An Evaluation of the Relative Safety of U.S. Mining Explosion-Protected Equipment Approval Requirements versus those of International Standards

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Introduction

"Explosion protection" refers to techniques used to minimize the potential for electrical and electronic equipment to create an ignition while operating in a hazardous location (HAZLOC). In particular, U.S. coal mines are required to use equipment in certain areas of the mine that has been approved by the Mine Safety and Health Administration (MSHA) for use in a methane and coal dust environment to limit the risk of the equipment creating an ignition-capable spark or a thermal energy ignition. In general, MSHA's regulations for explosion protection recognize two techniques: the use of explosion-proof enclosures (XP boxes) and 2-fault intrinsic safety for electrical and electronic equipment.

For 2-fault intrinsically safe (IS) equipment, the U.S. mining industry requirements are unique in that the equipment is certified by MSHA. The criteria MSHA uses to evaluate equipment for intrinsic safety, as required by Title 30 of the Code of Federal Regulations (30 CFR) [30 CFR, Sections18.20(b), 18.68(a)(1), 19.1(b), 20.1(c)(2), 22.6, 23.6, and 27.20(a)], is published in a document referred to as ACRI2001 (1). Outside of U.S. underground mining, many industries and countries accept equipment that is designed to a consensus-based international standard (ANSI/ISA 60079-11 is the U.S. version). The purpose of this study is to provide an overall assessment of the ANSI/ISA 60079-11 standard on 2-fault intrinsic safety and the MSHA ACRI2001 acceptance criteria, and determine if the ANSI/ISA document can be an alternative to ACRI2001 while maintaining an equivalent or better level of safety for miners.

There are many drivers for this study. First, immediately after the 2006 MINER Act (2) was passed, there was a perception in the industry that the unique MSHA requirements were contributing to delays or restricting the availability of equipment to meet the requirements of the Act. Additionally, the MINER Act required that mine operators submit an accident response plan for MSHA approval, to be reviewed every six months. MSHA is required to determine if these plans reflect the most recent credible scientific research and make use of currently commercially available technology. There is a concern, as expressed in a recent National Academy of Science (NAS) study (3), that the unique requirements for U.S. mining may be limiting the technologies available to coal miners and technology options for mine operators. Accordingly, the study recommended that the National Institute for Occupational Safety and Health (NIOSH) and MSHA re-examine their technology approval and certification processes to ensure they are not deterring innovation, and explore opportunities to cooperate with other international approval organizations to harmonize U.S. and international standards without compromising safety. Lastly, the National Technology Transfer Act (NTTA) and the accompanying Office of Management and Budget's OMB-119 circular mandate the use of consensus-based standards by federal agencies. However, for U.S. mining operations, MSHA cannot accept such standards unless a determination is made that such standards provide an equivalent level of protection for the miner, per the requirements of the 1977 Mine Act, the 2006 MINER Act, and 30 CFR Part 18 regulations.

In determining if the ANSI/ISA 60079-11 consensus standard for intrinsic safety can be considered equivalent to the MSHA ACRI2001 criteria, there are several approaches useful for analyzing these two documents and their effect on the safety of miners in their workplace. One is to do a micro-comparative analysis of the two documents to identify specific differences and their relative effect on miner safety. A second is to do a broader comparison of the level of safety provided by all the currently permitted explosion-protected types of equipment and assess their relative contributions to miner safety. A third would be even a broader approach of performing a functional safety analysis of an entire mine operation. This would be a macro-approach considering all factors and their relative importance in contributing to the safety of miners. In these contexts, the documents in question play a diminishing role in the perceived safety of miners as the scope of the analysis broadens.

Since both documents address all of the criteria needed to evaluate a specific product to determine if it qualifies to be called intrinsically safe, NIOSH decided to use the micro-option and compare the two documents directly. To date, NIOSH has put forth considerable effort in performing a detailed comparison of the criteria given in the two documents (4). Since the ACRI2001 criteria and the ANSI/ISA 60079-11 consensus standard both are applicable to the same explosion-protection technique (2-fault intrinsic safety), it was hoped that any differences could be reasonably resolved. However, the exercise identified many differences with either document being more conservative than the other on a variety of issues.

