workshop on Low Temperature Detectors, Munich, 1997, published by the Max Planck Institute of Physics, p. 232, and Web site: http://avmp01.mppmu.mpg.de/ltd7.
[56] D. L'Hôte et al., Proc. of the VIIth International Workshop on Low Temperature Detectors, Munich, 1997, published by the Max Planck Institute of Physics, p. 237, and Web site: http://avmp01.mppmu.mpg.de/ltd7.
[57] R.J. Gaitskell et al., Proc. of the VIIth International Workshop on Low Temperature Detectors, Munich, 1997, published by the Max Planck Institute of Physics, p. 221, and Web site: http://avmp01.mppmu.mpg.de/ltd7.
[58] R.M. Clarke et al., Proc. of the VIIth International Workshop on Low Temperature Detectors, Munich, 1997, published by the Max Planck Institute of Physics, p. 229, and Web site: http://avmp01.mppmu.mpg.de/ltd7.
[59] T. Shutt et al., Phys. Rev. Lett., 29 (1992) 3425. T. Shutt et al., Phys. Rev. Lett., 29 (1992) 3531.
[60] M. Sisti *et al.*, "Performance of the CRESST dtectors and status of the experiment," in proceedings of the *VIIth International Workshop on Low Temperature Detectors,* Munich, 1997, published by the Max Planck Institute of Physics, p. 232, and Web site: http://avmp01.mppmu.mpg.de/ltd7.

[61] D. L'Hôte *et al.*, "Dark matter search using a 60g Germanium bolometer in the Fréjus Underground Laboratory," in proceedings of the *VIIth International Workshop on Low Temperature Detectors,* Munich, 1997, published by the Max Planck Institute of Physics, p. 237, and Web site: http://avmp01.mppmu.mpg.de/ltd7.

[62] M. J. Penn, *et al., Journal of Applied Physics* **79**, 8179 (1996).

[63] S.W. Nam, *et al.*,Proceedings of the VIIth International Workshop on Low Temperature Detectors, Munich, 1997, published by Max Plank Institute of Physics, Munich, Germany.

[64] R. J. Gaitskell *et al.*, Nucl. Phys. B (Proc. Suppl.), **51B** (1996) 279

[65] T. Shutt, et al., Proceedings of the VIIth International Workshop on Low Temperature Detectors, Munich, 1997, published by Max Plank Institute of Physics.

[66] K. D. Irwin, *et al., Rev. Sci. Instrum.* **66**, 5322-6 (1995).

[67] Kent D. Irwin, *Appl. Phys. Lett.* **66**, 1998-2000 (1995).

[68] K. Irwin ,"An Application of Electrothermal Feedback for High Resolution Cryogenic Particle Detection", Appl. Phys. Lett. **66**, 1998-2000 (1995).

[69] K. D. Irwin, S. W. Nam, B. Cabrera, B. Chugg, and B. Young "A Quasiparticle-Trap-Assisted Transition-Edge Sensor for Phonon-Mediated Particle Detection", Rev. Sci. Instrum. **66**, 5322-6 (1995).

[70] S.W. Nam, *et al.*,Proceedings of the VIIth International Workshop on Low Temperature Detectors, Munich, 1997, published by Max Plank Institute of Physics, Munich, Germany.

[71] Y. Feige et al., J. Geophysics. Res., **73**, 3135 (1968).

[72] K. Ruddick,,"Underground particle fluxes in the Soudan Mine", NuMI-L-210, Sept. 18th,1996.