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SIMULATION OF NUCLEAR THERMAL RADIATION WITH HIGH INTENSITY FLA--ETC(U)

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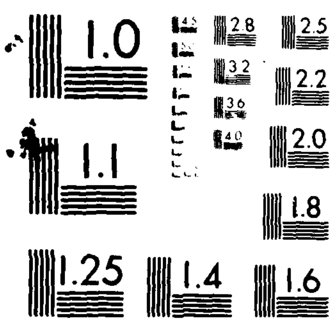

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SIMULATION OF NUCLEAR THERMAL RADIATION WITH HIGH INTENSITY FLASHLAMPS

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26 January 1979

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Problems relating to the simulation of high flux nuclear weapon thermal radiation are presented. Existing potential simulators are discussed and limitations identified. A potential simulator using flashlamps is outlined in detail. Theoretical calculations and preliminary design drawings are presented. Advantages of flashlamps, including first pulse simulation, UV spectrum component matching, and accurate second pulse shaping, are discussed.

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PREFACE

This report reviews the basic concept of a high intensity flashlamp source for simulating nuclear thermal radiation. Many of the present and projected thermal simulation requirements of the three services and DNA cannot be met by existing simulators. A review of the present technology of flashlamps is used to identify a possible source of thermal radiation meeting the requirements. A conceptual design of a high intensity thermal simulator is given. Discussion of use of existing Government energy storage equipment concludes the report.

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1.1 THE REQUIREMENT FOR NUCLEAR THERMAL SIMULATION

Use of simulated nuclear thermal radiation for effects testing is a program requirement in research and development, in weapon system procurement, and in field support. Research programs in thermal effects are generally directed by the Defense Nuclear Agency (DNA) who has also taken the lead in the development of nuclear simulators. Thermal test requirements often stress only one aspect of nuclear radiation at a time, i.e., maximum flux, UV exposure, etc. Hardness tests are required in procurement by all three services, but the U.S. Army has the most thorough testing program at present. Finally, non-defense agencies such as F E M A, N A S A and DoE have requirements for nuclear or high intensity thermal radiation sources.

Key simulation parameters of interest are radiation flux and fluence, sample area, test cost, and source development time. Requirements vary from a few to up to 2000 cal/cm^2 sec (8370 W/cm^2) flux, up to 200 cal/cm^2 (837 J/cm^2) fluence, and up to 100 cm^2 or larger sample areas. Since resources to develop and operate new simulators are scarce, there is a trend to develop multi-user facilities with flexibility to cover wide parameters of variation.

1.2 PRESENT THERMAL SIMULATOR TECHNOLOGY

For high flux radiative simulation the source alternatives generally considered are of three types (Reference 1):

- Solar Furnaces
  (3 principal facilities)
- Flashlamps
- Thermochemical Reactions (Metal Powder Oxidation)

In addition, arc lamps, heat lamps, and lasers may be used for smaller area tests, or for tests where the source spectrum need not match that of nuclear thermal radiation.

Characteristics of greatest concern in selecting the thermal energy source are shown in Table 1.1. Peak flux sample areas are indicated as key parameters. Source brightness (power per solid angle) is often important as are other factors such as instrumentation and computer support at the test facility.

Of the variety of sources initially considered, none provide the optimum for all of the desired characteristics. The requirements cover greater flux levels than provided at focus by any of the solar furnaces, so beam concentration is necessary. Further, when a horizontal sample surface is preferred, an approximately 90° flux diversion must usually be provided. Special concerns in testing are the need for flux redirection, flux-time variation control, measurement, and laboratory calibration. Table 1.2 summarizes a quantitative rating of alternatives of the three major sources. Figure 1.1 shows design trades between peak flux and nominal sample area for test users.

1.3 REVIEW OF NUCLEAR THERMAL RADIATION SIMULATION DETAILS

As an example of the requirements for thermal simulation, a brief review of the principal requirements of a DNA sponsored program on soil irradiation is discussed. This program has large flux and area requirements and thus covers most of the other project's needs (References 2,3).

The nuclear thermal pulse to be simulated is double peaked with a time-varying color temperature. At initiation the output is

TABLE 1.1

COMPARISON OF ALTERNATIVE SOURCES OF HIGH RADIANT FLUX

AND FLUENCE ON A PLANE SURFACE SAMPLE

PARAMETERS	SOLAR FURNACES	FLASH LAMPS	THERMO-CHEMICAL	HEAT LAMPS	CONVENTIONAL FURNACES
Peak Flux*	Moderate	V. High	Moderate	Low	Low
Flux Concentration	Feasible	Feasible	Not Practical	Feasible	None
Pulse Length	Hours	$(P.\ Flux)^{-1}$	Seconds	Indef.	Indef.
Pulse Control	Feasible	Feasible	V. Limited	Feasible	V. Difficult
Repeatability	Good	Exc.	Fair	Exc.	Exc.
Availability	Time & Place Restricted	Exc.	Limited	Exc.	Special Rqmt.
Test Costs	High	Low	High	Low	Unknown
Test Flexibility	Limited	High	Fair	High	Low
Location Flexibility	None	High	Fair	High	Low
Reliability	Low	High	Fair	High	High
Sample Area*	Low	Moderate	High	Moderate	Low to Moderate
Capability	Proved	Untested	Proved	Proved	Unproved

*Most Important Parameters

Table 1.2 Thermal Radiation Source Characteristics

SOURCE	POWER (KW)	NOMINAL PEAK FLUX (CAL/CM^2 SEC)	NOMINAL SAMPLE AREA AT PRIME FOCUS (M^2)
Solar Furnaces (SF)*			
Odeillo, Font Romeu (CNRS)	1000	400	0.06
White Sands Missile Range	30	100	0.01
Sandia (Central Receiver Test Facility - CRTF)	1700 (5000 planned)	60	4
Flashlamps	600**	1000-2000	>0.06**
Thermochemical Reactions	10^5	10-100	>100

*The Advanced Component Test Facility at the Georgia Institute of Technology was not considered due to the upward direction of the input flux.

**assuming 20 lamps

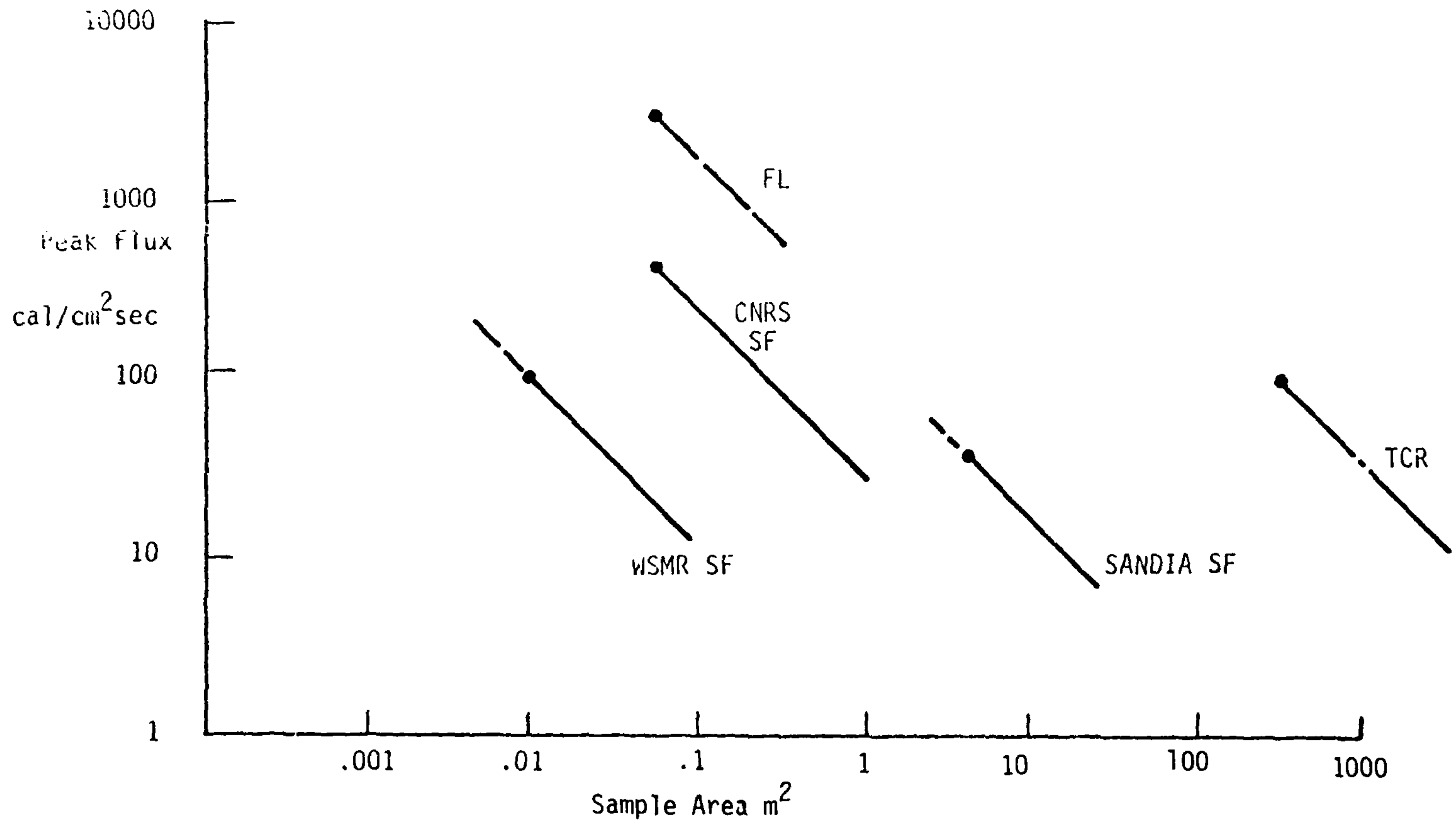

Figure 1.1 Nominal Peak Flux versus Nominal Sample Area for Sources (See Table 1.2)

strongly in the UV region; the first peak is a spike containing a small percent of the total pulse energy. The second pulse lasts longer and has a lower color temperature, decreasing in the tail of the pulse to red and then to IR color temperatures. The pulse energy scales with nuclear yield, while the pulse length scales as the cube root of yield. The details have been reviewed by many authors (References 4,5).

For the referenced program, the test goals for the second pulse only are:

Flux:	up to 2500 cal/cm^2 sec
Fluence:	up to 200 cal/cm^2
Pulse Length:	11 milliseconds to 6.5 seconds

A series of yields between 1 KT and 10 MT, HOB between 50 and 500 ft/KT$^{1/3}$, and ground ranges between 185 and 1100 ft/KT$^{1/3}$ were chosen for analysis. Test criteria and source capabilities were reviewed and a prioritized list of sources prepared. The review showed that the CNRS solar furnace was applicable for about 50 percent of the required test conditions, by far the highest percentage of any existing facility. The remaining 50 percent of the requirements (primarily 1 KT simulations) may be performed by developing a flashlamp source. Such a source, if developed, could presumably perform the other 50 percent of the tests now within the capabilities of solar furnaces. Combined use of both solar furnaces and flashlamps was reviewed. Flashlamps can create both the first and second pulse, a unique quality not available with any other source.

Review of other sources of the second pulse was performed. The planned 250 KW WSMR solar furnace may provide capability matching that of CNRS in flux delivery, but at the expense of test area. The DoE/STTF* furnace at Sandia/Albuquerque is presently capable of low

*Solar Thermal Test Facility, now renamed Central Receiver Test Facility (CRTF) level, large area irradiation. If an initially planned flux concentrator for STTF is successfully constructed and performs as anticipated, this facility would become a candidate for testing. Solar simulators and heat lamp facilities offer a low flux, large area test capability of possible use on other aspects of thermal layer studies. Thermochemical reaction sources offer a unique large area source for in-situ irradiation but appear unsuitable for a series of controlled tests due to test cost, shot to shot variability, source spectrum mismatch, and secondary source characteristics, such as debris.

It was determined that flashlamps could provide supplemental radiation of the following characteristics, compared to the best solar furnace performance:

- First pulse capability
- More rapid turn-on of radiation
- Higher flux
- Higher color temperature

These factors would allow simulation of the first maximum, enrichment of the UV component of the solar spectrum to match that of nuclear fireballs, and increased overall radiation flux beyond the fundamental limits of solar furnaces. A flashlamp capability would also be availalbe to support tests in the field, or augment flux at a solar furnace (Reference 6).

1.4 FORM OF STUDY RESULTS

Work reported during the study defined the various options of solar furnaces (SF), flashlamps (FL), and thermochemical reactions (TCR).

As a result of this study a cost/benefit table comparing source and program goals was prepared. Table 1.3 shows the form of such a table.

SAI's tentative conclusions are that flashlamps may offer a cost effective alternate to some solar furnace testing in the following areas:

- Laboratory tests
- High flux tests
- In-situ tests.