The paper presented herein provides a conclusion regarding the level of protection that would be afforded the miner by accepting ANSI/ISA 60079-11, and focuses on three questions: What are the provisions of each document and how do the differences, as identified in the NIOSH-sponsored comparison, bear on mine safety? What provisions are in place to keep the documents current? What oversight is provided for equipment evaluated per the criteria in the documents? The third category needs to consider qualification of manufacturers, ongoing audits of manufacturers/products, and how changes to both standards and products are monitored and evaluated. In coming to its overall conclusion, the paper also considers alternative methods for comparing the level of protection, analyzes the integrity and currency of the standards, and discusses the oversight of standards implementation.

Evaluation of the Differences in the Requirements

To begin this evaluation, it is important to understand that both documents were developed from the same set of fundamentals, which is the essence of intrinsic safety as given in its definition, which states that electrical equipment and wiring designated as intrinsically safe shall be incapable of releasing sufficient electrical or thermal energy under normal or abnormal conditions to cause ignition of a specific atmospheric mixture. This definition raises three questions:

- How much energy will cause ignition?
- What are abnormal conditions?
- How is a hazardous atmospheric mixture defined?

All 2-fault intrinsic safety standards ever written on the subject were, in essence, providing the answers to these questions. Very simply, the energy question was answered with the development of the ignition test apparatus, abnormal conditions were defined as two faults each of low probability after which no ignition is possible, and finally, the gas mixture question was fortuitously answered by research showing that the gas groupings developed with tests for explosion-proof enclosures correlated directly with arc ignition so the existing classification system could be used. There was and still is universal acceptance of these answers. This is why, fundamentally, all such standards could be viewed as being the same but with differences in detail. The world at large has solved these detail differences by bringing intrinsic safety experts from all interested countries together via the International Electrotechnical Commission (IEC), where all the different issues have been fully debated, proposals voted on, and ultimately producing an IEC document on intrinsic safety, IEC 60079-11. This standard has been adopted by all participating countries and is available to all others who wish to use it. It has been adopted with national differences by the United States via the American National Standards Institute (ANSI) and the standards developers International Society for Automation (ISA) and Underwriters' Laboratories (UL). Furthermore, OSHA has recognized the current IEC 60079-11 standard for years.

Although the documents are similar in content having common roots, the comparative study showed many differences. As detailed in the unpublished comparative study by Homce et al., of the more than 360 sections in ACRI2001, 68 were not relevant since the study was limited to portable products, 188 were effectively equivalent, 44 were less restrictive, and the remaining 66 were perceived to be more restrictive than the ANSI/ISA 60079-11 standard. An analysis of these 66 items showed they were in 28 technical categories. Each of these categories was further analyzed as to their effect on safety. Of these, 11 were determined to be potentially substantive, but their effect on safety could not be readily established, while the remaining 17 were considered not to affect safety.

Discussions of these differences with MSHA representatives resulted in a need to further address the issues to determine if irrefutable evidence could be found that supported the ANSI/ISA document's criteria as providing at least the same level of safety. Although there was some success in tracing the roots of the criteria on two of the issues, as discussed later in the document, this demand was essentially impossible to fulfill as most of the criteria were developed forty to fifty years ago by standards developers who for the most part are no longer with us. Unfortunately, the supporting data and arguments for these criteria are not publicly archived and their whereabouts are unknown.

There is one significant difference between the documents that presents a compelling argument for equivalent protection by ANSI/ISA 60079-11, because the difference is directly related to the question of safety margins. In this case, the ACRI2001 document is less conservative. In both documents, the standard evaluation process to establish whether or not ignition is possible considers no faults (i.e., normal operation), the application of one fault, and the application of two faults producing the highest voltage/current levels. This provision specifies the application of safety factors applied to voltage or current to raise the maximum value of either to artificial levels as part of the evaluation. This in effect increases the energy in the circuit to a level that is the square of the factor applied to voltage or current because energy is proportional to the square of voltage and current. The international and the ANSI standard specifies a safety factor that is equivalent to 2.25 applied to available energy for the no-fault and one-fault analyses, and there still can be no ignition. By contrast, the ACRI2001 document specifies a safety factor that is equivalent to 1.5 applied to available energy for the same fault conditions, and is therefore clearly less conservative for the no-fault and one-fault analyses. For the 2-fault analysis, both documents apply a unity safety factor.

