California State Fire Marshal
Information Bulletin

National Fire Protection Association (NFPA) Standards Council Decision Regarding Antifreeze in Residential Sprinkler Systems

Issued: August 16, 2010

At the August meeting of the National Fire Protection Association (NFPA) Standards Council meeting held in Boston, Massachusetts a final decision was made to issue the tentative interim agreements (TIA) 1000, 995, and 994 on NFPA 13, NFPA 13R and NFPA 13D, respectively to prohibit the use of antifreeze solutions within all NFPA 13D applications and within the dwelling unit portions of NFPA13 and NFPA 13R sprinkler systems. It is important to note that this agreement is NOT A REGULATORY NOR A CODE REQUIREMENT but an avenue to move discussion and research further that may lead to changes in regulation.

The NFPA Research Foundation conducted Phase I and II research and testing; and were part of the presentation to the Standards Council. A copy of that reports are available on the California Office or the State Fire Marshal (OSFM) www.osfm.ca.gov and NFPA www.nfpa.org websites. The Research Foundation reports provide insight into the factors influencing the impact of antifreeze use in residential fire sprinklers. The OSFM will be carefully reviewing all the factors of the reports and determining if regulatory adjustments are needed.

The nexus for the research by NFPA is based on two incidents involving antifreeze protected residential fire sprinkler systems under pressure in excess of 100 psi. The second phase report include two separate scope tests. The results of Scope A testing indicated that certain concentrations of propylene glycol- or glycerin-water solution have the potential to ignite when discharged through residential fire sprinklers systems. The potential for ignition depends on several factors including the propylene glycol- or glycerin-water solution, ignition source, sprinkler model, sprinkler elevation, and discharge pressure. The NFPA Standards Council believes that the research and testimony at the recent council meeting suggest that antifreeze solutions of propylene glycol exceeding 40% and glycerin exceeding 50% by volume are not appropriate for use in home residential fire sprinkler systems until research and testing are completed and vetted through the appropriate technical committees. The Standards Council also recognizes the need to limit the use of on-site mixing; when antifreeze is used, whereas the product should be factory pre-mix to obtain the correct concentration.

For existing residential fire sprinkler systems, the NFPA recommends draining the system and replacing with water only. Within California, this drained antifreeze and water mixture must be treated as waste water and be disposed of in accordance with appropriate waste water standards (please contact your local water purveyor for more information). Jurisdictions may use the latest testing report to evaluate methods to protect the water from freezing. As more information is released by NFPA, the Standards Council or the Technical Committee, the OSFM will notify all interested parties. As mentioned in the last OSFM information bulletin on this subject, The the sustained efforts of all stakeholders must focus on sharing information; working together; and continue to support the message that fire sprinklers are one of the most effective ways to save lives and property from fire; and to that end, assure the successful implementation of the 2010 California Residential Code and the residential fire sprinkler provisions.

For more information please visit our website http://osfm.fire.ca.gov

SC #10-8-15 thru 10-8-20
D#10-10

Amy Beasley Cronin
Secretary, Standards Council

16 August 2010

To: Interested Parties

Subject:

Standards Council Decision (Final):	**D#10-10**
Standards Council Agenda Item:	**#10-8-15 thru 10-8-20**
Date of Decision*:	5 August 2010
TIA Nos. 1000, 995, 994, 996, 997 and 998 on NFPA 13, 13D and 13R, all 2010 editions	

Dear Interested Parties:

At its meeting of 3-5 August 2010, the Standards Council considered an appeal on the above referenced matter.

Attached is the final decision of the Standards Council on this matter.

Sincerely,

Amy Beasley Cronin

Amy Beasley Cronin
Secretary, NFPA Standards Council

c: D. Berry, M. Brodoff, L. Fuller, J. Lake, J. Moreau-Correia
Members, TC on Residential Sprinkler Systems (AUT-RSS)
Members, TC on Sprinkler System Installation Criteria (AUT-SSI)
Members, TCC Automatic Sprinkler Systems (AUT-AAC)
Members, TC on Inspection, Testing, and Maintenance of Water-Based Systems (INM-AAA)
Members, NFPA Standards Council (AAD-AAA)
Individuals Providing Appeal Commentary

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*NOTE: Participants in NFPA's codes and standards making process should know that limited review of this decision may be sought from the NFPA Board of Directors. For the rules describing the available review and the method for petitioning the Board for review, please consult section 1-7 of the NFPA Regulations Governing Committee Projects and the NFPA Regulations Governing Petitions to the Board of Directors from Decisions of the Standards Council. Notice of the intent to file such a petition must be submitted to the Clerk of the Board of Directors within 15 calendar days of the Date of Decision noted in the subject line of this letter.