1.5 FLASHLAMP BASED SOIL IRRADIANCE FACILITY

A flashlamp based soil irradiance facility can offer a number of advantages over competing systems. Flashlamp systems are capable of very high flux densities. They can be extremely small and compact and consequently can be designed in such a way that they can provide a mobile test facility. This mobility would allow soil irradiation experiments to be performed at remote locations as well as in the laboratory.

A properly designed flashlamp system can simulate a wide variety of irradiation profiles by varying the pulse's shape, length, and height. In addition the first maximum can be added. Since the spectral, temporal, and spatial radiation characteristics are electronically changeable, the system can be easily set to produce the required result.

In view of their performance characteristics, flashlamp systems offer the potential either to supplement existing soil irradiance capabilities or to provide a self-contained versatile and mobile soil irradiance capability. A flashlamp based soil irradiance system can simulate radiant fluxes from a few hundred watts per square centimeter to over 10,000 watts per square centimeter. The temporal characteristics of the irradiation can be varied from a few milliseconds

TABLE 1.3

FORM OF COST BENEFIT COMPARISON

OF SOURCE VERSUS PROGRAM GOALS

	SOURCE		
GOALS	FL	SF	TCR
LAYER HEIGHT	YES	RESTRICTED	YES
HIGH FLUX	YES	RESTRICTED	NO
HIGH FLUENCE	NO	YES	YES
IN-SITU TESTS	YES	NO	YES
LARGE AREA	RESTRICTED	NO	YES

FL - Flashlamps

SF - Solar Furnaces

TCR - Thermochemical Reactions

to a second (or more) in duration. Addition of the first peak in the flux profile is easy with a properly designed flashlamp system. The spectral profile can also be varied to match the overall irradiation spectrum and to enhance the ultraviolet output of the first maximum. In consideration of the capability to precisely duplicate a wide range of soil irradiance conditions which cannot presently be duplicated, flashlamp-based soil irradiance systems clearly warrant further investigation. The sections which follow will examine the various components which would be required to build such a system. A preliminary conceptual design is also presented to illustrate the simplicity and versatility possible with these systems.

SECTION 2

ELEMENTS OF A FLASHLAMP IRRADIATION FACILITY

Electronic flashtubes were originally devised as instruments with which to accomplish the high-speed photography of nonluminous objects. Today, they are widely used in this capacity in both scientific and nonscientific applications. However, the ability of xenon flashtubes to produce pulses of radiant energy extending over seven orders of magnitude has led to the appearance of these devices in many widely differing applications. In addition to being used as thousand-flash-per-second light sources for high speed film exposure and as stroboscopic tools for the visual and photographic examination of oscillating or reciprocating machine parts, xenon flashtubes are used as optical pumps for lasers, as visual beacons in Coast Guard buoys and geodetic satellites, and as light sources for night aerial photo-reconnaissance systems. Small xenon flashtube systems, used for rendevous, location, tracking, recovery, and warning purposes, may also be found as accessories in aircraft, torpedoes, rockets, satellites, and space vehicles.

In all of the sophisticated applications wherein xenon flashtube systems are used, both photographic and nonphotographic, the characteristics of the individual components (References 7,8), such as the flashtube, must be thoroughly integrated with the requirements of the task to be performed. Details of the system's mission dictate the performance requirements of the xenon flashtube regarding life, pulse duration, average power, energy per flash, repetition rate, source size, and beam profile. On the basis of the specification of these parameters, the designer can then proceed to the specification of a particular xenon flashtube in terms of arc length, bore size, configuration, operating voltage, and capacitance.

In order to effectively employ flashlamps for soil irradiation,each of the elements of the system must be properly designed. The principal elements include the radiation source (flashlamps), the power conditioning system, and the optical system. In addition the temporal, spatial, and spectral characteristics of the radiation at the soil surface must be considered. The following sections will address these topics.

2.1 FLASHLAMPS AS RADIATION SOURCES

A flashlamp is a gas discharge light source designed to produce pulsed radiation. It is capable of providing much higher peak intensities than are available with continuous light sources. A wide variety of designs exist, each stressing some particular aspect of lamp performance. The range of performance is extremely broad -- electrical input energy may be varied from 10^{-2} to 10^{5} joules per pulse, pulse length from 10^{-3} to 10^{5} microseconds, and pulse repetition rate from single shot to 5×10^{4} Hz.

Flashlamps which might be of interest for use in a soil irradiation facility would be constructed of either linear or helical quartz tubes. The wall thickness of the tubing varies between 1 and 2 mm. Bore diameters from 1 to 19 mm are commonly available. Lengths from 5 to 100 cm might be practically employed.

2.1.1 Construction of Flashlamps

At present several construction techniques are used in the manufacture of flashlamps. The construction problem can be reduced essentially to sealing a metal electrode into a vitreous (i.e., glassy) material which is the body of the flashlamp. If the body of the lamp is a glass of high thermal expansion coefficient, the usual metal-glass sealing techniques may be used. (For example, Kovar metal may be sealed to 7052 glass.) However, if the lamp body is fused silica with its extremely low coefficient of thermal expansion, the problem is significantly more difficult. Low melting point indium based solders are used to solder invar to the quartz tubing. This provides a good seal at temperatures below the softening point of the solder, which is about 100°C. For higher temperature operation, a seal has been developed which uses a single grade glass between tungsten and fused silica. This seal can be operated for short periods at 600°C, and with proper cooling of the external metal parts and seal region, the full temperature capabilit' of fused silica can be utilized.

Seals have also been made which employ epoxy resins to seal the metal parts to a vitreous lamp body.. This technique has not been fully evaluated but appears to be useful for sealing large diameter heavy wall tubing for the manufacture of very large lamps.

2.1.2 Flashlamp Failure Modes

With any of the above techniques, if the seal has been made properly, the catastrophic failure mechanism is wall explosion rather than seal failure. This occurs when input energy is increased to the point where the wall is destroyed in a single flash. The single shot explosion limit is a function of input energy and pulse duration. This limitation on pulse energy is due to the shock wave created in the gas during the plasma formation.

The maximum energy per pulse which a flashlamp can withstand is determined by the size of the lamp and the duration of the pulse. For a given energy these two factors determine the wall loading and the shock which the flashlamp must withstand. The explosion energy which a given lamp can withstand is directly propostional to the area of the wall and to the square root of the pulse duration. For any energy E_o which is less than the explosion energy E_{ex}, the number of shots which a lamp can be expected to withstand is given by the empirical relation

$$N = \left(E_{ex}/E_o\right)^{8.5} \quad . \qquad (2.1)$$

Under certain severe operating conditions, two different types of flashlamp deterioration can be identified. If a lamp is operated at high peak power density, a small portion of the wall material is vaporized. It condenses on the wall in a crystalline state, and appears as a white powder. On successive firings, the white coating will absorb energy, thus increasing wall loading. Early lamp failure may result. Second, if a lamp is operated at high peak power or high average power, sputtering of electrode material becomes an important aging mechanism. The sputtering products appear as a dark deposit, and eventually reduce light output below the minimum useful level.

2.1.3 Flashlamp Fill Gas

Xenon is generally chosen as the gas fill for flashlamps, since in most applications it yields a higher output/input efficiency than other gases. Typical efficiencies range from 25 to 60 percent depending on lamp type and operating conditions, increasing with increasing power density. However, for short pulse, high current density applications, higher peak brightness can be achieved by using the lower atomic weight noble gases such as krypton, argon, neon, and helium (Reference 9).

In a small number of special cases, for low power density, the conversion efficiency in a narrow spectral region may be improved by using the rare gases in combination with various dopants such as mercury, iodine, cesium, or potassium to produce line radiation at a desired wavelength.

2.1.4 Optical Spectrum of Excited Gas

It is not simple to characterize the optical output of a flashlamp. The plasma emits radiant energy over an extremely wide range of wavelengths, from far infrared to ultraviolet. The radiation is composed of several different components, each corresponding to a different emission mechanism. The relative importance of each of these mechanisms depends strongly on the power density in the lamp, and so the low power density and high power density (i.e., w/cm^2) optical output spectra are markedly different (References 7, 8).

Characterization is made even more difficult by the fact that the plasma is a partially transparent emitting volume. The power radiated depends on the depth of plasma viewed, and therefore not only on the lamp's dimensions, but also on its orientation. The discharge in a flashlamp is initiated by causing a spark streamer to form between the electrodes. As the discharge channel grows, the electrical resistance drops sharply. The electrons in the plasma equilibrate in a high temperature distribution very quickly, and heat the plasma through collision.

Radiation from a flashlamp is made up of both line and continuum components. The line radiation corresponds to discrete transitions between the bound energy states of the gas atoms and ions (bound-bound transitions). The continuum is made up primarily of recombination radiation from gas ions capturing electrons into bound states (free-bound transitions) and of bremsstrahlung radiation from electrons accelerated during collisions with ions (free-free transitions). The spectral distribution of the emitted light depends in complex ways on electron and ion densities and temperatures; these parameters in turn are difficult to measure.

Rather than deal with these complex radiation processes explicitly, the radiation characteristic of a flashlamp $R(\lambda, T)$ is usually discussed relative to the characteristic of a black body. The black body radiation function $B(\lambda, T)$ is useful in that, for any source in local thermodynamic equilibrium, it gives an upper bound for the power radiated in watts per cm^2 per unit wavelength. Good tabulations of this characteristic are available (Reference 10). The departure of any practical light source from the black body function is accounted for in the emissivity, $\varepsilon(\lambda, T)$, which varies between zero and one. The radiation function of a light source, $R(\lambda, T)$, can now be related to the black body function, $B(\lambda, T)$, thus: $R(\lambda, T) = \varepsilon(\lambda, T) B(\lambda, T)$. We have written $\varepsilon(\lambda, T)$ to show explicitly that it is both wavelength and temperature dependent.

For hot solids such as tungsten or tantalum, $\varepsilon(\lambda, T)$ depends on the material, the wavelength, and the temperature only moderately; the emissivity for such materials is in handbooks. For a flashlamp gas, however, $\varepsilon(\lambda, T)$ depends strongly on temperature and wavelength. If we assume local thermodynamic equilibrium in the plasma, the black body function $B(\lambda, T)$ becomes the black body curve corresponding to the electron temperature in the plasma. The electron temperature is only weakly dependent on power density*, because, as the power density is increased, losses from the plasma (mainly in the form of continuum radiation) increase very rapidly, tending to cool it.

Direct measurements (Reference 11) show that these losses tend to occur in a systematic way. In general, for any given power density, the emissivity of the continuum radiation at any wavelength is greater than the emissivity at shorter wavelengths.† Since the emissivity can never exceed unity and the electron temperature does not change rapidly with power density, an increase in power density will result in a large increase in emissivity (and radiation) at short wavelengths, but only small changes at longer wavelengths where the emissivity is already close to unity.

---

* In normal operation, the electron temperature in flashlamps ranges between 9000 and 12000^{o}K.

† Due to the high density of bound-bound transitions in xenon from 0.8 to 1.1 μm, moderate deviations from this model may be observed.

In typical xenon flashlamps at low power densities ($3.5 \times 10^4 W/cm^3$ or $500A/cm^2$ current density), the emissivity is much less than unity from 0.25 to 1 μm, except at those wavelengths where bound-bound transitions radiate. In fact, the low power density spectrum is dominated by the bound-bound transitions in the near infrared. These lines are very intense because most of the radiation is down converted before it can be efficiently emitted. If the power density is increased to $3.5 \times 10^5 W/cm^3$ or $5000A/cm^2$ current density, the emissivity of the continuum radiation approaches unity from the far infrared all the way down to 0.4 μm, and the previously strong line structure in the near infrared is now seen only as minor perturbations in a spectrum dominated by continuum radiation.

In general the spectral output of a pulsed flashlamp at low current densities is dominated by the line spectrum which is characteristic of the fill gas. Such a spectrum is illustrated in Figure 2.1. As the current density and the effective electron temperature is increased the spectrum shows evidence of a continuum black body spectrum. With further increases in current density the black body predominates with the line spectra superimposed upon it. In Figure 2.2 the curve corresponding to $1700A/cm^2$ illustrates this behavior. It is basically a black body curve with the line spectra superimposed. The curve corresponding to $5300A/cm^2$ illustrates the behavior of a given flashlamp with further increase in current density. The line spectra is further reduced and the black body spectrum almost completely dominates. These curves illustrate that -- within limits -- it is possible to alter the spectral content of a discharge by carefully regulating the current. It is important to note that the vertical axis of Figure 2.2 is <u>relative</u> spectral radiance. In general, a higher current discharge will yield greater energy at all wavelengths. However, the relative composition at any two wavelengths will change in much the same way that the black body curve changes with black body temperature.