The difference in a safety factor of 2.25 and 1.5 as applied to energy is substantial. The U.S. standards prior to adopting the IEC 60079-11 criteria used the same safety factor as the current ACRI2001 document, but U.S. experts were unable to convince the IEC intrinsic safety committee that this was a reasonable consideration and hence established the more conservative safety factors in the latest version of IEC 60079-11. The difference in energy levels is significant because it is energy that is released in a spark that causes the ignition. U.S. experts at that time (as well as today) believed that the intrinsic safety criteria were already very conservative without using an excessive safety factor. This is very significant, for example, when considering allowable capacitance (which is a form of electrical energy storage) in an electrical circuit. If the maximum voltage is 10 volts, applying the IEC 60079-11 safety factor of 1.5 times voltage (2.25 times energy) for no-fault or one fault conditions to 10 volts brings the required voltage to 15 volts and the allowable free capacitance is greater than 80 µF, but less than 110 µF. Applying the ACRI2001 factor of square root of 1.5 times the voltage (1.5 times energy), the voltage becomes 12.25 volts and the allowable capacitance is greater than 1000 µF, but less than 2000 µF. The difference between an allowable capacitance using the IEC based safety factor of approximately 100 µF vs. the ACRI based safety factor of approximately 1500 µF is very significant in establishing if ignition is possible. Therefore, in this example the IEC 60079-11 standard is much more conservative than the ACRI2001 document. The large difference is due to the fact that the ignition curves are non-linear. The 10 volt figure is a real possibility as that value is similar to those used in battery operated personal communication devices such as PDA's or hand held communication radios (5).

If one were to look at short circuit current limits in resistive circuits or inductance (inductance is another form of energy storage) limits relative to available current, the results are similar. This more than any other factor strongly suggests that the two documents can be considered equivalent in evaluating the relative safety provided by one against the other, with the ANSI/ISA 60079-11 being considerably more conservative on this key provision.

In summary, based on the results of the micro-comparative analysis and consideration of the differences, it is the opinion of the authors that the two documents provide an equivalent level of protection for a miner when used as the basis for approval of portable equipment.

Alternative Methods to Compare the Level of Protection

<u>Equipment Protection Level Comparison</u>

An alternative way to view the level of protection afforded the miner is to consider the explosion protection that would be provided by equipment approved to the ANSI /ISA 60079-11 standard as compared to the level of protection by other allowable explosion-protection techniques in U.S. gassy mines. Historically, explosion-protection techniques have been divided into groupings based on the area within the plant or mine where they are allowed to be used. Techniques within each group are assumed to provide a sufficient level of protection suitable for the degree of hazard in that area (zone). This "zone approach" for grouping the equipment protection techniques has been in use for more than 50 years, but the technical justification for the groups is not well documented. To quote IEC 60079-0: “The installation standard, IEC 60079-14, allocates specific types of protection to specific zones, on the statistical basis that the more likely or frequent the occurrence of an explosive atmosphere, the greater the level of security required against the possibility of an ignition source being active.” More recently, the IEC refers to the groupings as “Equipment Protection Levels” (EPLs) and has provided more details as to the expected performance of the protection techniques for the various EPLs (6).

Hazardous areas are divided into zones based on the degree of hazard. As shown in table 1, the probability or frequency of the atmosphere becoming explosive defines the degree of hazard and hence the zone.

Table 1. Examples of zone designations and allowable explosion techniques

IEC/ISA and US NEC 505 Location designation	IEC/ISA and US NEC 505 Explosive Atm. (hrs/year)	IEC/ISA and US NEC 505 Techniques allowable	U.S. Mining Industry Location designation	U.S. Mining Industry Techniques required
Zone 0	Greater than 1000	IS - 2 fault Encapsulation	Inby last open	IS - 2 fault Explosion proof (XP)
Zone 1	Between 100 and 1000	IS - 1 fault Flameproof (XP) Powder fill Pressurization Increased safety Oil immersion	Outby last open	No protection required
Zone 2	Between 10 and 100	Non-incendive Non-sparking Limited energy Enclosed break Restricted breathing	Outby last open	No protection required
NRZ	Less than 10	No protection required	Outby last open	No protection required