Standards Council Decision (Final):	**D#10-10**
Standards Council Agenda Item:	**#10-8-15 thru 10-8-20**
Date of Decision*:	5 August 2010
TIA Nos. 1000, 995, 994, 996, 997 and 998 on NFPA 13, 13D and 13R, 2010 editions	

SUMMARY ACTION: *The Standards Council voted to issue TIAs 1000, 995 and 994 on NFPA 13, NFPA 13R and NFPA 13D, respectively, which, for new installations, prohibit the use of antifreeze solutions within all NFPA 13D applications and within the dwelling unit portions of NFPA 13 and NFPA 13R sprinkler systems. In addition, the Council directed that the responsible technical committees conduct further activities as set forth in the decision.*

At its meeting of August 3-5, 2010, the Standards Council considered six proposed Tentative Interim Amendments (TIAs), together with related appeals, regarding antifreeze in new residential fire sprinkler installations. Two TIAs were submitted on each of the following documents: NFPA 13, *Standard for the Installation of Sprinkler Systems*, NFPA 13D, *Standard for the Installation of Sprinkler Systems in One- and Two- Family Dwellings and Manufactured Homes*, and NFPA 13R, *Standard for the Installation of Sprinkler Systems in Residential Occupancies up to and Including Four Stories in Height*. Of the TIAs, one group of three (TIAs 1000, 995, and 994) sought collectively to prohibit the use of antifreeze solutions within all NFPA 13D applications and within the dwelling unit portions of NFPA 13 and NFPA 13R systems (the "No Antifreeze" TIAs). The other group of three (TIAs 996, 997, and 998) sought collectively to prohibit the use of antifreeze solutions in excess of 50% by volume within all NFPA 13D applications and within the dwelling unit portions of NFPA 13 and NFPA 13R systems (the "50% Antifreeze" TIAs). These latter TIAs permitted only the use of factory premixed antifreeze solutions.

The six proposed TIAs were balloted through the responsible Technical Committees – the Technical Committee on Sprinkler System Installation Criteria for NFPA 13, and the Technical Committee on Residential Sprinklers for NFPA 13D and NFPA 13R – as well as the Technical Correlating Committee on Automatic Sprinkler Systems (the TCC). Balloting was completed in accordance with the NFPA *Regulations Governing Committee Projects,* but, as detailed further in this decision, the ballot results are of limited significance because of new technical data and information that has recently become available. The TIAs, ballot results, and several related appeals have nevertheless been forwarded to the Council for consideration. In this unusual and compelling situation, in which the status quo in the existing sprinkler documents is no longer tenable, and in which circumstances require emergency action, the Council has voted to issue three TIAs, the effect of which, pending further technical committee consideration, will be to prohibit the use of antifreeze within the dwelling unit portions of sprinkler systems.

BACKGROUND

Antifreeze solutions have long been used in sprinkler systems to protect piping in unheated areas subject to freezing temperatures. Since at least 1940, NFPA standards have included guidance on the use of antifreeze solutions in sprinkler systems. The events that led to the development of the proposed TIAs to limit or prohibit the use of antifreeze solutions in residential sprinkler applications began when the NFPA became aware of a fire incident in Truckee, California, which took place in August of 2009. Emerging information concerning this incident raised concern surrounding the combustibility of antifreeze solutions in residential sprinkler systems. The incident reportedly involved a grease fire in a kitchen where a sprinkler system with a reportedly high - possibly in excess of 70% - concentration of antifreeze deployed. The fire resulted in a single fatality and serious injury to another person, and the possibility was raised that the antifreeze solution discharging from the sprinkler intensified the fire and resulting harm.

