## Executive Summary

A team from Fermilab was formed to investigate the chain of events that led to the use of Conspacers during installation of the MicroBooNE cryostat piping, comment on the adequacy of the piping system, and make a recommendation regarding the future use of Conspacers at Fermilab. The team consisted of Terry Tope (Mechanical Safety Subcommittee Chair), Cary Kendziora (Senior Associate Engineer), Jack Cassidy (ESH&Q Occupational Safety Group Manager), and T.J. Sarlina (QA Manager). The team conducted interviews with Fermilab personnel involved with the design and installation of the project and visited the MicroBooNE site in the Liquid Argon Test Facility (LArTF) building.

The decision to use Conspacers was made early on in the project by the Project Engineer and was approved by the Project Manager. Using these items would allow the project to weld large, prefabricated segments of piping together without the need to flow large volumes of purge gases through the piping while welding the final connections. This was viewed as a time and cost savings to the project that would result in an accelerated installation schedule.

Conspacers had not been used at Fermilab prior to this time and the Weld Shop was unfamiliar with the appropriate welding techniques. A series of test welds were done, procedures were developed, and three Fermilab welders were ultimately qualified to weld these into place.

Large sections of piping, termed Phase 1, were prefabricated and pressure tested in Lab F in compliance with the ASME code for Process Piping, B31.3. At least 5% of the Phase 1 welds received an in-process examination in Lab F and all sections were pressure tested at Lab F. The prefabricated sections were moved to the LArTF and Conspacers were used to connect the sections. The procedures for weld examination and pressure tests were the same as at Lab F.

The final six welds were close to the large LAr cryostat and Conspacers were employed for five of them. ASME B31.3 gives the option to either verify the weld integrity via a 5% examination in conjunction with a pressure test or to perform 100% in-process weld examination and radiography. In order to not have to pressurize the entire vessel, a management decision was made to perform in-process examination and radiography for these 6 closure welds.

The single weld without a Conspacer passed the radiography but all five welds using Conspacers failed. Welding work was halted on the project. The situation was evaluated and an engineering decision was made to completely remove one Conspacer and fabricate sleeves to install over the remaining four instead of cutting them out because of their close proximity to the vessel body. This decision was made in consultation with the engineer responsible for reviewing the piping engineering note required by FESHM 5031.1 which documents B31.3 compliance.

Subsequent to this determination, a question was raised by the Fermilab Site Office (FSO) concerning the adequacy of the piping system. The head of the Cryogenic Safety Panel that oversees MicroBooNE conducted an initial investigation and reported back to FSO. The complete system, including the vessel, will be pressure tested in accordance with the code requirements after an oxygen deficiency hazard analysis has been completed.

## Recommendations

1. The in-process weld examination forms should be formalized and added to the appropriate FESHM chapter. A lab-wide effort should be made to replace all existing versions of the form with the new controlled form.
2. Develop or identify an appropriate training course for in-process weld examination.
3. The Weld Shop should be informed of welding plans such as radiography.
    - Include a requirement for radiographic testing when qualifying a welding procedure which will require radiography in the field.
4. This panel believes that the existing Conspacers in the piping are acceptable for continued service.
    - Due to the relatively low maximum system pressure which leads to a small primary stress and the fact that secondary stresses due to thermal contraction are claimed to not exceed half of the code allowable.
    - Phase 1 has been successfully operated including numerous thermal cycles between ambient and cryogenic temperatures.
    - The Large Quantity Liquid Argon Panel chaired by Jay Theilacker and the reviewer of the piping engineering note, required by FESHM, that documents B31.3 compliance will have final say in this matter.
5. Do not use Conspacers in the future.
    - A code required impact test of the Conspacer welding procedure has not been performed such that the procedure is not fully qualified.
    - The welding professionals at both Fermilab and Argonne recommend against Conspacers.
    - Welding professionals suggest that achieving a weld that can pass radiographic examination with Conspacers is difficult under the conditions encountered in the field.
    - The ID of straight pipe and elbows and tees often don't match perfectly leading to a poor fit of the Conspacer.
    - The impact of purging pipes prior to welding can be mitigated by work planning.