In reference to table 1, Column 3 lists the explosion-protection techniques allowable in each zone. In terms of zone designations, Zone 0 is more restrictive than Zone 1, and Zone 1 is more restrictive than Zone 2. NRZ indicates a “No Requirement Zone,” meaning that no explosion protection is required. The values assigned to frequency of the atmosphere becoming explosive have never appeared in any standard or regulation, but experts agree that if numerical values were applied, these would be fairly representative. In practice, the areas which are required to be Zone 0, 1, and 2 are assessed somewhat subjectively as it is difficult to estimate the frequency with which an area might become potentially explosive. What is not shown on the table is that the IEC standards also allow combinations of Zone 2 explosion-protection techniques to improve the protection level of an equipment to make it acceptable for use in Zone 1 or Zone 0 (7).

The IEC standards recognize four zones (including the NRZ), which accommodate thirteen different explosion techniques. Table 1 provides some insight into the types of explosion-protection techniques that have become available over the years and the equipment design alternatives that might be introduced if the U.S. mining industry were to move towards IEC-based explosion-protection techniques. Of all the techniques, none of them have a better EPL than 2-fault intrinsic safety, but several of them have a better or equal EPL relative to XP enclosures.

The U.S. mining industry recognizes two areas that are similar in concept to zones. In U.S. coal mining, everything "outby" the last open cross-cut is treated as always non-explosive; therefore no explosion protection is required in that area. Everything "inby" the last open cross-cut is considered a potentially explosive area and generally requires either 2-fault IS or XP enclosure techniques in that area. It should be noted that ACRI2001 does allow encapsulation as part of an intrinsically safe system, but does not allow it as a stand-alone technique for higher power applications in the same manner as the IEC standards, so encapsulation is not included in the table for the U.S. mining industry.

Based on MSHA requirements, as shown in Table 1, XP enclosures are considered permissible for use "inby" in U.S. gassy mines. Referring back to the IEC/ISA zones, the XP enclosures are considered to provide an EPL that is less than the protection provided by 2-fault intrinsic safety based on the IEC historical groupings. XP enclosures enjoy a safety record of over billions of hours of operation worldwide. Even so, all other factors being equal, from an EPL perspective, 2-fault intrinsic safety is considered to be several orders of magnitude less likely to fail than XP enclosures (8).

In the context of equipment protection level, in addition to intrinsically safe equipment and equipment in XP enclosures, there is a special category that is neither of these, but is allowable in gassy U.S. mines (9). An example is a battery box that can weigh anywhere from less than 1,000 pounds to in excess of 4,500 pounds, which suggests a significant amount of enclosed energy. The criteria for such boxes are that they be robust, being made from cold rolled steel or other material that has similar strength characteristics. The enclosure may have an insulating cover that would have to withstand pre-conditioning and impact tests. There are spacing requirements for exposed electrical parts such as terminals. Internal insulation is required on the cover if it is conductive as well as protective insulation as needed between batteries and the enclosure. The enclosure is required to have drains for water or electrolyte as well as significant vents for any gas emissions.

Although such an enclosure is robust, nevertheless it is not an XP enclosure and would allow methane gas to freely enter were it present. Further, even though there are no normally arcing or sparking parts inside, a loose terminal or other failure mode could generate a spark with significant energy (ignition-capable) that could be an ignition source for a methane cloud. Therefore, if the use of a battery box were analyzed, the EPL would be considerably lower than for an XP enclosure, and much less than 2-fault intrinsically safe equipment.

As can be seen from this example, if one were to use the EPL of the explosion-protection techniques currently allowed in underground coal mines as the basis for determining the equivalent level of "protection afforded the miner," one could argue that, for comparison's sake, the baseline level of protection afforded the miner is established by the EPL of XP enclosures and other accepted practices. **Therefore, 2-fault intrinsically safe equipment built to either standard would offer at least the equivalent level of protection, and in fact be greater than the current level of protection afforded the miner.** Under this approach, differences between the ACRI2001 acceptance criteria and the ANSI/ISA document, even those that appear to be substantive at the micro-level, would be inconsequential relative to the level of protection afforded the miner when viewed from this macro-comparative approach.

