SHIELDING AND FILTERING TECHNIQUES TO PROTECT SENSITIVE INSTRUMENTATION FROM ELECTROMAGNETIC INTERFERENCE CAUSED BY ARC WELDING

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ABSTRACT

Electromagnetic interference (EMI) caused by arc welding is a concern for sensitive CANDU® instrumentation and control equipment, especially start-up instrumentation (SUI) and ion chamber instruments used to measure neutron flux at low power. Measurements of the effectiveness of simple shielding and filtering techniques that may be applied to limit arc welding electromagnetic emissions below the interference threshold are described. Shielding configurations investigated include an arrangement in which the welding power supply, torch (electrode holder), interconnecting cables and welder operator were housed in a single enclosure and a more practical configuration of separate shields for the power supply, cables and operator with torch. The two configurations were found to provide 30 dB and 26 dB attenuation, respectively, for arc welder electric-field emissions and were successful in preventing EMI in SUI set up just outside the shielding enclosures. Practical improvements that may be incorporated in the shielding arrangement to facilitate quick setup in the field in a variety of application environments, while maintaining adequate EMI protection, are discussed.

INTRODUCTION

Electromagnetic interference (EMI) caused by arc welding is a concern for sensitive CANDU instrumentation and control (I&C) equipment. Arc welding has caused interference with startup instrumentation (SUI) and normal ion-chamber-based neutronic instrumentation on a number of occasions. Although the problem is most severe when the reactor is at low power and the flux signal is very small, there is concern about possible EMI effects whenever arc welding near sensitive equipment is considered. This often results in restrictions on or deferral of maintenance work involving arc welding.

This paper describes simple shielding and filtering techniques to mitigate electromagnetic emissions from arc welding and measurements of the effectiveness of these techniques. The techniques discussed may be applied in the construction of temporary shielding enclosures for arc welding to reduce concern over possible EMI to nearby I&C equipment. The work complements previous investigations that are summarized below.

A literature search and discussions with personnel at nuclear power plants and with EMI consultants in Canada and the US has shown that arc-welding EMI in instrumentation is a common problem. Administrative controls are widely used to avoid arc welding near potentially sensitive equipment [1]. At some plants, the use of high-frequency (HF) stabilization is prohibited for arc welding near sensitive equipment.

Guidelines on electromagnetic compatibility (EMC) recently published by the Electric Power Research Institute (EPRI) advise that arc welding be avoided in rooms containing in-service EMI-sensitive safety equipment, but may be permitted, provided the arc welding equipment is contained in shielded enclosures [2, 3]. However, the authors were not able to identify any implementation guidelines for shielded enclosures, nor any plants that have applied shielding to arc welding operations.

An experimental investigation of EMI effects in SUI operating in proximity to an industrial arc welder of a type used at some CANDU stations was performed. The investigation showed a low level of disturbance that has little effect on the SUI output when the arc welder is operated in direct current (DC) mode without HF stabilization [1].

Measurements of arc welder electric and magnetic field emissions showed strong emissions in the frequency range 0.25 to 10 MHz for welder operation in alternating current (AC) mode, with or without HF stabilization, and DC mode with HF stabilization. Strong emissions were found whenever HF stabilization was selected, even in the absence of a welding arc, indicating that significant emissions originate in the welding power supply. In contrast, welder operation in DC mode with HF stabilization disabled was found to cause peak electric and magnetic

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field emissions that are more than 100 times lower and are not far above the ambient level [4].

A number of recommendations were made to help avoid EMI caused by arc welding, including avoiding the use of AC welding and HF stabilization [1]. However, as the above are necessary for certain welds, and use of HF stabilization allows superior welds to be made, the above restrictions sometimes present problems for maintenance operations and are not a fully satisfactory solution to the problem.