## Background

MicroBooNE project personnel proposed using Conspacers in 2011. Conspacers are a welding backing ring with a consumable insert that is manufactured by Robvon Backing Ring Company. The manufacture's website makes the claim that using a Conspacer eliminates the need for gas purging and provides an automatic backup for the molten mass. The filler metal feature of the Conspacer insures a quality weld on the first root pass and eliminates interrupting the pass due to possible wire feed problems. The Conspacer reduces the cost of joints by eliminating the gas purge process. The Backing Ring feature of the Conspacer provides the chilling effect advantage on the inner part of the weld joint while allowing excellent root penetration. The internal bevels and flat inner land of the Backing Ring provide minimal fluid flow restriction and turbulence. In joining thin wall pipe or tube, a finished weld may be produced in a single pass by employing a Conspacer. This finished joint is ready for use or radiography. The Project Engineer agreed that these would be appropriate for use in the high purity argon system and the appropriate timelines were inserted into the schedule. At the same time, it was planned to perform in-process examination and radiograph the final six welds near the cryostat vessel to avoid having to pressurize the entire vessel in order to pressure test those six welds.

The Fermilab Weld Shop was consulted about the Conspacers but they were unfamiliar with them and did not have procedures that addressed them. The Weld Shop Supervisor at the time was uncomfortable using a consumable insert on a stainless steel piping system because it was a non-standard approach at Fermilab. He felt that a gas purge and butt weld combination should be used. None of the welders had ever used this type of insert and had no experience with them. A Senior Welding Engineer at Argonne National Laboratory was contacted and neither he nor any of his personnel had any experience with Conspacers so he did not endorse their use.

The Project Engineer decided to use the Conspacers due to the time and cost savings the project would realize so the Weld Shop set about developing procedures and qualification requirements. Test welds were done and sent to an independent testing facility to certify the quality of the welds. Three Fermilab welders were certified for this effort in February 2013.

The prefabricated piping assembly was done at Lab F using traditional butt welds with a purge gas. Conspacers were only used at the LArTF site when the piping sections were connected together in late 2013. Phase 1 piping was commissioned in early 2014 and run without incident. The system experienced repeated thermal cycles as it was cooled and warmed over the course of several weeks. The Phase 1 cryogenic operation was a success and achieved the required purity.

Phase 2 Conspacer welds were done during the summer of 2014. There are 28 Conspacers in the Phase 1 piping and two in the Phase 2 piping for a total of 30. Five percent of the Phase 1 welds were examined in-process by a technician that had been assigned by the Level 2 Manager for Installation.

The six connections located close to the vessel body were welded on August 7 & 8, 2014 with one of the qualified welders assigned to the task. Most of the final welds were in very tight spaces and the welder had difficulty getting proper access to them. Several things that contributed to this were:

- Building walls were very close to the tank in some places,
- Some of the piping from the vessel was very near the vessel wall,
- Other piping interfered with access to piping to be welded,
- The vessel had been insulated with 18 inches of a sprayed on foam that, in some cases, completely covered the piping to be welded so that foam had to be removed in order to expose the piping, and
- He had to lay on his back or side on scaffolding that had been provided. In some cases, he had to have the mechanical technician operate the foot pedal as he called out commands.

The technician assigned to examine the welds performed a visual check of the welds at each stage. He was required to fill out an in-process examination sheet for each weld and on Friday August 8th, after several of the welds had been completed, he made the comment that he felt it was unnecessary because the welds were going to be radiographed. When a pressure test will not be performed, the code does require both 100% in-process inspection and 100% radiography so there was some unfamiliarity with the code requirements on the technician's part. This was the first the welder had heard of the planned radiography and he stated that he was certain the welds wouldn't pass. The L2 Manager and Project Engineer told him they had confidence in his abilities and urged him to complete the final welds. The welder complied and finished the remaining welds but was worried that the welds would fail radiography.