Functional Safety Analysis

A still broader view of the level of protection afforded a miner could possibly be arrived at through a functional safety analysis. A functional safety analysis is a semi-quantitative method of analyzing an entire system. The IEC has developed standards for this type of analysis such as the one for Safety Instrumented Systems IEC 61508, which provides guidelines for quantitative assessment of the Safety Integrity Level (SIL) of a system. This type of analysis is similar in intent to the level of protection afforded the miner evaluation, in that a code of practice can be compared to a desired safety level. However, in the case of a functional safety analysis, the comparison is made to a well-defined safety level involving calculable probabilities, rather than trying to compare it to a previous standard or code of practice for which a safety level was never quantified.

A functional safety analysis would represent the most complete analysis of all the factors that bear on the risk of an explosion, of which the EPL of the equipment is just one factor. Other factors include the frequency and duration of the atmosphere becoming explosive, the number of equipment and types in the potentially explosive atmosphere, the maintenance history of the equipment, the self-diagnostics capability of the equipment, how the mine is monitored for applicable explosion risks, how often and when the equipment is used, and other factors. Such an approach requires assessing the risk of each relevant part of the operational mine system and assigning numerical values to the risk (10). Obviously, the risk and the resulting numbers would vary amongst mines, and such mine-specific risk analysis is simply not a part of the current approach to mine safety analysis in the U.S.

In a functional safety analysis, the main risk factors are quantified wherever possible, in which case the non-quantified EPL ranking discussed previously would be replaced with a statistical-based numerical probability akin to the EPL. The concept that there is a numerical probability associated with the failure of a protection system is captured in various terms such as: 'Probability of Failure on Demand for a Safety Instrumented System'; or 'Probability of Dangerous Failure per Hour for Safety of Machinery' (11). It is generally recognized in the safety community that the probability of failure has a time dependency, such that the longer an equipment is in service without maintenance (that includes verification of the protection mechanism), the higher the probability of failure.[7] The nature of the time dependency is given by the following equation:

$$\text{PF is proportional to } 1 - e^{-t^{*}\text{lambda}}$$

where PF is the Probability of Failure and lambda is the failure rate, and t is the time in service since the system, subsystem, or component (in our case the explosion-protection mechanism) was verified to be working properly.

This equation captures the important role of maintenance and verification of explosion-protection systems as part of safety considerations. The equation suggests that an equipment with a relatively low failure rate (lambda), based on the design and component consideration, could actually have an unacceptably high probability of failure of the explosion-protection mechanism if the equipment is left in service for a long period of time (t) without verification and safety-related maintenance (perhaps because the equipment is designed without a means to verify the protection). Conversely, an equipment that may be considered to have a relative high failure rate (based on the explosion-protection technique and equipment design consideration) could conceivably have a very low probability of failure if the equipment has a means to readily verify the protection and the equipment is maintained and inspected often (such as XP enclosures in mines). This equation provides some insight into the pitfalls of focusing on the equipment standards without consideration of the broader operational mine considerations (such as time in service of the equipment) as a determination of the level of protection afforded the miner.

While a functional safety analysis approach would be new to mining, it involves well-established analysis techniques such as Layers of Protection Analysis (LOPA) and Fault Tree Analysis (FTA) that are in common usage within the safety engineering community (12). Additionally, there is one particular type of equipment that was the subject of a lawsuit and has subsequently been allowed for use “inby” the last open cross-cut for certain mines by MSHA that deserves discussion. In rendering their decision (13), MSHA and the court applied a non-quantitative thought process very similar to what would be involved with a functional safety analysis. The equipment involved was the electronic total stations for mine surveying. Prior to this decision, the use of mechanical transits and steel tapes were required, which presented no explosion-protection risk at all since there are no electrical components involved. By contrast, the electronic total stations are battery powered and do not have any certification or circuitry specifically designed for explosion protection. Therefore, from a purely EPL comparison, the equipment by itself could not possibly provide the same level of protection.

As would be the case with a functional safety analysis, MSHA and the courts considered broader aspects of the factors that affect the safety of the miners other than the equipment-level considerations. Although no certification of test data was presented, the arguments presented asserted that the equipment was non-sparking and non-thermal during operation (implying the same EPL as the IEC Non-incendive and Non-sparking standards would provide as listed in the Table 1), and that the use of these systems were essential to miner safety since the mechanical transits were no longer available. Further, it was successfully argued that if the mine only uses the equipment during non-mining periods and complies with certain stipulations, including continuously monitoring the atmosphere for methane, then the use of this equipment provides the same level of protection as the previous practice. This was a decision that was very difficult to make and came after many years of debate about the merits of the use of electronic stations, and the decision was ultimately forced by the court (14).