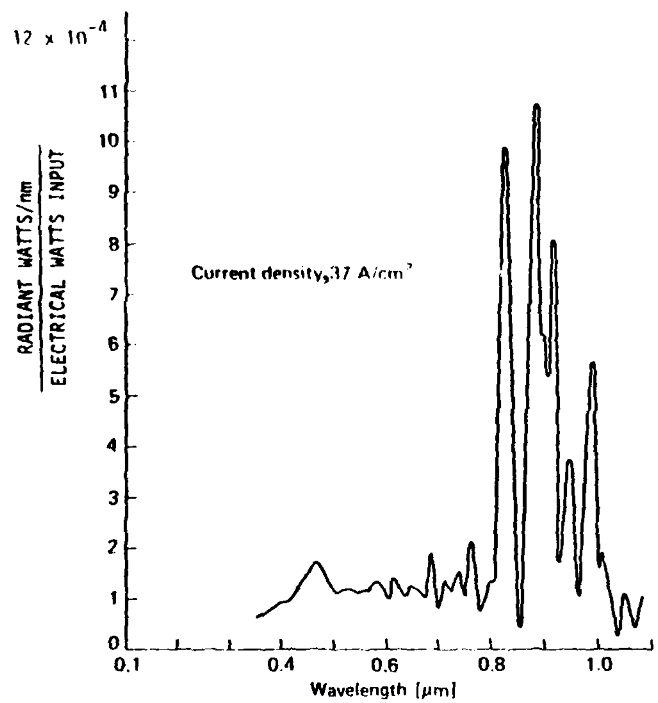

Figure 2.1 Flashlamp Spectrum - Low Current Density

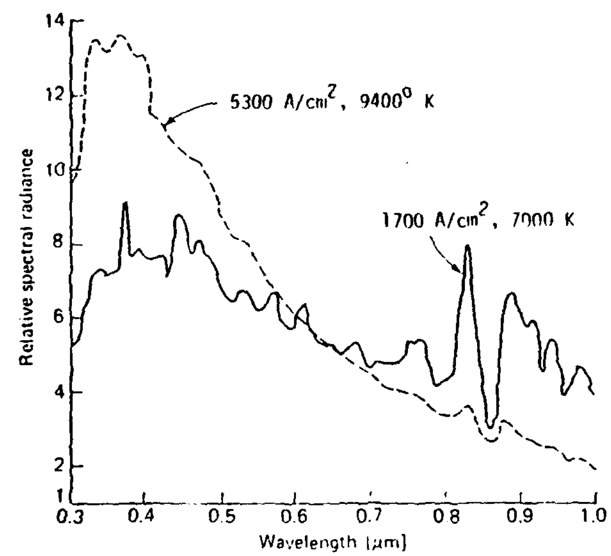

Figure 2.2 Flashlamp Spectra - Two High Current Densities

2.1.5 Transmission Properties of Flashlamps

The transmission properties of the flashlamp envelope also modify the optical output. Usually the envelope is fused natural silica, which transmits light between 0.2 and 4 μm. Figure 2.3 shows the transmission of fused silica, together with the transmission of other materials occasionally used as envelopes. UV-absorbing fused silica is used to absorb radiation below 0.25 μm to prevent the production of ozone, an oxidant. Glass envelopes are inexpensive, but absorb short-wavelength radiation and have an upper working temperature of approximately 100^{0} C in contrast to 1100^{0} C for fused silica. For transmission down to 0.16 μm, synthetic fused silica is available at high material cost.

As illustrated in Figure 2.4 the transmission property of a flashlamp is also a function of the current density within the lamp. This fact is very important because it affects the spectral character of the flashlamp light which must traverse the flashlamp volume before it impinges on its target.

2.1.6 Flashlamp Electrical Efficiency

Figure 2.5 illustrates the energy balance in a flashlamp system. As shown the flashlamp is an efficient converter of electrical to optical energy. After accounting for normal circuit losses, approximately 55 percent of the electrical input energy to a typical xenon arc lamp is converted into output optical radiation between 0.3 and 1.5 μm. The remaining 45 percent of the energy is dissipated as heat by the flashlamp. Approximately 30 percent of the heat energy goes into heating of the quartz envelope, 10 percent into the anode and 5 percent into the cathode. For continuous or repetitively pulsed operations this heat must be removed in order to prevent destruction of the flashlamp.

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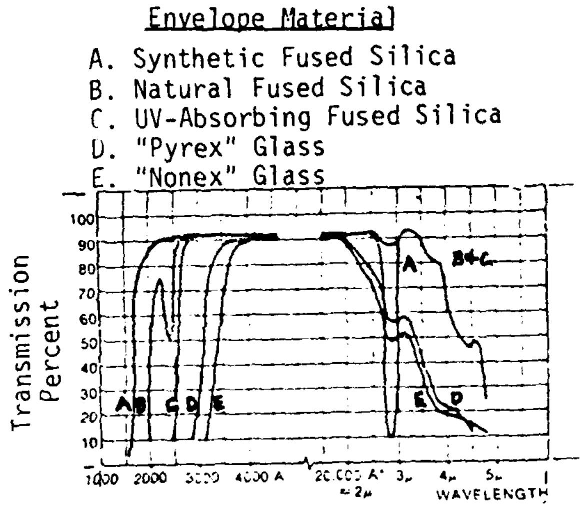


Figure 2.3 Optical Transmission of Envelope Materials

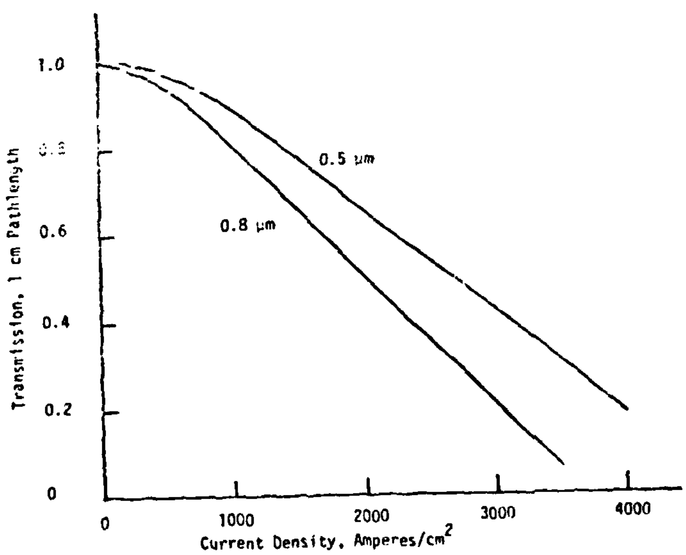


Figure 2.4 Transmission Through 1 cm of Xenon Flashlamp

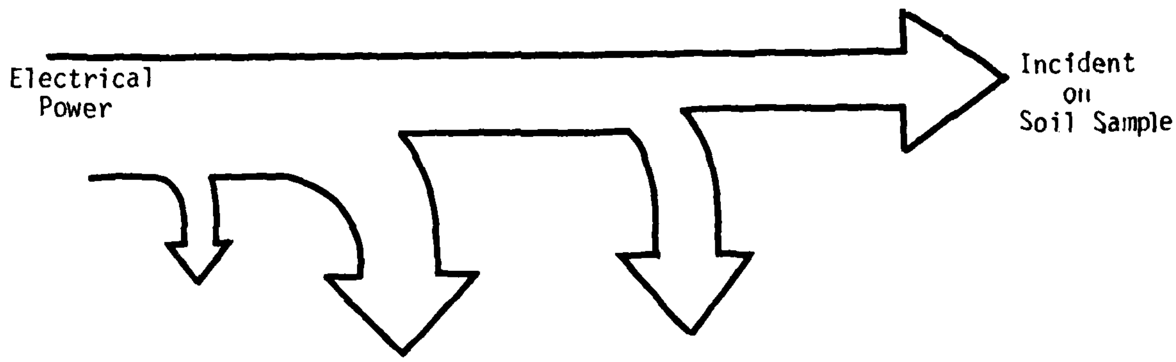


Figure 2.5 Energy Balance

2.1.7 Lamp Cooling

The maximum average power which a flashlamp can dissipate is determined by the size of the lamp and the type of cooling used. Either liquid or gas cooling may be used. The specific choice depends on the intended application. For liquid cooling, water, water-alcohol mixtures, or flourinated hydrocarbons are the commonly used cooling mediums. Gas coolants such as dry nitrogen and forced air are also used. For very low repetition rate applications convective cooling is acceptable. The fundamental limitation to the maximum average power which a lamp can handle is caused by overheating of the lamp envelope or seal. For quartz the maximum temperature rise is approximately 1800^{0} C. The heat which must be dissipated to prevent overheating is given by

$$Q_{Max} = \Delta T_{Max} K/d \tag{2.2}$$

where

Q = Heat Dissipation (W/cm)
K = Thermal Conductivity of the quartz wall
d = Thickness of the quartz wall.

2.2 POWER CONDITIONING

The power conditioning system for a flashlamp irradiation facility must contain four principal elements: a generating system, an energy storage system, a pulse forming system, and a switching or triggering system. Each of these elements has an essential function to perform and this function must be executed in the proper sequence and in unison with each of the other elements of the power conditioning system. The generating system must supply the energy which will eventually be delivered to the lamp. The storage system must store this energy until it is required. The pulse forming network must shape the electrical pulse to the flashlamps to ensure that they provide optical output of the correct intensity and duration. Finally, the switch or triggering system must cause the flashlamp gas to break down so the electrical current can flow through it.

2.2.1 Generation

The generating system is actually a fairly simple system. Its exact specification is dependent on the design of the energy storage medium. The basic function of this system is to provide power at moderate rates to the energy storage system. If capacitive energy storage is utilized the generating system might be a high voltage power supply. If kinetic energy storage is utilized it might take the form of a motor to energize the storage medium. In general, this should be a simple and relatively straightforward system in terms of design and development.

2.2.2 Storage

The energy storage system is an essential and difficult portion of the power conditioning system to specify. In general there are three types of energy storage which could be considered for use in a flashlamp system of this type. They are:

- Capacitative Energy Storage
- Kinetic Energy Storage
- Explosive Power Generators .

Capacitative energy storage relies on properly selected capacitors to store the required electrical energy. Either a high voltage power supply or direct line connections (doubled or tripled) may be used to provide the initial energy. This type of energy storage is simple, direct, and well understood. However, a large number of capacitors would be needed to store the energy which is required for a facility of the type contemplated.

Kinetic energy storage utilizes the fact that a mass rotating at very high speed can store a tremendous amount of energy. Such a system might consist of a solid steel cylinder which is used as an armature and energy storage medium. A small asynchronous electric motor would cause the cylinder to rotate at ever increasing angular velocities. By causing the cylinder to decelerate rapidly, very large electrical currents can be generated. These currents far surpass those used to cause the initial rotation. Systems of this type can be very efficient and compact. However, they are rather unique and not completely developed for commercial usage.

The final energy storage option involves the use of chemical explosives to cause the rapid compression of a magnetic field and, consequently, the generation of very large currents. Generators of this type are small, inexpensive, and portable. Their high output energy is applicable wherever infrequent pulses with energy levels up to the ten's of megajoules are required. They do, however, have the drawbacks associated with explosives.

In general neither kinetic energy storage nor explosive generators are readily available as "off-the-shelf" items. Due to the nature of the energy generation process, explosive generators are only used where the repetition rate is very low ($\sim$1/day). In addition the hazards presented by the explosives and the limitations to system mobility which they present, diminishe the attractiveness of this alternative. Kinetic energy storage is still in the developmental stage and considerable effort might be required to field a workable system for this application. Overall the capacitative energy storage systems present the most attractive alternative. They are very highly developed, low in cost, readily available, and their technology is well understood.

2.2.3 Pulse Forming Network

The purpose of the pulse forming network is to control the intensity and the duration of the electrical pulse to the flashlamp. By the proper design and selection of inductor/capacitor networks a wide variety of pulse shapes can be obtained. In general the time constant for a critically damped pulse is given by the following equation

$$t = \sqrt{LC} \qquad (2.3)$$

where t = time constant (seconds)

L = circuit inductance (henries)

C = capacitance (Farads) .

The time duration of the pulse is approximately three times the circuit time constant. Since the circuit capacitance is related to the energy stored by the following equation

$$E = \frac{1}{2} C V^2 \qquad (2.4)$$

where E = stored energy (joules)
V = voltage (volts)

and since it is not possible to increase the circuit inductance beyond certain practical limits without incurring prohibitive penalties in size and cost, proper circuit design must be a delicate balance of the stored energy, pulse duration, inductance, and capacitance.

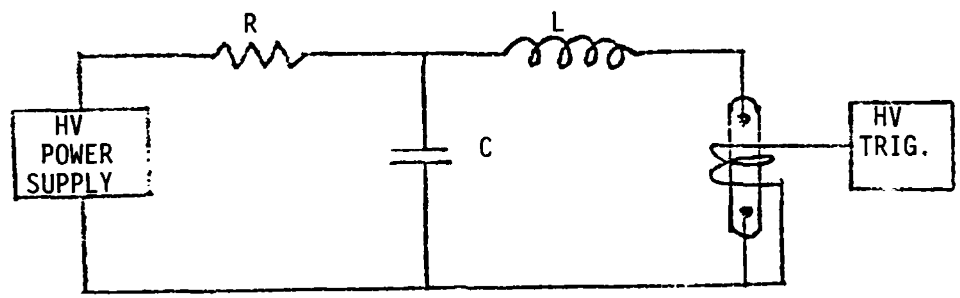
2.2.4 Triggering Circuits

The function of the trigger signal is to create an ionized spark streamer between the two electrodes so that the main discharge can occur. The initial spark streamer is formed by the creation of a voltage gradient of sufficient magnitude to ionize the gas column. The concept of a voltage gradient is important here, since it implies the existence of a stable voltage reference level in close proximity to the flashlamp. Regardless of the triggering method used, reliable triggering cannot be achieved without this reference.