In response to these reports, several activities were initiated within the NFPA and the NFPA-affiliated Fire Protection Research Foundation (the Research Foundation). These activities and especially the resulting reports of the Research Foundation will be described here only in brief, and the reader is urged to consult the Research Foundation reports available at www.nfpa.org/antifreeze for the presentation of the available research and analysis. With this caveat, it suffices to say, in outline, that the NFPA, in response to reports of the Truckee incident, commissioned the Research Foundation to conduct a literature review and develop a research plan on antifreeze solutions and residential fire sprinkler systems. A report on this project was published by the Research Foundation as "*Literature Review and Research Plan Antifreeze Solutions in Home Fire Sprinkler Systems,"* (prepared for the Fire Protection Research Foundation by Code Consultants, Inc., May 28, 2010) (the First Research Foundation Report). Meetings of the NFPA Technical Correlating Committee on Sprinkler Systems (the TCC) were also convened to review available information. During this period, Underwriters Laboratories (UL) conducted a series of tests in an effort to begin exploring the effect of antifreeze solutions in certain residential sprinkler configurations (the Phase I tests). The Phase I tests were not conducted as part of the Research Foundation activities, but several of the tests were witnessed by researchers working on behalf of the Research Foundation and are summarized in the First Research Foundation Report. The results of these Phase I tests were also presented at a meeting of the TCC. The results of these limited Phase I tests could not provide answers to all questions concerning the safe use of antifreeze solutions in residential sprinkler systems. They did point to serious concerns with the use of higher concentrations of antifreeze and were inconclusive as to the safety of antifreeze in lower concentrations of 50% by volume or less.

With the Phase I tests, the First Research Foundation Report and other available information, two sets of competing TIAs on antifreeze in residential sprinkler systems were developed and submitted by several parties. As summarized more fully above, the three No Antifreeze TIAs, prohibited the use of antifreeze solutions and the 50% Antifreeze TIAs prohibited the use of antifreeze solutions in excess of 50% by volume and required that only factory premixed solutions be used. The TIAs were submitted to the ballot of the responsible technical committees and the TCC. Five of the TIAs failed letter ballot of the technical committees. The No Antifreeze TIAs showed considerable support, including one TIA which failed by only a single vote. One of the TIAs, the 50% Antifreeze TIA on NFPA 13 did pass ballot. Unlike the balloting on the TIAs for NFPA 13D and NFPA 13R, however, the 50% Antifreeze TIA on NFPA 13 was balloted separately from the No Antifreeze option for NFPA 13, and it is not clear what effect the sequencing of the balloting on NFPA 13 may have had on the outcome.

The confusing and inconclusive ballot results may have stemmed from the limited nature of the data then available to the technical committees. The Council, however, need not undertake to analyze these TIA results in any depth because events have largely superseded them. Specifically the First Research Foundation Report had concluded that "the existing research as well as the recent near-term [Phase I] testing conducted by UL indicate the urgent need for further research into the effectiveness of currently permitted antifreeze solutions." This conclusion led to the development of a Phase II test plan to investigate in greater depth the potential for large-scale ignition of antifreeze solutions discharged from residential sprinklers and the influence of antifreeze solutions on the effectiveness of residential sprinkler systems in controlling a fire condition and maintaining tenable conditions for egress. With great rapidity, the Research Foundation mounted a project to fund and conduct the Phase II testing, with UL and Code Consultants, Inc. under contract to do the testing and to develop a report. However, even under the aggressive testing schedule, the test results did not become available until after the close of balloting on the TIAs. Indeed, the Phase II tests were completed just prior to the commencement of the Standards Council's August meeting and have now been published as "Interim Report: Phase II Research Antifreeze Solutions in Home Fire Sprinkler Systems, (Prepared for the Fire Protection Research Foundation by Code Consultants, Inc., August 11, 2010) (www.nfpa.org/antifreeze) (the Second Research Foundation Report).

At the Standards Council meeting, Steve Wolin, of Code Consultants, Inc., presented the Research Foundation reports, including the results of the Phase I and II tests. A hearing then proceeded to consider appeals and arguments as to what course of action the Council should pursue with respect to the TIAs. Rather than focus on the various arguments presented on the TIAs, the Council for purposes of this decision, focuses on some undisputed conclusions of the Phase II testing, namely that the existing provisions in NFPA 13, NFPA 13R and NFPA 13D, relating to antifreeze are no longer supportable as written. Specifically, current standards recommend the use of the antifreeze solutions, depending on the chemical being used and level of freeze protection being sought, to exceed 50% concentration, by volume, up to, in some cases, as much as 70%. See, e.g., NFPA 13, Table 7.6.2.2. The conclusions of the Research Foundation report, however, were clear this was no longer acceptable. Specifically, the new research from the Phase II testing clearly indicates that antifreeze solutions of propylene glycol exceeding 40% and glycerin exceeding 50% by volume are not appropriate for use in residential sprinkler systems, and the fire size increased (to some extent) for all the antifreeze solutions tested under certain sprinkler discharge and fire test conditions. Moreover, although these concentrations met UL 1626 fire control criteria and exhibited similar performance to that of water alone, consideration must also be given to adding appropriate safety factors for concentrations of these antifreeze solutions in the relevant standards. See Second Research Foundation Report at Executive Summary, pp. 1-2.