This case may very well be a harbinger of things to come as the U.S. coal market shrinks and correspondingly less electronic equipment manufacturers are willing to design and build equipment specifically for a criteria that applies only to U.S. underground coal mines.

Quantitative functional safety analysis may provide a more reasonable path forward in this regard, but would require extensive training and research in the area of quantified risk assessment, agreement on assumed failure rates and calculation techniques, and concurrence on acceptable levels of risk.

This discussion is important because it suggests that the line-by-line comparison of any two sets of intrinsic safety criteria and the exposing of differences between the two, whether they can be resolved or not, would have little impact on any subjective or quantitative approach to analyzing the safety of a mine system in terms of the probability of ignition. The detailed requirements given in the intrinsic safety criteria have little to no effect on these calculations because the fundamentals of the technique itself are the basis for the high level of safety afforded by this approach. **Thus, a quantitative systems engineering approach to assessing the safety or level of protection afforded a miner would consider the ACRI2001 acceptance criteria and the ANSI/ISA document equivalent as a de facto assumption for such analysis.**

Integrity and Currency of Standards

To make a standard truly effective, it must be developed and managed with an open process such as that described in the ANSI document, "Essential Requirements: Due process requirements for American National Standards" (15). In this document, ANSI asserts that due process consists of nine elements that apply to any activities related to the development of consensus for approval, revision, reaffirmation, and withdrawal of American National Standards (ANS). In this case, due process means that anyone having a direct and material interest in the subject has the right to present an issue and its justification, have that issue considered, and have the right to appeal. It is based on equity and fair play.

Some of the more important elements of due process include openness for participation, balance of interests including actively seeking participants to achieve balance, providing public notice to announce the opportunity for participation, conducting appropriate votes and providing evidence that a consensus was achieved, and being receptive to appeals and dealing with them in an appropriate manner. In relation to standards evaluation, exercising such due process in the development and maintenance of a document provides a large measure of assurance that the document is technically sound and that the opportunity to participate is afforded to those who are materially affected by the contents.

Another important aspect of standards development is ongoing maintenance to ensure their integrity and to keep them current by reflecting changes in technology as well as ongoing research results that justify altering any of the criteria in such standards. For example, all consensus standards recognized by ANSI must be reviewed at least every five years to ensure that the document is current and the criteria within are valid.

The MSHA process for generating documents such as ACRI2001 is internal to MSHA and does not include inviting participation from others outside of MSHA who may be materially affected, although MSHA draws heavily on ANSI/ISA documents in its update process. Internal procedures direct appropriate levels of management to initiate the development of such documents as well as for ongoing maintenance of existing documents. The nature and frequency of the review process for existing documents is at the determination of appropriate management levels but is not supposed to exceed 5 years between such reviews (16). Approval of the results of any such work is also relegated to internal management.

The open, inclusive, consensus process with regular formal updates required for ANSI recognition ensures that the standard represents the best science available. By adopting the ANSI/ISA document the miners should benefit by having the best safety technology at the earliest available date.

Oversight of Standards Implementation

NIOSH has commissioned the preparation of a report, "Quality Assurance of Nationally Recognized Test Laboratories Using ANSI/ISA Standards for Certification of Intrinsically Safe Equipment" (17), which gives details of the ANSI and OSHA processes. As revealed in this report, the oversight performed on both standards writing organizations (such as the International Society for Automation (ISA) or Underwriter's Laboratories (UL)) and Nationally Recognized Testing Laboratories (NRTLs) that associate with American Standards Institute (ANSI) and the Occupational Safety and Health Administration (OSHA), respectively, is significant. For a standard to become recognized by ANSI, the writing organization is required to function against a rigorous set of procedures as set forth by ANSI. In addition, those testing laboratories recognized by OSHA as NRTLs, who use these same ANSI-recognized standards to evaluate products, are governed by an equally rigorous set of procedures administered by OSHA. Both the ANSI and OSHA systems require audits of these organizations, focusing in particular on the performance against the procedures.