Two methods of triggering flashlamps are illustrated in Figure 2.6. Each method has its own particular advantages. External triggering provides greater pulse circuit design flexibility, because the secondary winding is not in the main discharge circuit. External trigger circuits are also lighter, smaller, less expensive, and are more straightforward to design. Series triggering, on the other hand, is indicated when no exposed high voltage is permitted. In a given application, series triggering also provides reliable triggering at lower capacitor charging voltages. When triggering reliability is absolutely essential, series triggering is recommended.

A third method of firing the flashlamp involves the use of a triggered spark gap. A voltage which would be sufficient to fire the lamp by itself is used to charge the storage capacitors. However, a spark gap is placed in series with the lamp to prevent its firing.

Example: Single Mesh Network and Parallel Triggering



Example: Three Mesh Network and Series Injection Triggering

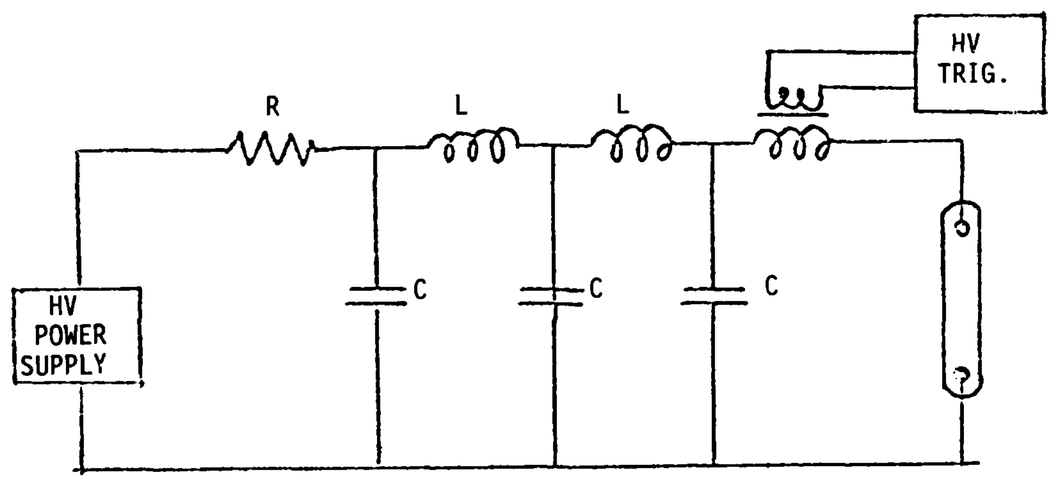


Figure 2.6 Two Examples of Flashlamp Triggering

When the proper time arrives the spark gap is triggered and the applied voltage causes the lamp to fire. This is by far the most expensive alternative and, in general, should not be used unless absolutely necessary.

2.3 OPTICAL SYSTEM

The optical system performs two functions. It redirects light, which would otherwise be lost, toward the target; and it concentrates the source energy on the target in order to increase the incident power density at the soil sample. Figure 2.7 illustrates various systems which might be of use in this application. The design of Figure 2.7a employs a parabolic reflector with the lamp placed at its focus. Two characteristics of parabolas are worth noting at this point:

1. the dimensions of the light source located at the focus must be small compared to the dimensions of the parabola in order to produce a uniform flux across the opening, and
2. the output of the parabola is a parallel beam of light.

The first of these characteristics puts severe restrictions on the light source. In order to achieve the required flux densities it would be necessary to severely overdrive a small lamp. If multiple lamps were to be used the parabola would become very large. The second characteristic necessitates some type of focusing element to achieve high flux densities at the sample location. A fresnel lens could be used for this purpose. Unfortunately, the lens would be susceptible to damage from blast particles from the surface. A blast shield could be incorporated to protect the lens. However, the extra optical surfaces would increase reflection losses and the damaged surface of the blast shield would increasingly scatter light out of the beam. Therefore, this design is not attractive due to

- the large size of the reflector
- the severe requirements on the flashlamps

- requirement for a lens and a blast shield
- absorption losses due to the large area of the parabola
- reflection losses due to the large number of surfaces in the beam path
- scattering losses due to damage to the blast shield .

An alternate design is shown in Figure 2.7b. This design employs an axicon instead of a parabola. The requirements on the light source are somewhat reduced in this design and the dimensions of the axicon can be smaller than those of a parabola; but in general designs of this type suffer from the same problems as the previous design, namely

- large size
- high cost
- low optical efficiency .

The third design (Figure 2.7c) utilizes a simple back reflector, a series of lamps, and a flux concentrator. A system of this type can be made very small and compact. It can use many lamps and hence it can handle a great deal of power. Lamp loading is greatly reduced and consequently lamp lifetime can be greatly increased. Since the surface of the rear reflector is decreased, absorption losses in this area are decreased. However, reabsorption by the opaque plasma in the lamps themselves is increased because the lamps subtend a greater solid angle than they do in the previous design. Due to the small area of the lamp reflector and due to the action of the flux concentrator, no lens is required in a design of this type. However, a blast shield may be required to protect the lamps. Scattering due to damage centers in the blast shield is not as important in this design because the flux concentrator redirects the scattered radiation toward the target.

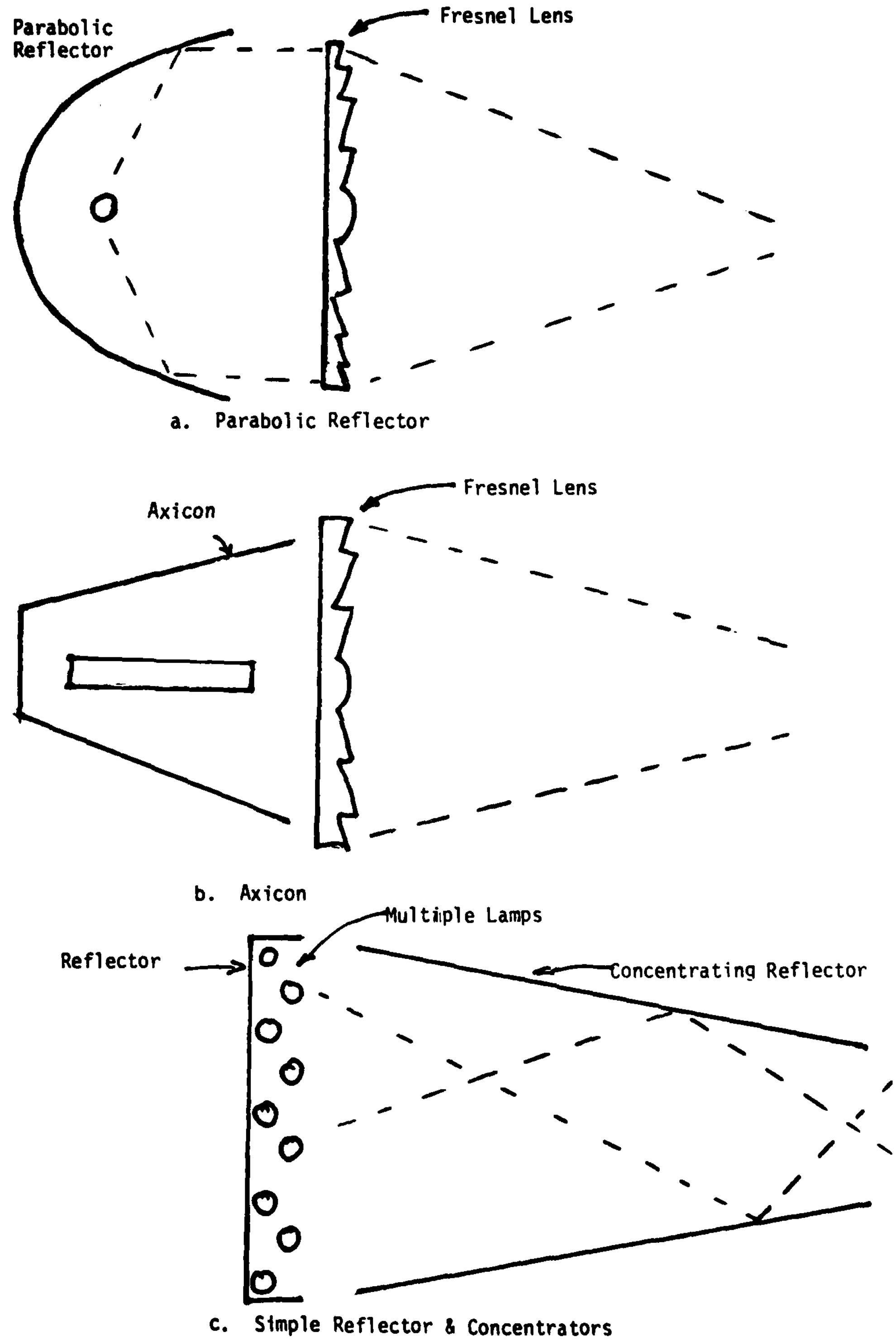


Figure 2.7 Reflector Concepts

The multiple reflections which take place in the concentrator cause the attenuation of the light to increase. In addition they broaden the angular distribution of the rays incident on the soil sample. In general, the greater the concentration, the greater the optical losses in the tube will be. The advantages of a design of this type include:

- very compact design
- very low lamp loading
- high power handling capability
- simplicity of design
- low cost (compared to other design configurations)
- ease of manufacture.

The disadvantages include low concentration ratios and the attenuation of light in the flux concentrator.

2.4 RADIATION AT THE SOIL SAMPLE

The intensity of radiation at the soil surface can be expressed in the following manner

$$I = \frac{P_{el}\,\eta_l\,\eta_c}{A_s} = \frac{P_{el}\,\eta_l\,\eta_c\,C}{A_l} \tag{2.5}$$

where

I = intensity at the soil surface
P_{el} = electrical input power
η_l = lamp radiation efficiency
η_c = radiation transfer (concentrator) efficiency
A_l = source (lamp) area
A_s = sample area
$C = \frac{A_l}{A_s}$ = concentration ratio .

Since we are interested in maximizing the intensity this equation dictates several points. The ratio P_{el}/A_l must be high so that the source should be a high intensity source. Since η_l should be as high as possible, a high current density must be employed in the discharge. Finally the product $\eta_c C$ must be optimized. A high concentration ratio implies a low radiation transfer efficiency and so an optimum value for this product must be found.

In addition to optimizing the intensity at the soil surface a number of additional requirements must be satisfied by the irradiation facility. The temporal distribution of the light output should closely follow that of the nuclear blast. The first maximum should be adjustable from 5 to 50 msec, while the second maximum should be adjustable from 50 msec to 1 sec. Energy in the first pulse should be approximately 1 percent of that in the second pulse.

Spectral content of the first and second pulse should be different. The first pulse should contain a greater relative percentage of ultraviolet energy in its spectrum. Modifications to the original plasma spectrum due to the lamp envelope and the specular reflectivity of the reflector must be taken into account.

In order to ensure a realistic simulation the spatial distribution of energy at the soil surface should be uniform to within ±20 percent of the mean value. The angular distribution of the incident radiation should also be controlled by proper selection of the length to diameter ratio of the concentrator and the reflectivity of the reflecting surfaces.

SECTION 3

CONCEPTUAL DESIGN

In this section a brief description will be given of a conceptual design of a system containing the elements described in the previous section, and suitable for a soil irradiation facility. The system outlined here meets all the essential requirements for a versatile cost effective installation. It is small and compact. Its output is variable both in intensity at the soil surface and in the time duration of the irradiation pulse. Finally its operation is simple and predictable and its cost projections are low compared to equivalent facilities using large solar furnaces.

3.1 PERFORMANCE GOALS

Table 3.1 lists the performance goals for a soil irradiation facility in both the long and short pulse modes of operation. These performance figures refer to the main soil irradiation pulse. Since the first irradiation pulse contains only 1% of the energy of the main pulse, the requirements for the generation of the first pulse are considerably reduced from those given here.

3.2 THE RADIATION SOURCE

In view of geometrical considerations and in order to reduce system duplication and cost, it would be desirable to use the same lamps for both long and short pulse irradiation. This is possible with the current selection of the flashlamp and with appropriate power conditioning circuits. The design which will be described contains 20 flashlamps each with a length of 20 cm and a bore of approximately 1 cm. The driving circuit for each lamp would be designed to produce a 50 millisecond pulse. With this arrangement any desired nuclear pulse shape could be generated by properly controlling the triggering for each flashlamp. For example, if a 50 millisecond pulse were desired, all the flashlamps could be fired together to give the desired pulse. If a one second pulse were desired, the flashlamps could be

Table 3.1

CONCEPTUAL DESIGN

SOIL IRRADIATION FACILITY EMPLOYING LONG ARC FLASHLAMPS

PERFORMANCE GOALS

	LONG PULSE OPERATION	SHORT PULSE OPERATION
IRRADIATION	200 CAL/CM^2-SEC OR 837 W/CM^2	2000 CAL/CM^2-SEC OR 8370 W/CM^2
PULSE DURATION	1 SECOND	0.050 SECONDS
SAMPLE AREA	100 CM^2	100 CM^2

triggered in series at 50 millisecond intervals to generate a long pulse. Any pulse duration between these two extremes could also be generated by programming the timing signal to the trigger circuits. In addition, the intensity incident on the soil sample could be adjusted by either changing the number of lamps which fired in a given pulse or by decreasing the charging voltage to the energy storage capacitors.