SHIELDING ENCLOSURES FOR ARC WELDERS

Requirements

The requirements for a shielding enclosure for arc welding are as follows:

- must provide adequate electric-field and magnetic-field shielding,
- must provide for penetrations of the shield by electrically-conductive structures such as the power line and work piece, without overly compromising shielding effectiveness,
- must allow the welder operator easy access to the work piece, admit light and provide for ventilation of gases evolved in welding,
- must be easily constructed, using materials that are easily brought to the site, and
- must be grounded.

Based on previous work, it is concluded that the required shielding effectiveness (ratio of field strength in the absence of the shield to that in the presence of the shield) is no more than about 60 dB for electric fields and 40 dB for magnetic fields, and may be much less.

The shielding effectiveness of a shielding enclosure is determined by the following factors:

- intrinsic shielding effectiveness of the shielding materials used,
- electric and magnetic field emissions from high-frequency currents conducted along the AC power line, pipes or other metal structures penetrating the shielding enclosure, and
- leakage through seams, holes and other apertures in the shield.

Shielding Materials

Test shielding enclosures were constructed of hot-rolled steel sheet, steel screen (expanded metal), aluminum foil and EMI tape.

As shielding structures and sensitive equipment are typically located in the near field of strong arc-welder emissions, the attenuation of electric and magnetic fields needs to be evaluated separately. The shielding effectiveness of aluminum and steel sheet of practical thickness is expected to exceed 145 dB for both electric and magnetic fields, while aluminum foil is expected to provide minimum shielding effectiveness of 120 dB for electric fields and 55 dB for magnetic fields, in the frequency range of interest [5].

The shielding effectiveness for screen material is expected to be somewhat lower than for solid sheet. Nevertheless, shielding effectiveness of a practical shielding enclosure made of any of the above materials, including screen, is expected to be limited by radiation from conducted emissions and leakage through apertures.

Control of Conducted Emissions

The test shielding enclosure constructed for the welding power supply was penetrated by a 600 VAC, single-phase power line and by the pipe being welded.

A power-line filter was installed in the power line near the entrance to the shielding enclosure to minimize high-frequency conducted emissions from the shielding enclosure. Such emissions give rise to electric and magnetic fields that reduce the effectiveness of the shielding enclosure.

The power-line filter selected for the application was a π-type, low-pass filter. The nominal insertion loss of the filter was at least 50 dB in the frequency range 0.25 to 10 MHz. The filter case and ground terminals were bonded to the input AC power ground, the welder ground and the shielding enclosure.

Conducted emissions from the shielding enclosures via the pipe being welded were minimized by (i) securely clamping the welder ground electrode cable to the pipe inside the shielding enclosure, (ii) circumferentially bonding the pipe to the shielding enclosure at each penetration, and (iii) bonding the welder ground and shielding enclosure. This provides low-impedance return paths for welding current through the welder ground cable and shielding enclosure, and minimizes stray currents conducted along the pipe outside the shielding enclosure.

Bonding of Shielding Panels

To avoid high leakage through gaps between shielding panels, the maximum dimension of any holes in the shielding and gaps between shielding panels must be small compared with a quarter wavelength. For effective shielding, various sources recommend limiting maximum dimensions of holes and gaps to values from 0.02 to 0.1 of a wavelength. As significant arc welder emissions are limited to frequencies below 10 MHz, even the more stringent criterion is easily satisfied as it requires that the maximum dimension of holes and gaps be held to 0.6 m.

Tack welds and EMI tape were used to bond shielding panels in the 2 shielding enclosures constructed. The EMI tape used is an embossed copper tape 0.035 mm thick and 5 cm wide, having adhesive applied on the high points. When applied to a conductive surface and pressed down, the copper makes contact with the conductive surface and gives a low-resistance connection.

Description of the Shielding Enclosures

Two shielding enclosures were constructed. Shielding Enclosure 1 (SE1) was constructed for investigation of the shielding effectiveness that may be expected for a shielding enclosure that is penetrated by a power line and the pipe being welded, and includes gaps between shielding panels consistent with quick assembly. To ensure that emissions from all parts of the welding apparatus are included in tests, SE1 was made large enough to contain the arc welding power supply, the power-line filter, the welding electrode and ground cables, the work piece and the welder operator.