On the following Tuesday, August 12, 2014, the radiography was completed and the five welds with Conspacers did, in fact, fail due to incomplete penetration. The one traditional butt weld passed. Work was immediately halted and word was passed on about the failure. The L2 Manager was informed and halted further welding work but it does not appear that the project managers were informed until the next day. The Project Engineer was not at work that day so he was told at a later date.

One of the engineers assigned to MicroBooNE contacted the person reviewing the piping engineering note and they agreed on a plan to address the failed welds and correct the situation. Repair parts were ordered, the pipes were prepped, and the repairs were made on August 18 & 19, 2014.

During this time, the Federal Project Manager for FSO became aware of the failed welds and requested that the engineer in charge of the Large Quantity Liquid Argon Cryogenic Safety Review Panel look into the situation and report back to him. The engineer complied and produced a report that he sent to FSO. No one from the MicroBooNE Project Management team had been informed of this inquiry and it only came to their attention in an informal way.

As of this writing, MicroBooNE welding work has restarted and the further use of Conspacers has been discontinued. All piping will be purged and butt welds will be used for the remaining connections. Final approval for operation of the entire system has not been granted because all of the installation work has not been completed.

## Observations

The project attempted to take advantage of a technology little known to Fermilab in order to achieve a time savings and accelerate their installation schedule. The project determined that this was an acceptable method by talking with the manufacturer and evaluating their literature. Both the use of Conspacers and the use of radiography for the 6 closure welds were seen as ways to accelerate the installation schedule by not having to purge long sections of piping in order to obtain a good weld and not having to pressurize the large vessel for the final test.

Initially, concerns about using the Conspacers were expressed to representatives of the project by the Weld Shop because they had never had experience with them. This also deviated from what they considered to be the standard procedure of flowing purge gas and using butt welds when welding stainless steel piping.

After making the decision to proceed with Conspacers in specific locations, project representatives asked the Weld Shop to develop procedures and qualify welders. After some effort, the Weld Shop developed a procedure and successfully qualified three welders for Conspacer work.

Bend tests were conducted on the welded samples by an independent testing facility and they all passed. However, sample welds fabricated according to the new Conspacer procedure were not impact tested by the independent certification facility as required by B31.3 Table 323.2.2. Radiographic testing of the samples is not part of the certification process.

The welders were qualified using schedule 10 pipe but the cryostat piping was schedule 40. The procedure that was used did not address any changes that might be necessary for schedule 40 pipe. The welding process for Conspacers is very sensitive to how much current is being used during the weld. Too much current would cause too much penetration. Too little current would fall short of producing an acceptable weld. The visual signature that most welders depend on during a full penetration weld is obscured by the use of Conspacers.

There was a gap between initial welder qualification and actual Conspacer installation of approximately 18 months. No requalification or refresher training was required and none was done.

The in-process examination form was first developed by Bob Sanders, Roger Hiller, Wilson Cross, and Arkadiy Klebaner. These four employees represented Accelerator Division, Particle Physics Division and the Technical Division Weld Shop. The form has been informally used at Fermilab as needed. An approved version of the form does not exist (i.e. it is not housed in the FESHM chapter on Piping) so updates or changes by one group would not necessarily be transmitted to any other user.

The in-process welding examination form does not address the requirements for proper acceptance of a Conspacer weld. The in-process form used by the MicroBooNE engineers has since been revised to include Conspacers.

The technician assigned to examine the welds lacked formal welding experience. He was assigned the task due to his length of service at Fermilab and the expectation that he would be able to tell the difference between a good weld and a bad one. Only visual inspections were performed.