Table 3.2 gives the relevant flashlamp circuit design parameters. The flashlamp arc length would be 20 cm in extent and its bore should be on the order of 1 cm. For a circuit damping factor, α, we have selected a value of 0.8. This value will ensure that the pulse from the flashlamp is critically damped and has the shape depicted in Figure 3.1. The time constant has been selected to ensure that a 50 msec pulse is obtained. This term is equal to the square root of the product of the inductance and capacitance of the discharge circuit and so specification of this parameter places bounds on the values allowable for capacitance and inductance. The specification of voltage and energy completes the specification of these parameters. The values of voltage and capacitance were selected to meet the required energy and to allow the use of very low cost electrolytic capacitors.

Consider the long pulse case in which the 20 flashlamps are fired in series at 50 msec intervals for a total duration of 1 second. Since only 1 lamp is firing at a time, it determines the radiation intensity at the soil surface. The electrical input to the flashlamp at full voltage (1400 V) is on the order of 20 KJ. With the parameters specified, a 50% conversion efficiency of electrical energy into optical energy is realistic and this would mean 10 KJ of optical energy is supplied by the flashlamps. Approximately 50% of this optical energy is absorbed or lost before it reaches the soil sample. Thus approximately 5 KJ of energy actually reaches the surface in a 50 msec interval. Since the soil sample is 100 cm^2, this corresponds

Table 3.2

LAMP CIRCUIT DESIGN PARAMETERS

LAMP PARAMETERS:	
Arc Length	s = 20 cm
Bore Diameter	d = 1 cm
CIRCUIT PARAMETERS:	
Damping Factor	α = 0.8
Time Constant	$T = \sqrt{LC}$ = 0.016 sec
Impedance Parameter	K_o = 26 OHM $A^{1/2}$
Capacitance	C = 21,000 μF
Voltage	V = 1400 V (adjustable)
Inductance	L = 12 millihenries
Impedance	R $\cong$ 1 Ohm
Peak Current	I_p = 1100 A (at 1400 V)
PERFORMANCE PARAMETERS	
Pulse Duration	t = 3T=0.050 seconds
Pulse Energy to Lamp	E_E = 20 kJ (assuming a 3T pulse)
Pulse Energy (light)	E_o = 10 kJ (max) (assumes 50% conversion)

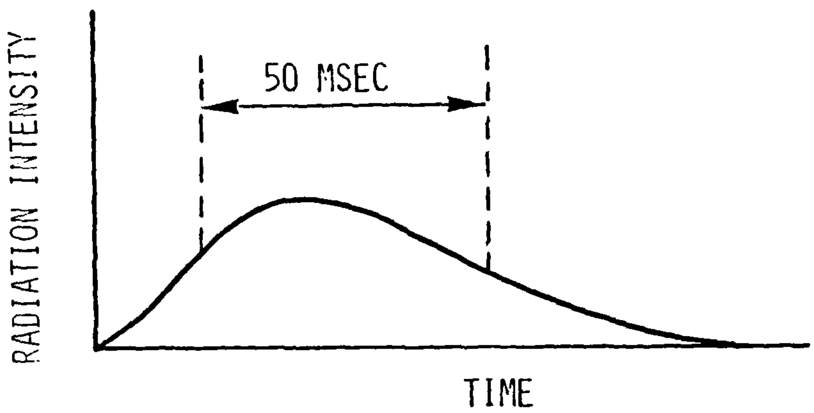


Figure 3.1 Radiation Intensity versus Time
For a Critically Damped 50 msec Pulse

to approximately 1000 W/cm^2. This value is in excess of the design goal. By properly designing the optical system uniform soil illumination can be attained.

Now consider the short pulse (50 msec) case, in which all lamps are fired simultaneously. Assume the lamps are run at 1000 V to lower the input energy to 10 KJ/lamp with a resulting 2.5 KJ/lamp incident on the soil surface in 50 msec. This corresponds to 50 KJ over 100 cm^2 in 50 msec since all lamps fire at the same time. In terms of power density this corresponds to 10,000 W/cm^2 which is also in excess of the design goal.

In terms of lamp lifetime, the long pulse case, which corresponds to operation at approximately 30 percent of the flashlamp explosion energy, should allow lamp usage in the vicinity of 30,000 shots. For the short pulse case, the lamps are being operated at 15 percent of their explosion energy and therefore - on the average - should be good for greater than a million shots.

Figure 3.2 depicts the pump head in cross section to show the placement of the flashlamps and the pump head reflector. Figure 3.3 shows the lamp dimensions and the clearances between the flashlamps in the pump head. One of the advantages of this design is the fact that the pump source is essentially square and this should be of assistance in modeling the experimental results. Figure 3.4 depicts the lamp mounting within the pump head while Figure 3.5 gives a perspective of the pump head in relation to its mounting and the reflector. Finally, Figure 3.6 is a cross sectional view of the entire soil irradiation test facility including pump head, lamp reflector, concentrating reflector, and soil sample area.