Shielding Enclosure 2 (SE2) was constructed for subsequent investigation of a more practical arrangement involving separate shielding for the welding power supply, welding arc and welding cables. In this arrangement, shielding for the above items was provided by SE1, SE2 and an aluminum foil wrapping, respectively.

Figure 1 is a front view of SE1 showing the welding power supply inside the open door. The following additional features may be seen in Figure 1:

- a pipe serving as the work piece, penetrating a panel of aluminum foil at the rear of SE1;
- the welder ground cable, clamped to a strut supporting the screen roof of SE1 (The welder ground cable is normally clamped to the work piece near the weld site.);
- the power-line filter, located on the floor just inside the door;
- the welder foot control, which is moved inside when welding inside SE1; and
- the rod antenna (for measuring the electric field), supported in a horizontal position above the shielding enclosure on a cardboard box.

The floor of SE1 was made from two sheets of hot-rolled steel sheet tack welded at several points. The sides of SE1 were made using existing structures used to partition welding work areas. These structures consisted of hinged sections made of steel sheet welded to a tubular steel frame supported on casters. One partition formed the front, left side and half the rear wall of SE1 and another partition formed the other half of the rear wall and the right side. A gap in the rear wall roughly 0.4 m by 1.2 m was covered with aluminum foil. The foil was bonded to the steel panels and pipe using EMI tape and a pipe clamp. A roof of steel screen and a door of steel sheet were added to complete the enclosure. Gaps in the shielding of a few centimetres were left around the 7 casters and long, narrow gaps, roughly 2 mm by 1 m, were left between hinged sections of the enclosure.

SE2 was constructed quickly of lightweight materials using very few tools. The walls of SE2 were made of two sheets of steel screen, each having a right angle bend. The roof was made from another sheet of steel screen. Loosely-rolled aluminum foil was placed between adjacent panels to act as an EMI gasket. The weight of the roof was used to compress the foil, while the wall panels were held together with wire. Aluminum foil was used for the floor and to cover the access opening of the enclosure. A pipe penetrating the walls of SE2 was set up to serve as the work piece.

Figure 2 shows the rear of SE1 at left and SE2 at right. The following features may be seen in Figure 2:

- the welder ground and electrode cables (and gas line), wrapped in aluminum foil shielding, entering the panel covering the SE2 access opening from the left;
- the pipe serving as the work piece, and aluminum foil stuffed in the gap between the pipe and SE2 wall to provide an electrical connection;
- a welder operator seated just behind the access opening;
- the rod antenna, set up to measure electric-field emissions from SE1 and SE2; and
- the back of the low cabinet containing SUI

equipment, situated between SE1 and SE2.

EVALUATION OF SHIELDING ENCLOSURES

Shielding enclosures for arc welding were constructed and evaluated in the high bay area of the Bldg. 412 machine shop at the Chalk River Laboratories. The effectiveness of the shielding enclosures was evaluated by comparing measured electromagnetic emissions caused by an arc welder, with and without shielding in place.

Measurements of electric and magnetic fields were performed using calibrated antennas and a spectrum analyzer. The equipment used to generate and measure arc-welding electromagnetic emissions is listed in Table 1.

The electromagnetic field was generated by powering the arc welder and selecting HF stabilization. It was not necessary to strike a welding arc in order to generate a strong broadband electromagnetic field. However, an arc was struck for most tests. The tungsten-inert-gas (TIG) welding process was used. The welding power supply was set up for 70 A direct current.

Arc welder electric and magnetic field emissions were first measured in the frequency range 0.010-32 MHz, with and without SE1 in place around the welding power supply, welding cables, welding electrode and work piece. Maximum emissions were found to occur just above 1 MHz. Electric-field emissions were 30 dB below emissions measured with no shielding, but still nearly 20 dB above the ambient level. In contrast, magnetic field emissions measured with SE1 in place were only slightly above the ambient level. Consequently, further investigations included only electric-field measurements in the frequency range 1-2 MHz.