One of the MicroBooNE engineers provided us with a count of 28 Conspacers in the Phase 1 piping and 2 in the Phase 2 piping. This is the count after the five failed Conspacers were reworked. All Phase 1 piping has all been thermally cycled multiple times. The Phase 2 piping has not been cold yet. There will be no additional Conspacers used on MicroBooNE.

According to ASME B31.3, liquid argon is a “normal” fluid (i.e. dangerous) which means that 5% of butt welds must be radiographed or have an in-process examination performed on them.

Installation personnel did not communicate work schedules to engineers prior to work being done. Many times, the engineers found out about work in progress by chance or after the fact. In this case, the MicroBooNE engineer was not informed prior to the start of the welding. He happened upon it during a routine visit to the LArTF building. Late notification was a recurring issue during installation.

The assigned welder was not informed of the radiography plan prior to beginning work on the six difficult welds. He found out during the process and stated that he didn’t believe the welds would pass. He informed the L2 Manager and the Project Engineer but was instructed to continue with the work.

The L2 Manager and Project Engineer did not take the welder’s statements about weld quality seriously when he stated that the welds would not pass radiography. They assumed he was just complaining about the difficult conditions on the final welds. They had confidence in the welder’s abilities and urged him to continue. Their thinking was that if you had an experienced, qualified welder using an approved procedure you should get a weld that would be able to pass radiography. They failed to completely grasp the difference in difficulty between performing a qualification weld on a bench and performing a weld under difficult field conditions with tight spaces and limited visibility.

The decision to proceed was based on the fact that the radiography was already scheduled and they were almost done with the work when the welder raised his concerns. They believed the welds would pass and they did not have a Plan B in mind at this point. Another contributing factor might have been an incomplete understanding of the relevant code and what would be needed to recover from a failed radiograph. The Level 2 Manager thought that since the code allowed for either radiography or a pressure test, if the first one failed you could recover by conducting the pressure test and everything would be okay. This is not the case.

The weld repair method was selected by discussing options with a number of Fermi personnel. The MicroBooNE engineer proposed the repair method to the engineer reviewing the engineering note and he agreed that the selected repair method, using sleeves with socket welds to complete the work, was acceptable.

The project held to their installation schedule that had been designed years earlier even though it might have been better to hold off on certain aspects when the details and constraints of the actual work became better understood. For instance, applying the insulating foam to the vessel prior to the piping welds being done resulted in having to remove much of the foam in the vicinity of the pipes in order to gain access to them. The insulation company under contract had a set time slot for MicroBooNE. If the project missed their window, the company would not guarantee when they could return so the work was allowed to proceed. The missing insulation will have to be replaced at a later date.

Due to the relatively low maximum operating pressure of the system, all of the engineers we interviewed were comfortable with the integrity of the system. The MicroBooNE piping engineer states that the maximum secondary stress due to thermal contraction is less then half of the code allowable. The code analysis performed by the MicroBooNE piping engineer suggests that the system should be good for 7000 thermal cycles. This system will see cycles in the dozens at the very most during its 5 years of operation.

The five repaired welds will be tested when the final system pressure test is performed. Since the repaired welds are fillet welds, radiography is not applicable. It is difficult to capture an informative radiographic image of a fillet weld. Typically when a weld fails radiography, the weld type is not changed as was done in this case. The failed weld is simply repaired. It is acceptable to change the type of weld. When a required examination fails, the code says to examine two additional welds by the same welder. Thus at minimum it could be argued that two other Conspacer welds performed by the welder whose work failed radiography should be examined. It isn't clear if there are two other Conspacer welds performed by this welder in the system because a weld map was not created at the time. However, if there are, these welds may have already been placed in service during Phase 1.