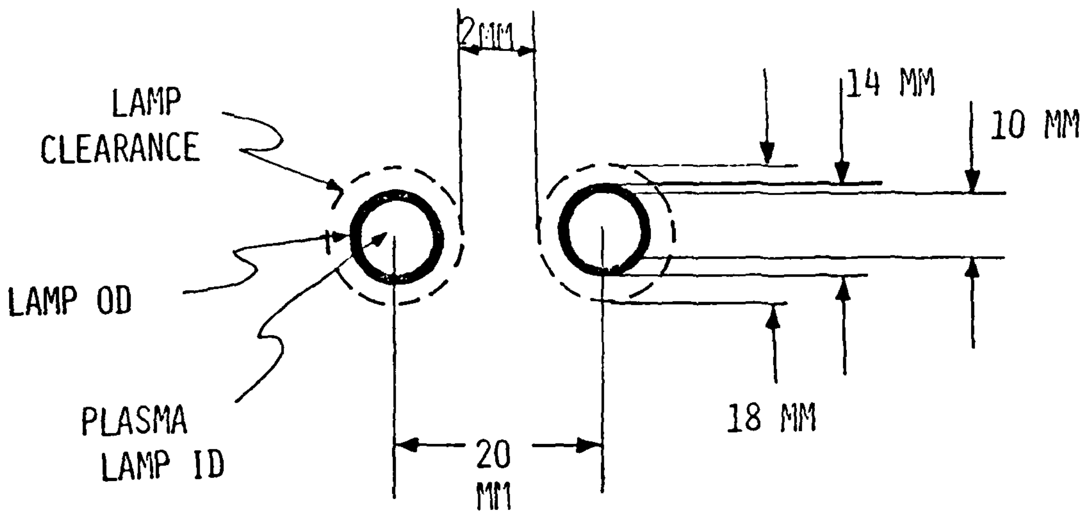


Figure 3.2 Lamp Array

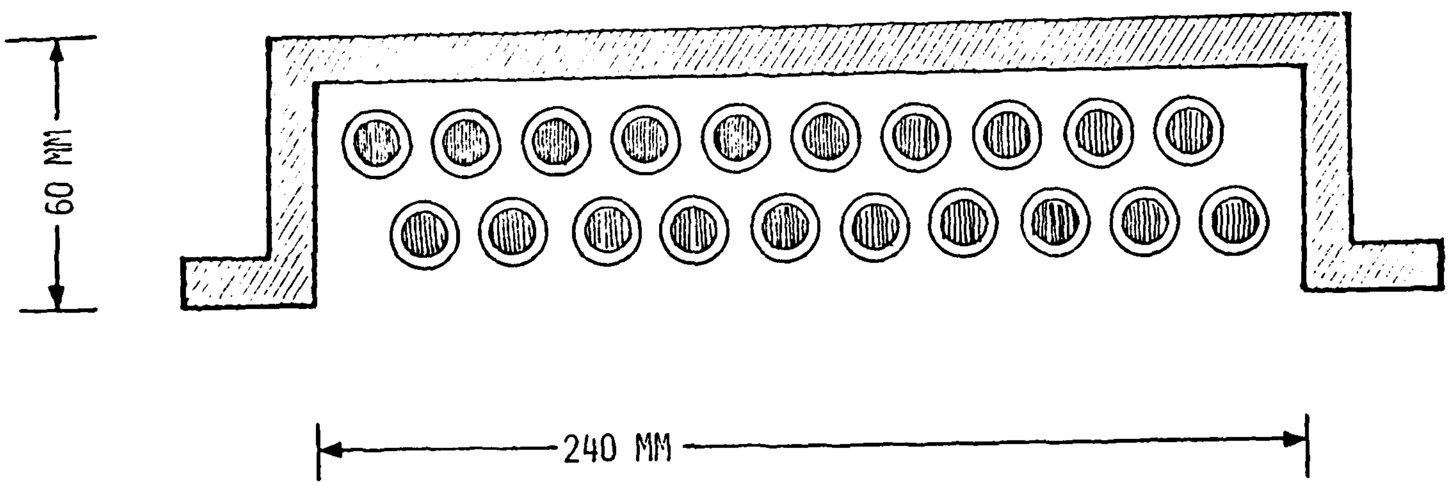


Figure 3.3 Reflector & Lamp Mounting Support

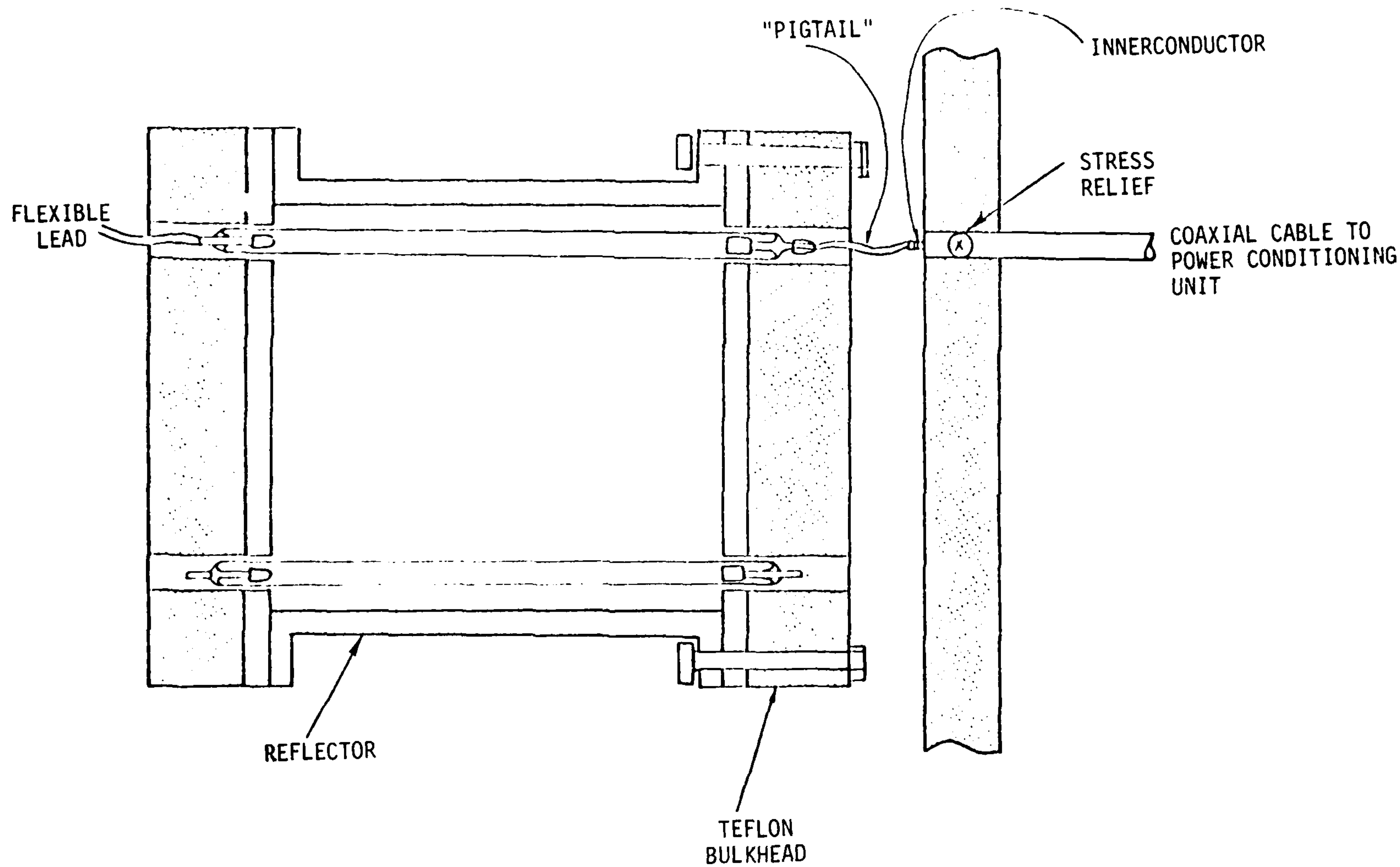


Figure 3.4. Cross-Section: Pumphead

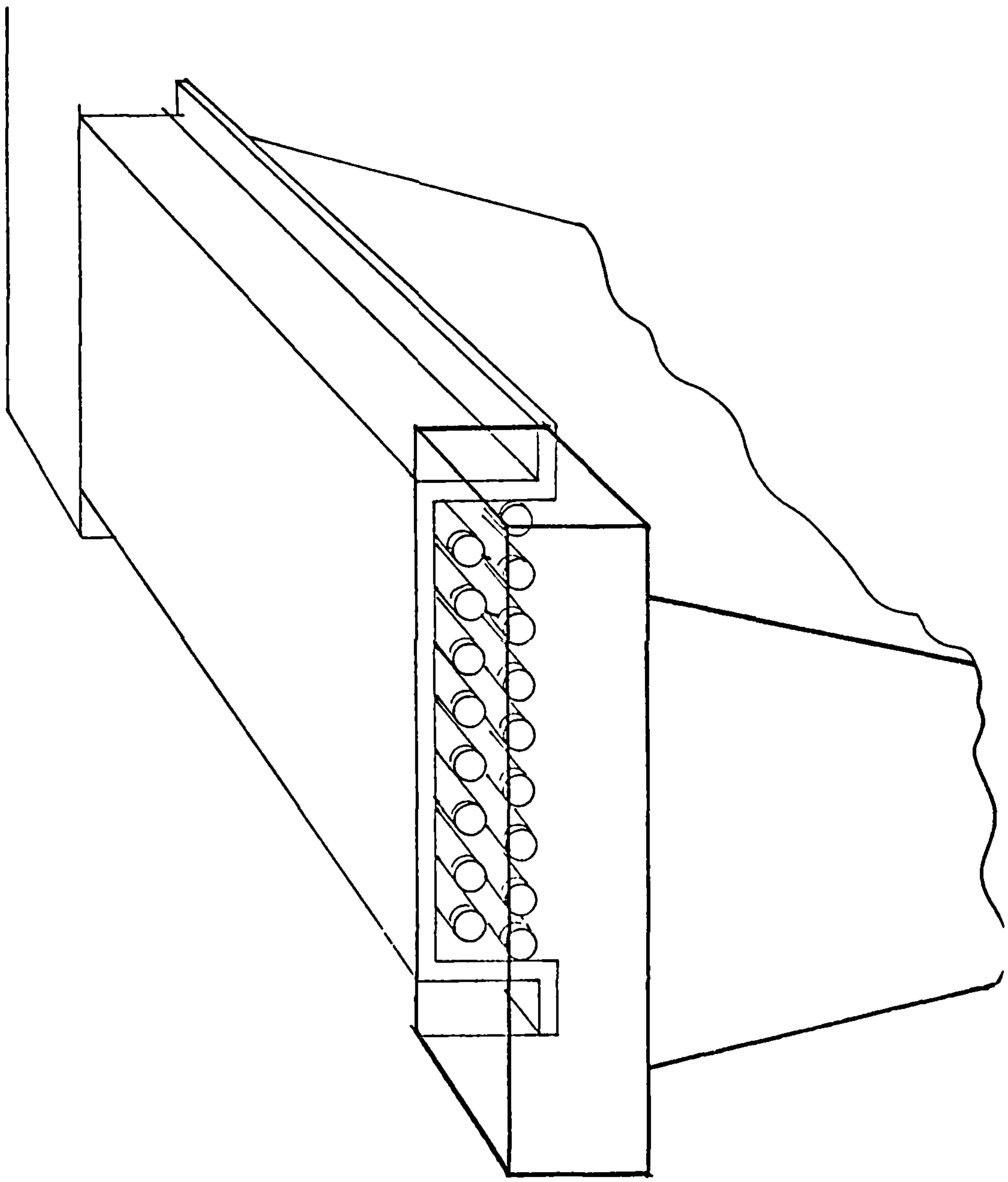


Figure 3.5 Perspective: Pumphead

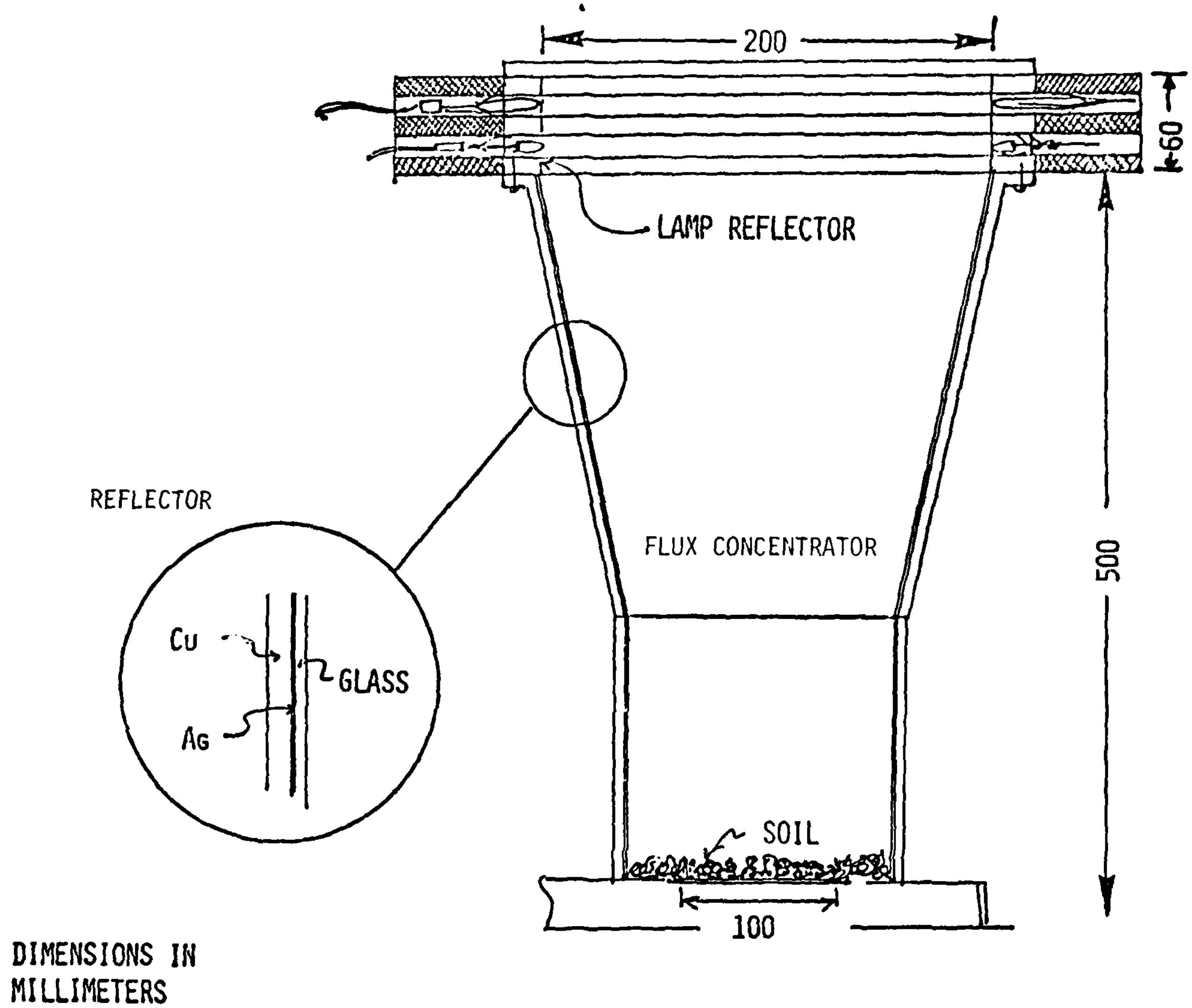


Figure 3.6 Soil Irradiation Test Facility (Cross-Section)

3.3 REFLECTOR

The concentrating reflector will consist of a sandwiched structure consisting of a copper outer structure for support and strength. A thin layer of silver would be deposited on the back surface of the glass inner liner and between the glass and the copper. This is shown in the insert in Figure 3.6. Since the overall radiation source area is approximately 400 cm^2 and the soil sample area is 100 cm^2, the concentration ratio of the reflector is approximately 4. For concentration ratios of this order, transfer efficiencies of 50% can be expected.

3.4 POWER CONDITIONING SYSTEM

A simple schematic of the discharge circuit is shown in Figure 3.7. The reasons for selecting capacitive storage and an LC discharge circuit include the simplicity of the system, its ease of design, its dependability, availability, and low cost. The actual firing of the lamp is controlled by a trigger pulse which breaks the lamp down and allows conduction through it. A functional representation of the entire electrical network is depicted in Figure 3.8. A common charging system would be utilized by all the lamp circuits. Trigger pulses would be provided to the trigger units at precisely timed intervals according to the pulse shape desired.

The discharge circuit and voltages specified allow the use of electrolytic capacitors. This type of capacitor is inexpensive and very durable for the a... t of energy stored. In addition, the low voltages employed are low enough that special high voltage engineering requirements and high voltage safety hazards will be minimal. As an example of a capacitor which might be used consider the Sprague model 312F450DJ2ABL. This is a 3100μF 450V/525V electrolytic capacitor which sells for $20 each in units of a thousand. If 4 of these capacitors are wired in series the resultant capacitor has a voltage capability of 1800V/2100V and a capacitance of 775μF. If 27 of these series groups are then wired in parallel, the resultant capacitance