The effectiveness of the shielding enclosures was also evaluated by monitoring for EMI in SUI under various conditions. Excursions in the indicated count rate were used as an indication of EMI in these tests. The equipment used and its setup were very similar to those described in reference 1. With the cabinet containing SUI equipment located just outside SE1, severe EMI was observed when the SUI detector and detector cable were inserted into SE1 while HF stabilization was on, but no EMI was observed when the detector was withdrawn to a location just outside SE1. The above result suggests that the shielding effectiveness of 30 dB achieved for SE1 is adequate to protect SUI systems from EMI caused by arc-welding.

Table 1: Equipment used in evaluation of shielding enclosures

Equipment Description
• Industrial arc welder (CANOX model C-330A/B SP)
• Spectrum analyzer, display unit & plotter
• Rod and loop antennas, couplers, tripod and output cable
• Power supply (for loop and rod antenna couplers)
• Current probe

To investigate the effect of different shielding materials and construction features, the electric field was measured outside SE1 near four faces differing in the above respects, while the arc welder was operated inside SE1. No significant difference was found in electric fields measured near the rear wall, which is penetrated by the work piece, the left side, which is made of steel sheet, the front, which has a door (closed) of steel sheet, and the roof, which is made of steel screen. Opening the door of SE1 caused the electric field measured near the door to increase 3-fold, but had no effect on the electric field measured at the other locations. The above results show that adequate performance can be achieved in shielding enclosures made of screen materials and having walls that are penetrated by conductive structures.

In a further test, the welder return cable was removed from the work piece and clamped at the roof strut, as shown in Figure 1, thus forcing the welding current to return via the enclosure wall. This did not affect the shielding performance of SE1, suggesting that the work piece may form one of the walls of a practical shielding enclosure. Note, however, that it is important the return cable is clamped inside the shielding enclosure. It was confirmed that a shielding enclosure becomes ineffective if the return cable connection is made outside the shielding enclosure.

Subsequently, the welding power supply was left inside SE1, but the welding cables and welding electrode were removed, and welding was performed outside SE1 without shielding the welding arc or cables. Then, SE2 was constructed to enclose the weld site and welder operator, and the welding cables were wrapped in aluminum foil. Shielding measurements were made at several stages, as additional shielding was provided, ending with an arrangement where shielding material fully enclosed all parts of the welding equipment (with the exception of the work piece and ac power line). The findings in the above tests were as follows:

- There is no significant reduction in emissions when welding is performed with unshielded cables and no shield, or an incomplete shield, around the arc, even if shielding is provided for the welding power supply.
- Shielding the welding power supply and cables, and partial shielding of the welding arc (no floor in SE2), results in roughly 16 dB reduction in emissions.
- Shielding the welding power supply in SE1, the welding arc in SE2, and interconnecting cables in aluminum foil results in a 26 dB reduction in emissions.

The shielding effectiveness of SE2 and aluminum foil covering the welding cable was not significantly degraded in moving SE2 and rerouting the cables around the other side of SE1, indicating that shielding performance is not critically dependent on minor details of shielding arrangement.

A low level of EMI was observed when the SUI detector was shielded from direct emissions from the welding power supply, but exposed to emissions from the welder cables and the welding arc. This observation is somewhat surprising, as electric field measurements showed only a small shielding effect.

No EMI was observed in the SUI when arc welding was performed nearby using HF stabilization, with welding power supply emissions shielded by SE1, welding arc emissions shielded by SE2, and welding cable emissions shielded with aluminum foil.

A current probe was used with the spectrum analyzer to measure high-frequency conducted emissions on the AC power line. Conducted emissions measured on the supply side of the filter outside SE1 were higher than expected on the basis of filter specifications and emissions measured on the load side of the filter. This may be because the filter was installed such that a short length of AC power cable on the supply side of the filter was exposed to the high-frequency electromagnetic field inside SE1. To minimize conducted emissions on the AC power line, it is important that the filter is installed in the wall of the shielding enclosure such that there is continuous shielding between AC power cables connected at the supply and load sides of the filter.