If MSHA were to accept the IEC-based standard for evaluating intrinsically safe equipment, there are benefits that would accrue. For example, if a product had to be approved to both the IEC version and to the current MSHA criteria, it is likely the product designed to meet the MSHA criteria would be physically different from that designed to meet the ANSI/ISA IEC standard. The manufacturing process would have to accommodate both designs with one of them likely to be low volume (the MSHA version), resulting in higher manufacturing costs and a more expensive product. These costs would be avoided if a common standard were used.

Another significant benefit is the oversight of both the manufacturers and their permissible products conducted by the NRTLs. NRTLs perform quarterly audits at the manufacturers' facilities to ensure that the product being produced is exactly the same product that was found permissible. These audits review current production and the procedures used by the manufacturers to maintain control of the products. This is, of course, in addition to the oversight performed by MSHA. MSHA quality control auditing is focused not on the manufacturers but on the mining industry end-users. MSHA inspectors regularly inspect MSHA-approved equipment in service at operating mines and while it is being repaired at rebuild shops. MSHA engineers conduct random audits of new and repaired equipment at mine warehouses.

All of the above makes a powerful statement in the quest to ensure the safe operation of electrical equipment in the workplace, whether in mines or above-ground operations. If MSHA were to accept an IEC-based standard for evaluating intrinsically safe equipment, miners would benefit from an enhanced quality control program.

Overall Discussion of Specific Differences in the Standards

Historically, the several attempts to detail the root of the differences between the ACRI2001 acceptance criteria and the ANSI/ISA document have only emphasized the difficulties encountered in such an exercise. There are several reasons for this, but the primary one is the subjective judgements used where a sound technical basis could not be established for many of the detail requirements. Many of the requirements in the IEC intrinsic safety standard are technically supported, such as the energy required for ignition, but the major contributor to the differences are the issues where subjective judgement was used. Examples of this are numerous: Should the safety factor applied to circuit analysis be 1.5 times the voltage and/or current, or should it be 1.5 times the energy? or should the current in a circuit having a protective fuse rate the maximum current that can flow at 1.7 times the fuse rating, or the current required to blow the fuse within 2 minutes? These safety factors are similar, but fundamentally different, and either can be correct. The basis for most of the subjective criteria is lost in antiquity. Some of the issues can be traced, but for the most part the trail is not easily uncovered as many of the participants have died or have long since been retired and have no idea what became of the supporting documentation. Most of the information was in private files or even in public files that have either been stored in some obscure location or even discarded, since there were no rules about retaining such information.

What did happen is that a large number of recognized experts of the world assembled via an IEC committee addressing intrinsic safety, and these experts agreed to a set of criteria that may not have been perfect, but resulted in a conservative protection technique that has withstood the test of time. Many of these experts had to abandon requirements developed in their own countries in order to come to a consensus. It is difficult to comprehend that such a collection of experts could be wrong.

In considering the MSHA ACRI2001 document, it is clear that several of the subjective criteria were accepted, such as the spacing criteria applied between intrinsically safe and non-intrinsically safe circuits within an enclosure, or the thickness specifications for insulating materials, or the construction criteria for isolating components such as transformers.

One specific difference that was pursued is the temperature limit relaxation for small components. NIOSH commissioned an in-depth study of this issue that resulted in a report, "Evaluation of the Technical Basis for Specific Provisions of the ANSI/ISA Intrinsic Safety Standards, Report 1, Small Component Temperature Ratings" (18). The research uncovered specific test data of tests performed both in England and Germany, with accompanying analysis that clearly demonstrated that a large variety of small components including fine wire can be heated to temperatures considerably higher than the autoignition temperatures of all the gases that were tested. From this example, it is clear that the ACRI2001 requirements are extremely conservative when considering small electronic components.