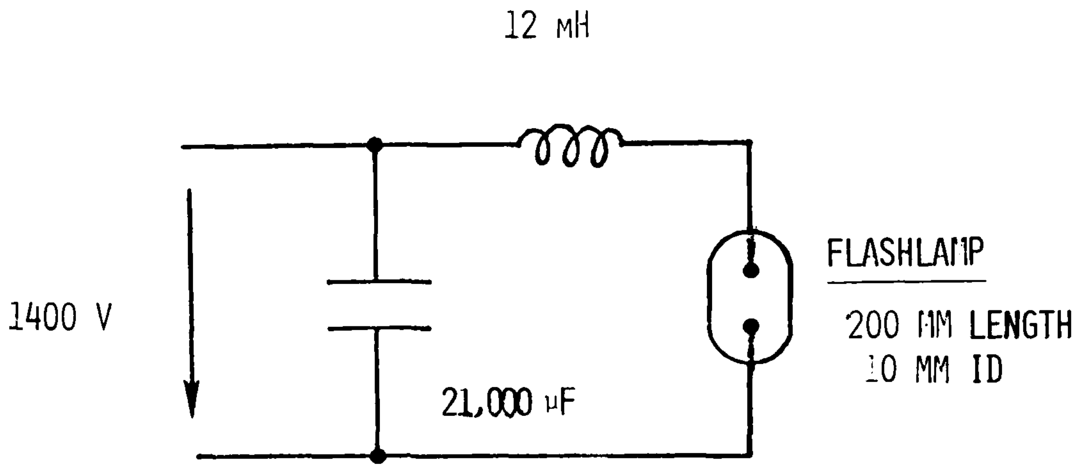


Figure 3.7 Discharge Circuit

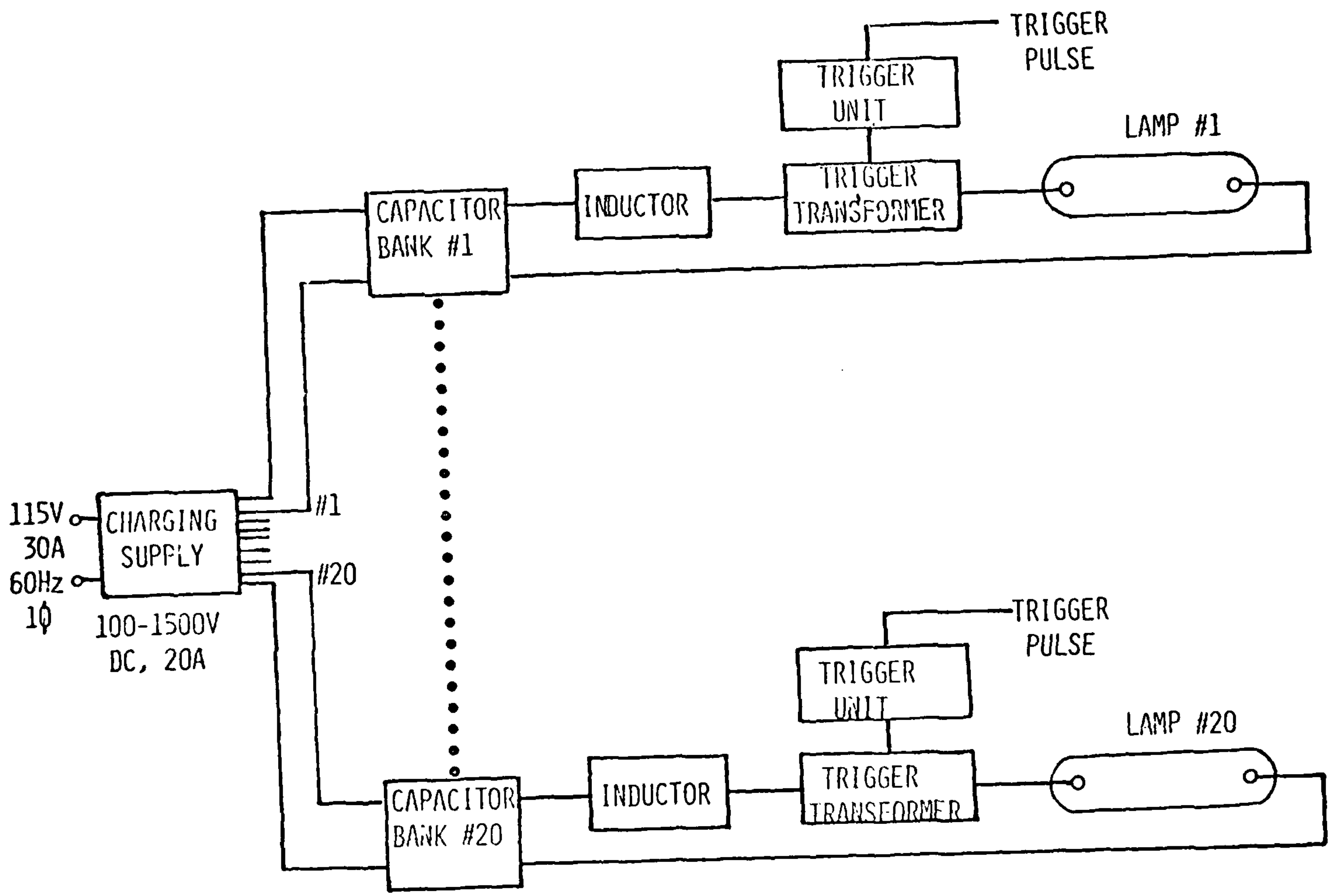


Figure 3.8 Power Conditioning

is 20,925μF ≈ 21,000μF. This would require 108 capacitors. Since 20 such capacitor stacks would be required, 2160 capacitors would be required overall at a cost of approximately $43,200 + labor and some additional materials. The total stored energy of such a storage system would be in excess of 400 KJ, making this quite reasonable.

Packaging of the entire discharge circuit for a single lamp could be accomplished in a modular fashion as shown in Figure 3.9. Each of these modules could be fitted into a rack as depicted in Figure 3.10. In this way the overall system would be a compact unit which could be mounted in a trailer for mobile tests at selected sites.

3.5 SYSTEMS INTEGRATION

Each of the subsystems discussed earlier must be properly mated together and the entire system must be outfitted with the control and diagnostic equipment needed for a complete package. The complete system would consist of the following elements:

- Pump Head
- Reflector
- Sample Holder
- Diagnostic Package
- Support Structure
- Power Conditioning Unit
- Charging Supplies
- Control Panel (Flux Control, Trigger Button, Voltage Selector, Capacitance Selector, Lamp Selector).

Figure 3.11 shows the overall systems integration required for the soil irradiation facility to be effective. Each of the subsystems should be optimized within its own parameter space and then the entire system carefully interfaced.