CONCLUSIONS

Strong electromagnetic emissions are generated when arc welding is performed using HF stabilization. It is possible to avoid causing EMI in nearby sensitive equipment by providing electromagnetic shielding for the welding power supply, cables and welding arc, and installing a low-pass filter at the AC power entry. All the above measures are necessary to provide confidence that EMI will not result.

Shielding enclosures for the welding power supply, cables and welding arc were constructed and evaluated. It was shown that shielding enclosures constructed quickly, of easily available materials, and without taking pains to eliminate all known leakage paths, can be used to significantly reduce the risk of EMI in sensitive equipment located near a prospective weld site. The shielding effectiveness of the shielding enclosure SE1 was measured to be at least 30 dB, and the shielding effectiveness of the more realistic arrangement, where SE1 was used to shield the welding power supply, SE2 was used to shield the weld site, and the welding cables were shielded using aluminum foil, was measured to be 26 dB. The above shielding enclosures were shown to be effective in preventing EMI in SUI located close to operating arc welding equipment.

EMI tape was found very useful in bonding shielding panels of aluminum foil and solid sheet. It was found less useful in bonding expanded metal screen because it is too stiff to conform well to the material. However, adhesion to screening material that is thinner and has larger openings may be more satisfactory.

The investigation provided a proof-of-principle demonstration of shielding techniques to protect sensitive electronic equipment from EMI caused by arc welding. For field application, a reusable shielding enclosure for the welding power supply can be made much smaller and lighter than the enclosure SE1 used in this investigation. The shielding enclosure can be made of light screening and only large enough to house the welding power supply and power-line filter. Access openings or panels can be provided for the welding power supply controls to facilitate setup by an operator who remains outside the shielding enclosure. An alternate, and possibly more attractive, solution is to upgrade the shielding performance of an existing welding power supply cabinet, by improving the bonding of metal panels and installing a power-line filter.

Shielding for the welding cables can be improved through the use of commercially-available cable-shielding products (based on metal foil and/or braid shields, combined with a fabric backing) that are easier to apply than aluminum foil and are more robust.

It is anticipated that the shielding enclosure for the weld site can be made much smaller than the enclosure SE2 constructed for this investigation by using an arrangement where the welder operator remains outside the shielding enclosure and manipulates the work and torch through ports in the enclosure. The shielding material is a flexible and light mesh permitting adequate freedom of movement and viewing of the work. Such an arrangement may be no more difficult to use than a glove box for welding under an argon atmosphere. Where welding is performed on a fairly large structure, the structure itself may form part of the shielding enclosure for the weld site. A concept sketch for a light, portable shielding enclosure for the weld site is provided in Figure 3.