A second issue given considerable study was the factor applied to fuse ratings for test purposes for components and circuitry beyond the protective fuse. NIOSH also commissioned a study of this issue, resulting in a report, "Evaluation of the Technical Basis for Specific Provisions of the ANSI/ISA Intrinsic Safety Standards -- Report 2, Fuse Factor Ratings and Other Issues" (19). In this case, the ANSI/ISA standard specifies a factor of 1.7 times the fuse rating to establish the downstream current to be used in testing, while the ACRI2001 document uses the current required to open the fuse in two minutes or less. This current is always at a higher level than when applying the 1.7 factor. The research into this was more obscure, but those involved in the process were able to provide the history. It was developed in England more than fifty years ago when several test programs were initiated to try to determine a reasonable factor to apply to fuses. The results were so highly variable that no technically sound conclusion could be drawn. The fuse experts at that time came to a subjective judgement that a 1.7 factor would be a reasonable compromise and would represent a conservative approach based on the data they had. This number was proposed in the standards at the time and accepted by the European standards committee and ultimately adopted in the IEC standard. Years of experience have demonstrated that the 1.7 factor is reasonable for the intended purpose of assessing thermal effects beyond the fuse. Literature addressing thermal ignition has always maintained that thermal ignition is a very inefficient process due the ideal conditions used to establish material auto-ignition temperatures vs. the conditions encountered in the normal environment. Because of the large difference in conditions, the practices in use are quite conservative when considering potential thermal effects.

To resolve the fuse current issue on a technical basis would require a carefully contrived test. As stated above, our predecessors who tried to devise such tests 50 years ago were unsuccessful, and it would seem that the prospects for success today would be no more likely than the earlier attempts. At best, it would require testing literally thousands of units and a variety of types to get some kind of data to be able to compare the 1.7 factor to the two-minute criteria. Fuse manufacturers today cannot accurately predict fuse responses except generally, which is why they provide time-current blowing characteristics in plots that represent a best statistical fit in the tests that they perform. Fuse technology is not precise in that the rupture current has a range based on several factors such as temperature, the characteristics of the element, and the nature of the current increase such as a slow rise as opposed to a spike.

These examples demonstrate that the issue-by-issue comparison of the two documents may well be an exercise in futility. Yes, there are differences, but within the intrinsic safety concept, they are essentially irrelevant in affecting the potential for ignition to occur. Equipment that has been certified as meeting the IEC intrinsic safety criteria have logged millions of safe hours of operation in atmospheres far more dangerous than those posed in mines (Groups A, B, and C gasses as opposed to methane, a Group D gas). Further, in the context of a total mine structure, intrinsically safe equipment that would be used in mines pales in the danger it presents as compared to all of the other equipment permitted in mines.

The exercise in futility is also due to the fact that the IEC criteria are based principally on European-developed standards because the initial draft was based on existing European practice at the time. There were actually few technical differences with North American practice with the exception of the safety factor issue – 1.5 on energy as opposed to 1.5 on voltage or current. The differences that did exist were principally based on practices steeped in local history. In North America, much of the routine test criteria such as dielectric strength tests or impact tests were taken from practices of UL or FM. These pretty much agreed with European practice as well.

As demonstrated in this report, from the overall perspective of miner safety the differences between the ACRI2001 criteria and the ANSI/ISA 60079-11 standard are rather insignificant. The work (opinions, knowledge, experience, etc.) of the individual intrinsic safety experts representing several countries, including the US, which resulted in the ANSI/ISA standard cannot to be discounted. These experts have thoroughly vetted and upheld the standard in repeated reviews.

Overall Findings Regarding Level of Protection

All of the evidence to date would strongly suggest that there is an equivalent level of safety for miners when either the ACRI2001 acceptance criteria or the ANSI/ISA document is used. For those areas where the IEC-based standard is less conservative, that delta is more than made up by the difference in safety factor applications where the ACRI2001 is far less conservative. **The additional benefits to be derived from the NRTL-based oversight and quality control, as well as the potential for increasing the equipment available for use in the mines and reducing approval times, suggest that the overall level of protection afforded by the miner will not be reduced, and may be improved, by accepting the ANSI/ISA 60079-11 standard for portable equipment, as an alternative to ACRI2001.** Because the scope of the micro-comparative study was restricted to stand-alone equipment, and it was used as the basis for our evaluation, the findings are restricted to portable equipment. However, the macro arguments presented herein apply to all IS equipment, and it is likely that with additional research our findings can be extended to other IS equipment.

The findings and conclusions in this report are those of the author(s) and do not necessarily represent the views of the National Institute for Occupational Safety and Health.

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