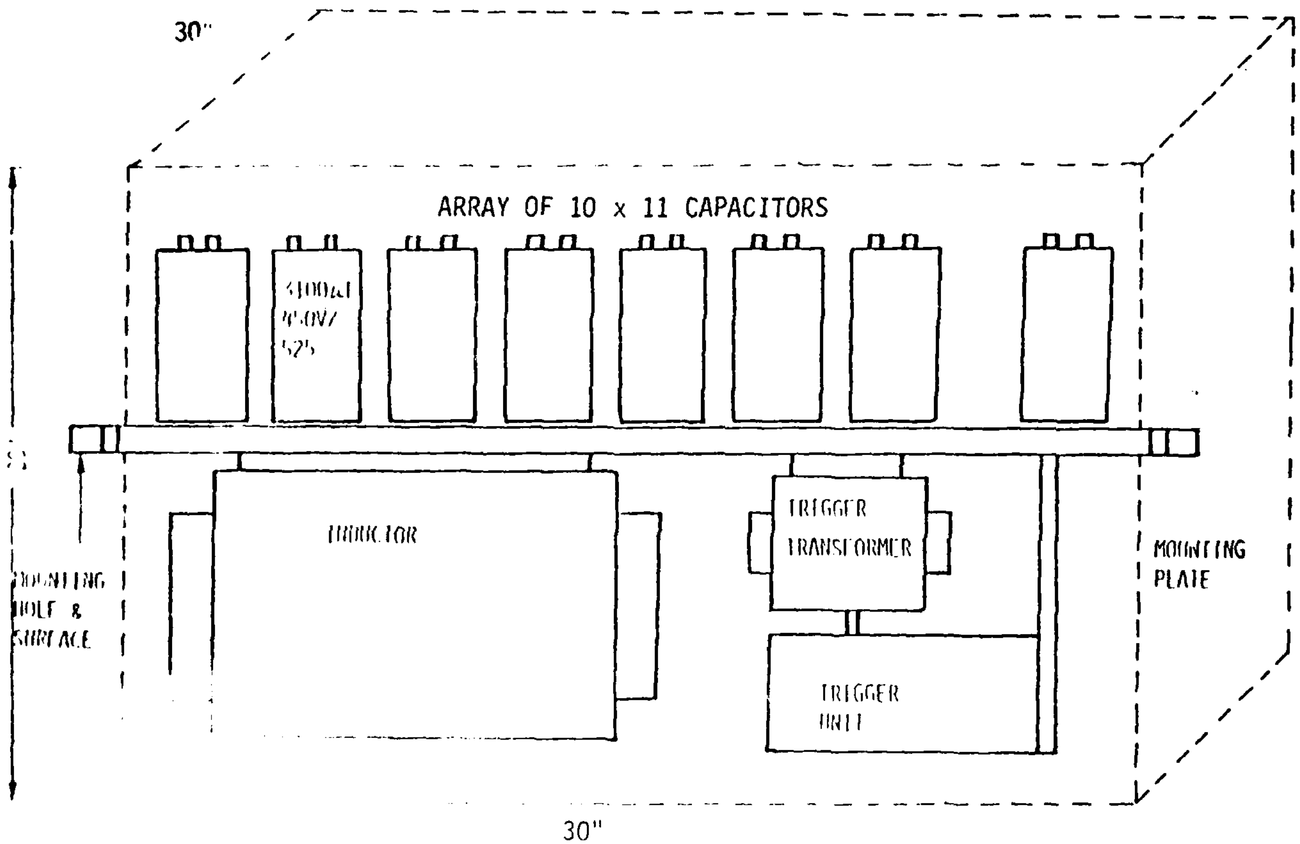


Figure 3.9 Packaging of Powered Conditioning Unit for One Lamp

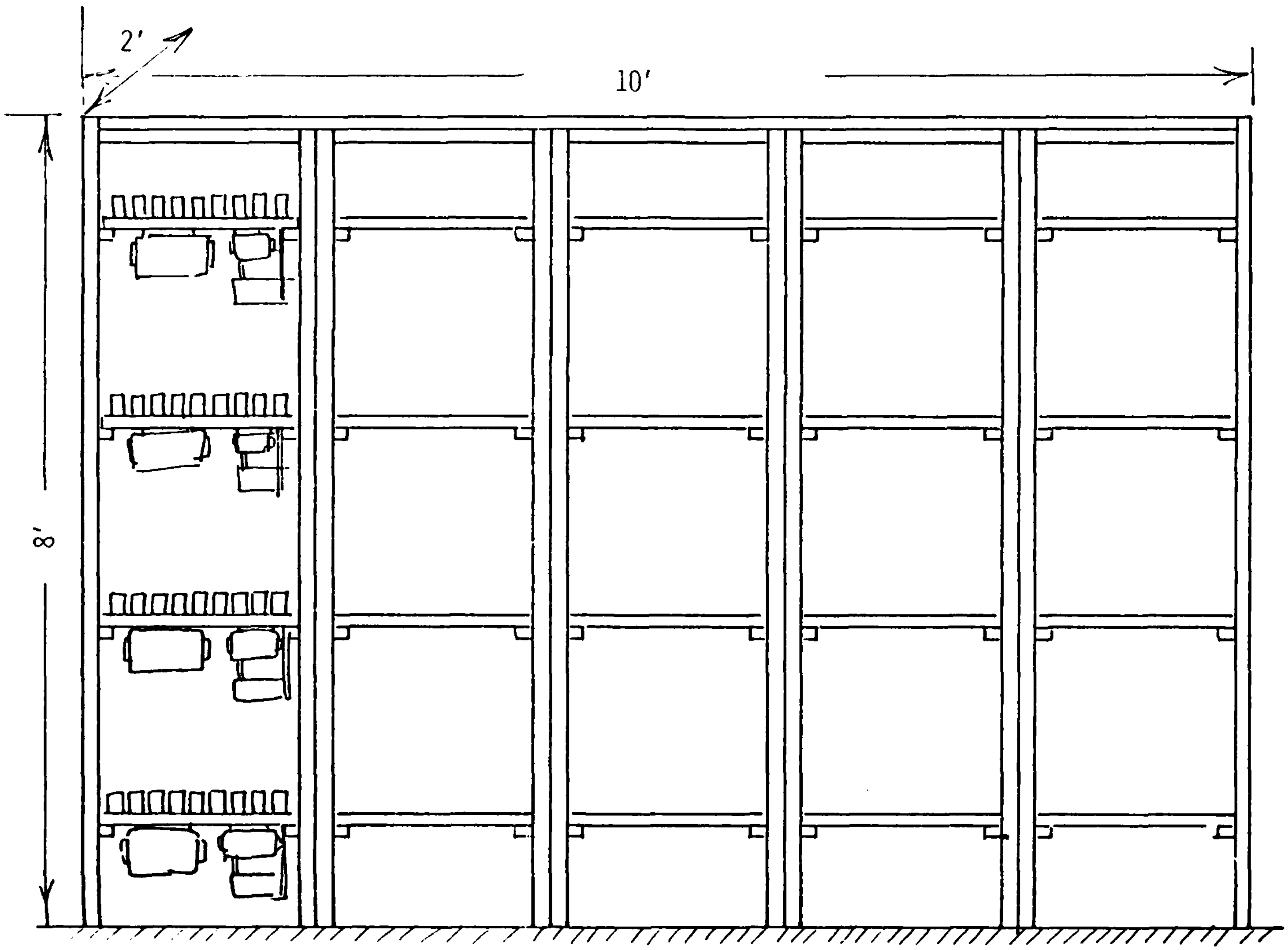


Figure 3.10. Open-Rack Mounted Power Conditioning

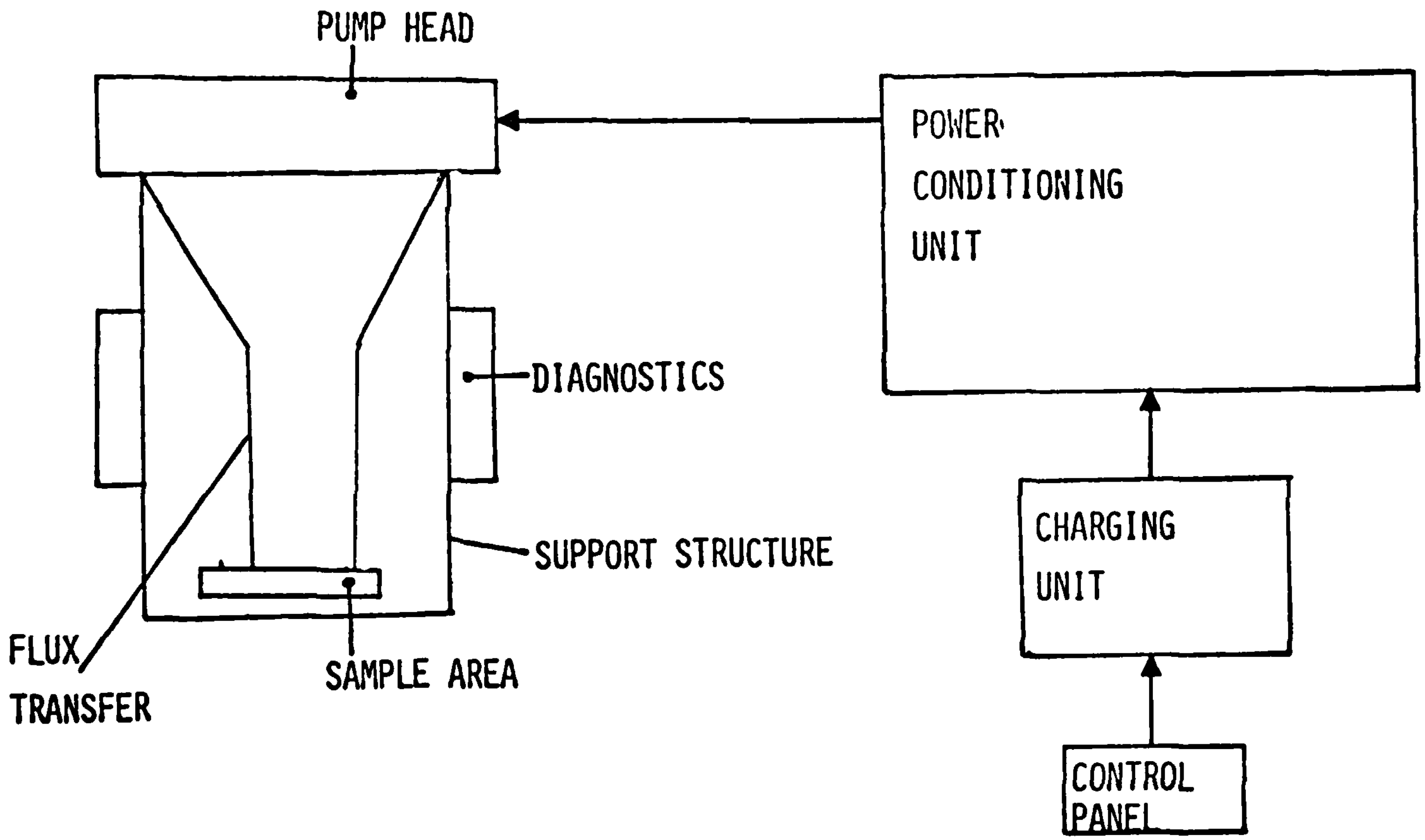


Figure 3.11 Systems Integration

In order to evaluate the performance of the soil irradiation facility a number of parameters should be measured. The pulse shape and duration should be carefully monitored to ensure that they are as planned. A simple silicon detector coupled to an oscilloscope should be adequate for this measurement. The total energy deposited within the sample area is another important measure of the system's performance. Perhaps this could be evaluated by measuring the temperature rise of a black anodized aluminum block placed in the sample area. A measurement of the power density distribution within the target plane is also essential to characterize the incident radiation for modeling. A metal plate with holes located at the sample area and backed with silicon detectors should be suitable for this purpose. Diagnostic equipment developed in a parallel SAI solar furnace irradiation program would be available for use in flashlamp irradiation testing.

SECTION 4
MODIFICATIONS TO INITIAL DESIGN

4.1 ALTERNATE DESIGN CONFIGURATIONS

The basic design concept presented in Section 3 may be modified in several ways to provide high intensity flux for a variety of applications. Several potential concepts are summarized below.

- Integration with Soil Test Apparatus for Solar Furnace Experiment

  The equipment designed for the solar furnace irradiation work can be used with the flashlamp system by removal of the diverter and mounting of the flashlamp unit. The flux concentrator then feeds optical energy into the sample containment tube rather than directly onto the sample.

- Irradiation of a Distant Target

  The flashlamp module could be used at the focus of a large parabolic dish to provide high intensity radiation on a distant target. The optics are fairly straightforward. Several firms manufacture suitable steerable dishes for use. Tests of optical transmission through fogs, or atmospheric dust could be accomplished in this way.

- Sidewise Irradiation of Large Samples

  When larger areas of target are required, a sidewise illumination scheme may be provided.

- Fieldable Limits

  For irradiation of undisturbed soil samples a field unit is required. The concept can be appropriately modified. The storage system, lamps and flux concentrator can be mounted in a truck bed. A mechanism to lower the concentrator and soil containment tube over undisturbed ground would be provided. Portable generators would provide field power without need for utility power connections.

- Hybrid Flashlamp Solar Furnace Unit

  Use of both flashlamps and solar furnace is readily provided since the flashlamps are transparent. In this case the flashlamp unit could be mounted near the top of the sample chamber just below the flux control shutters.

In summary, the basic design appears to have great flexibility to provide irradiation under a wide variety of situations beyond those initially described in Section 3. In all cases reviewed here the auxilliary systems required are off-the-shelf items, although some meodification would be necessary to accomodate the flashlamps.

4.2 USE OF EXISTING ENERGY STORAGE FACILITIES

Approximately 30 percent of the cost estimated for the soil irradiation system is taken up by energy storage items. The capacitors themselves cost about $30K to $40K. There are existing government energy storage facilities. As part of this work, SAI reviewed the potential for use of these existing facilities. A brief review indicated that the NASA/Ames facility was the best initial match. Dr. G. Ullrich of DNA/SPSS was instrumental in identifying this resource.

The conceptual design for a flashlamp based soil irradiation facility outlined in Section 3 requires an energy storage capacity of approximately 400 kilojoules. There is already in existence at the NASA/Ames test facility a capacitive energy storage with a 500 kilojoule storage capacity. Since this facility does have the necessary storage capacity and since it is already in existence, it should be considered for use with the flashlamp system. In the following sections we describe the NASA/Ames facility and then consider its potential application to the flashlamp system. The description of the NASA/Ames facility was made based on a site visit and from references kindly supplied by Mr. Robert Dannenberg of NASA/Ames.

4.3 ENERGY STORAGE AVAILABLE AT THE NASA/AMES RESEARCH CENTER

The NASA/Ames energy storage system consists of a high-voltage power supply, a capacitor bank, a capacitor shorting system, and a discharge resistor assembly. Pertinent power supply specifications are:

Input Voltage	480 volts AC, 60 Hertz, 3 phase
Input Current	38 amps maximum
Output Voltage	0-50 kilovolts DC
Output Polarity	Reversible (normally negative).

The capacitor bank consists of 168 capacitor units (GE Catalog No. 14F1502). The capacitors are rated at 15 microfarads, 20 kv, and 50 ka with a nominal self-inductance of 0.25 microhenry and a 0.4 percent dissipation factor. The capacitors have extended foil connections and the dielectric stress has been limited to 2000 volts per mil. Each capacitor is rated for 80 percent voltage reversal and is fused with an expulsion fuse (GE Catalog No. 39F503G1). These fuses were designed to provide protection against failure of a capacitor by rapidly isolating the faulty capacitor from the remainder of the bank without interrupting the bank operation. The capacitor bank was designed with individual fuses located such that no danger of bank breakdown to ground is incurred during fuse expulsion.

The capacitor rack structure was designed to house a maximum of 252 capacitors. In the present system, 168 units are arranged in 12 rows of 14 capacitors each, with 7 units on either side of the cable passageway. The rack buss bars allow the capacitor groups to be connected in a partially series, partially parallel arrangement (40kv) or in a fully parallel arrangement (20 kv).

The shock driver tube and the capacitor bank are linked by coaxial cables. Two cables (Type RG-21G/U) connect each row of capacitors to the current collector assembly on the shock driver tube. Each pair of cables has a capacitance of 0.0023 μf, an inductance of approximately 1.8 μh, and a resistance of approximately 12 milliohms. The total system has the following electrical characteristics as shown in Table 4-1.

Table 4.1 Characteristics of the NASA/AMES Storage Bank			
Configuration	Capacity	Inductance	Resistance
40 kv connection (series-parallel groups)	630 μf	0.167 μh	1.33×10^{-3} ohm
20 kv connection (parallel groups)	2520 μf	0.154 μh	1.08×10^{-3} ohm

A complete system for charging the capacitor bank and discharging the residual energy at the conclusion of the discharge is operational. This system also provides a fast abort capability. Each capacitor is shorted once the bank voltage has been reduced to less than 10 volts. The entire system is interlocked for safety and equipment protection.

4.4 DISCUSSION CONCERNING USE OF THE NASA/AMES STORAGE FACILITY

If it were possible to utilize this energy storage facility, there would be an advantage in so doing. Unfortunately, energy storage systems are generally tailored for specific applications, and it is usually not easy to adapt them to a task which is essentially different from their original design. The facility at NASA/AMES is a high voltage, low capacitance, low inductance system which is designed to discharge in a very short interval of time, that is, a short time constant. On the other hand, the flashlamp system requires a relatively slow discharge time in order to meet its design goals.

The energy stored in a capacitive system is directly proportional to the capacitance and to the square of the voltage. Energy storage in the NASA/Ames facility is achieved at high voltage (20,000V) and low capacitance 2520 μf. Since the time constant of the circuit is equal to the square root of the product of the circuit capacitance and inductance, our desired time constant of 16 milliseconds for the Ames capacitance of 2520 μf would require an inductor in excess of 6 henries. This is an extremely large inductance. Inductors of this size would be very large and very expensive.

The extremely high voltages used in the NASA/AMES facility are high enough to self trigger the flashlamps. Consequently, spark gap switches would be required to control the lamp firings. Flashlamps are sometimes wired in series to hold off high voltages; however, this becomes impractical for more than two lamps due to leakage and misfiring problems. In addition, lamps wired in series fire at the same time. This would be satisfactory for the short pulse case but would not allow the system to be used in the long pulse mode. This would negate one of the principal advantages, its versatility.

In order to use the facility, extensive rewiring would be required. In fact, the cost of modifying the system - if it could be modified - could outweigh the cost of constructing a dedicated energy storage system for the flashlamp facility. In light of the above and in view of the relatively low cost of a dedicated energy storage facility ($\sim$100K), it does not appear that the use of the NASA/AMES facility is a viable option. However, there exists considerable design experience, instrumentation and support services at NASA/AMES. They have exhibited great interest in a joint development program. These factors argue for active participation by NASA/AMES in the program despite the fact that their existing storage bank appears unsuitable for use for the soil irradiation facility.

SECTION 5
CONCLUSIONS

The main conclusions of this study are reviewed and outlined in this section.

5.1 THE INITIAL DESIGN GOALS FOR SOIL THERMAL IRRADIATION CAN BE MET WITH A FLASHLAMP FACILITY

Conceptual design engineering and cost estimation tasks were performed. These show that a 21 lamp unit, with flux concentrator, energy storage and triggering circuitry could be developed, constructed, and acceptance tested for approximately $400K, over a 12-18 month period. Such a unit would provide 20,000 calories of optical radiation (about 80 Kjoules) on target. Pulse times would vary between 0.05 and 1.0 seconds. A bright UV rich first pulse (of ∿ 1% energy content) would precede the main pulse.

5.2 THE FLASHLAMP CONCEPT CAN BE READILY EXTENDED TO A WIDE VARIETY OF APPLICATIONS, HOWEVER, LITTLE IS TO BE GAINED BY USING EXISTING CAPACITOR ENERGY STORAGE BANKS

The flashlamp unit is inherently adaptable to several situations of interest. It mates naturally with the experiment chamber being designed for solar furnace irradiation testing. Due to the transparent nature of the flashlamps, solar furnace radiation could pass through the flashlamp unit and strike the target while it was being irradiated with the flashlamps. Such a hybrid arrangement would provide a unique irradiation capability. In such an arrangement the flashlamps would operate at reduced efficiency, however.

The flashlamp source can be configured in a parabolic reflector for distant irradiation, or can be mounted in a truck for in-situ soil irradiation. Existing capacitor storage banks are configured for too high a voltage (typically 20 to 40 kv) to be very useful for the 1 to 2 kv requirements of flashlamps.

5.3 THE FLASHLAMP CAPABILITY SHOULD BE DEVELOPED IN A TWO-PHASE PROGRAM

Phase I consists of a 6 month, 100K effort that demonstrates the performance of a single lamp unit and provides the detailed engineering, drawings, and specifications for the facility. Phase II consists of a 8 to 12 month, 300K development effort for the facility, including acceptance testing. Phase I and II may overlap slightly. Total development time is estimated at between 12 and 18 months.

5.4 THE FLASHLAMP FACILITY SHOULD BE USED TO PROVIDE LOW KILOTON THERMAL SIMULATION FOR SOIL SAMPLES, UV EXPOSURE TO AEROSPACE MATERIALS, AND, IN CONJUNCTION WITH A LARGE SOLAR FURNACE, TO INVESTIGATE MEGATON RANGE THERMAL EFFECTS.

The facility will be unique in its peak flux and ability to simulate the first peak preceding the main thermal pulse. Tests requiring this capability include low kiloton thermal nuclear simulation, and tests of aerospace equipment such as light sensitive canopies. The UV content of the flashlamps and first pulse make certain types of tests of these objects possible for the first time. To make up for the lack of prolonged pulse ability the flashlamp unit should be combined with a large solar furnace. In operation the first pulse (UV rich) would be provided by the lamps. The initial part of the main pulse would also come from the lamps - running in the blue region. The solar furnace output would overlap the second pulse - providing a more red spectrum, tailing off to a near IR content. Such a hybrid facility would correctly simulate a megaton type pulse for the first time.

SECTION 6

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