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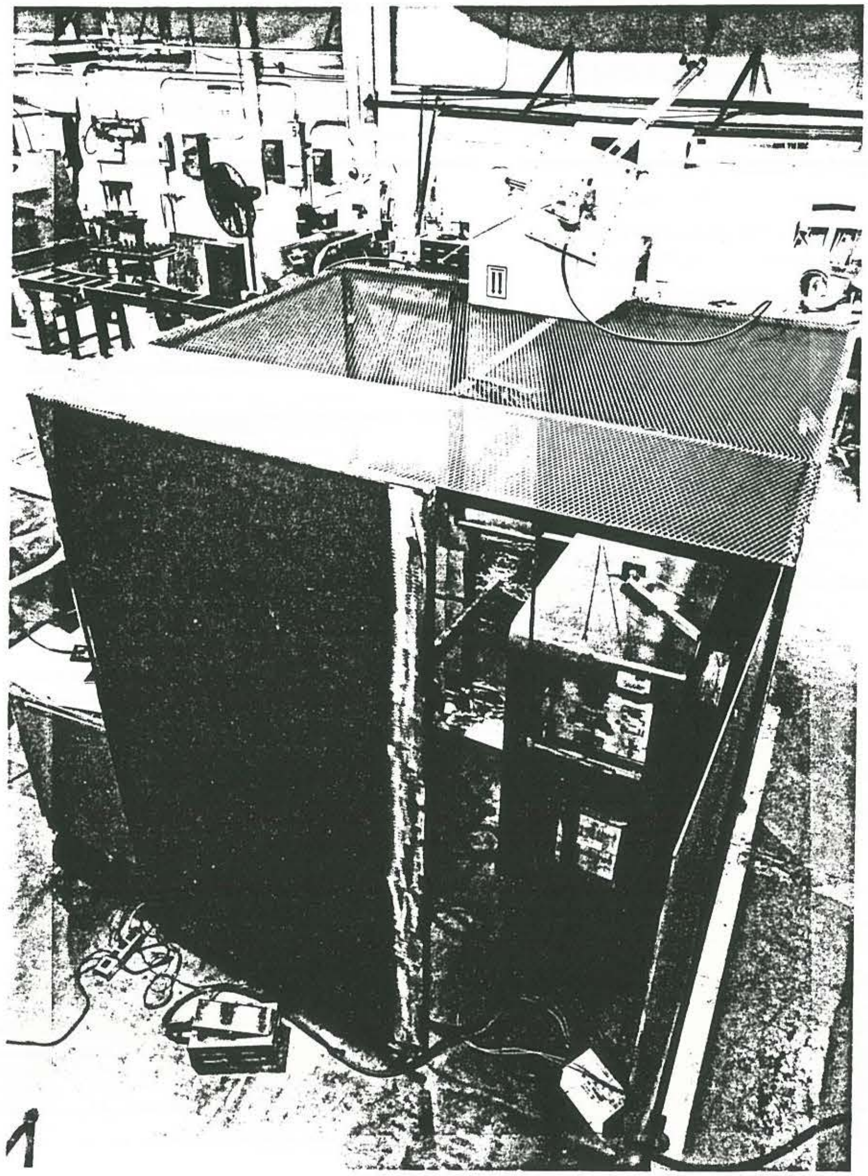

Figure 1: Front view of Shielding Enclosure 1.