## Personnel Interviewed

Catherine James – MicroBooNE Deputy Project Manager
Jim Kilmer – MicroBooNE Project Engineer
Bob Sanders – MicroBooNE Engineer
Mike Zuckerbrot – MicroBooNE Engineer
John Voirin – MicroBooNE Level 2 Manager for Installation
Tim Griffin – Fermilab Mechanical Technician
William Toter – Argonne Laboratory Senior Welding Engineer
Jamie Blowers – Head of the Fermilab Machine Shop
Jim O'Neill – Weld Shop Supervisor
Ryan Mahoney – Fermilab Welder
Bill Gatfield – Fermilab Welder

## Human Performance Improvement (HPI) Organizational Weaknesses

| Common Organizational Weaknesses | | | |
|---|---|---|---|
| **Training** | In process welding examiner not formally trained | **Procedure Development or Use** | In-process examination process was inadequate due to improper form and inexperienced examiner. |
| **Communications** | | **Supervisory Involvement** | |
| **Planning & Scheduling** | Management failed to evaluate the success of the Conspacers in the actual application. | **Organizational Interfaces** | |
| **Design or Process Change** | Management failed to evaluate the success of the Conspacers passing a radiographic examination. | **Work Practices** | |
| **Values, Priorities, Policies** | Management continued to weld the Conspacers after the welder stated they wouldn't pass the radiograph.<br>Time and cost caused the Conspacers not to be fully evaluated even when problems came up.<br>Radiographing the Conspacers was a poor decision to save time and cost of pressure testing. | **Other** | |

## HPI Error Precursors and Causal Codes

| Error Precursors | | | |
|---|---|---|---|
| **Task Demands** | | **Individual Capabilities** | |
| ☒ | **Time Pressure**<br>Project management felt pressure to cut time off the schedule leading them to use the Conspacers and radiograph the welds. | ☒ | **Unfamiliar with task/ First time**<br>Welding in very tight spaces with limited access. This was very different from bench welds. |
| ☐ | High Workload (Memory Requirements) | ☐ | Lack of knowledge (mental model) |
| ☐ | Simultaneous, multiple tasks | ☐ | New technique not used before |
| ☐ | Repetitive actions, monotonous | ☒ | **Imprecise communication habits**<br>Welder was not informed that welds were to be radiographed before he started. Once he learned about the radiography, he told the L2 Manager welds would not pass. |
| ☐ | Irrecoverable acts | ☒ | **Lack of proficiency / Inexperience**<br>The welder had not welded a Conspacer in 18 months such that the welder was unfamiliar with the process. |
| ☐ | Interpretation requirements | ☐ | Indistinct problem solving skills |
| ☒ | **Unclear goals, roles & responsibilities**<br>The in-process welding examiner did not understand his role or responsibilities. | ☐ | Hazardous attitude for critical task |
| ☒ | **Lack of or unclear standards**<br>The inspection report used for the in-process examination was the wrong version of the form.<br><br>Field personnel did not have a clear understanding of the piping code requirements regarding the welds. | ☐ | Illness / Fatigue |
| **Work Environment** | | **Human Nature** | |
| ☐ | Distractions / Interruptions | ☐ | Stress |
| ☒ | **Changes/Departures from Routine**<br>The Conspacers had to be modified to fit in some situations and this was not discussed with the engineering team. | ☐ | Habit patterns |
| ☐ | Confusing displays or controls | ☐ | Assumptions (inaccurate mental picture) |
| ☐ | Workarounds / OOS instruments | ☐ | Complacency / Overconfidence |
| ☐ | Hidden system response | ☐ | Mindset (tuned to see) |
| ☒ | **Unexpected equipment conditions**<br>The environment to weld the spacers was tightly confined and difficult to reach. | ☒ | **Inaccurate risk perception (Pollyanna)**<br>Even after the welder informed his supervisor the welds would fail radiography the supervisor thought they would pass. |
| ☐ | Lack of alternative indication | ☐ | Mental shortcuts (biases) |
| ☒ | **Personality Conflicts**<br>There were personality conflicts between the welder and the project installation supervisor. Conflicts also existed between the project installation supervisor and the engineers on the project. | ☐ | Limited short-term memory |