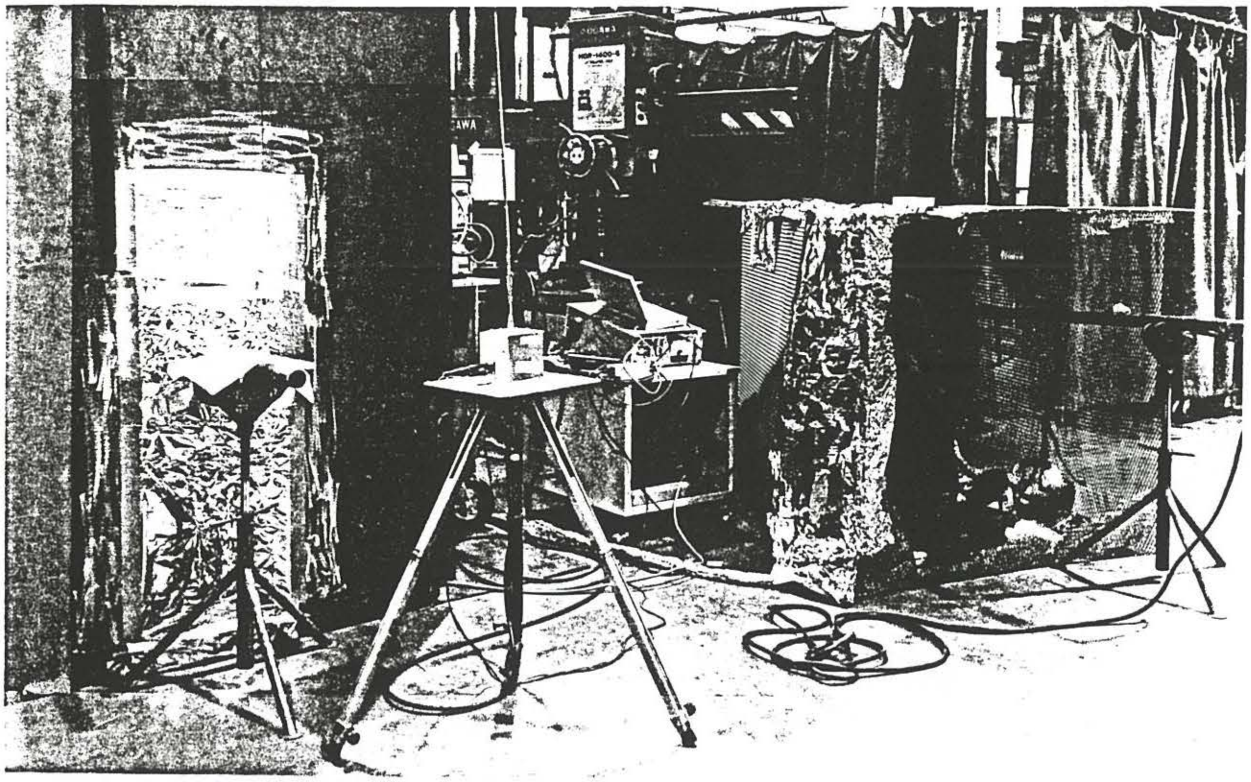

Figure 2: Shielding Enclosures 1 and 2.

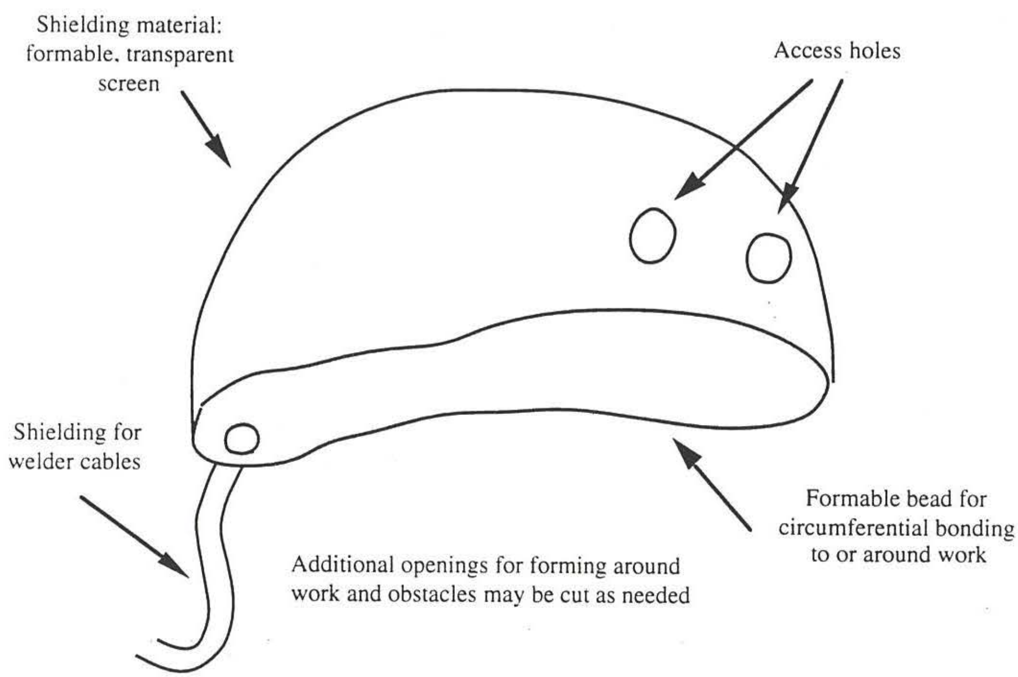

Figure 3: Concept sketch for a light, portable shielding enclosure for the weld site.