Given these conclusions, the Council must now determine how to proceed. At the hearing to consider the TIAs, several alternatives were suggested and advocated to varying degrees, including: take no action and refer the matter back to the responsible technical committees to review the new technical data from the Phase II testing and consider further appropriate action; issue the 50% Antifreeze TIAs; issue the No Antifreeze TIAs; or issue modified TIAs taking into account the test results reported by the Research Foundation.

In normal circumstances, the Council might well have delayed taking any action in order to give time to the responsible technical committees to review and take action based on the technical issues and new data presented by the Research Foundation reports. It is clear, however, from the discussion at the hearing, and from the complicated nature of the technical information that will need to be reviewed that consideration by the technical committees will require some time. Given the serious nature of the safety concerns related to the current concentrations of antifreeze permitted in existing NFPA standards, the Council believes that immediate action needs to be taken.

As to the actions that have been proposed, issuing TIAs that would merely limit antifreeze solutions to 50% by volume is not an adequate step. The Phase II test results showed that a 50% by volume limitation for propylene glycol is not appropriate, and, depending on what safety factors may be needed, may not be appropriate for glycerin either. The 50% Antifreeze TIAs, moreover, would allow 50% solutions of other antifreeze compounds including diethylene glycol and ethylene glycol, which have not been tested and may well require different limits. Given the circumstances, the Council does not believe it would be appropriate for the Council to issue the 50% Antifreeze TIAs.

Nor is it appropriate for the Council itself to craft and issue new TIAs that fully consider and address the technical issues raised by the Research Foundation data and other information now available. Crafting new TIAs is the province of the technical committees. In the interim, however, emergency action needs to be taken. This is not in dispute as the balloting on all the TIAs confirmed the emergency nature of addressing the existing antifreeze provisions concerning residential applications.

Considering the entire record before it, the Council has concluded that the most prudent course of action at this time must be the most conservative approach to assuring safety in new residential sprinkler installations. That course of action is to prohibit the use of antifreeze in new residential sprinkler systems unless and until the responsible technical committees, after due consideration and any correlation by the TCC, reach consensus on a different approach. Accordingly, the Council has voted to issue the three TIAs 1000, 995 and 994 on NFPA 13, NFPA 13R and NFPA 13D, respectively, that prohibit the use of antifreeze solutions in new residential sprinkler applications.

In reaching this decision, the Council wishes to make several points. First, the Council's action follows on previous action already taken by the NFPA. On July 6, 2010, the NFPA, separate from its standards development process, and acting in its role as a safety advocate, issued a Safety Alert responding to developing concerns about the use of antifreeze solutions in residential applications. The Safety Alert urged that, until further information was available, new residential sprinkler systems should be designed and installed so as not to require the use of antifreeze solutions. The TIAs now being issued merely extend this recommendation, pending any further consideration and action by the responsible technical committees.

Second, it should be noted that for 13R and 13D residential systems, sprinklers are not required to be installed in unheated areas. At any rate, the use of antifreeze should be avoidable in most if not all residential installations through alternative design approaches including the use of insulation and other means.

Third, the Council wishes to emphasize that in issuing the TIAs, it is not undertaking to make any final technical determination about the correct course of action that may eventually emerge. The technical issues concerning the content of NFPA codes and standards are generally for the responsible consensus based technical committees to determine, and the same should be true in this case. The Council’s action is an emergency action only, and is not intended to prejudge the merits of any further revisions that the responsible technical committees may propose. As to the technical committees’ further consideration of the technical issues, the record suggests that the Research Foundation reports and other information now available will require careful and considered review. This, of course, may take some time, but it is also possible that the technical committees may be able to act quickly to bring new recommendations to the Council. The Council urges the committees to address this matter with reasonable speed and provide clear technical substantiation for any further actions that are proposed. Should the committees do so prior to the Council's next scheduled meeting, the Council will make every effort to expedite its consideration of the matter through a special meeting or letter ballot.

The Council wishes to address two additional important matters beyond the scope of the present TIAs. First, the TIAs that were presented to the Council all involve standards that address the design and installation of new sprinkler systems. The important question of what should be done to address antifreeze in existing residential sprinkler systems is, therefore, not addressed by these TIAs. Fortunately, the NFPA in its July 6, 2010 Safety Alert has addressed existing systems. Specifically, the Safety Alert stresses that fire sprinklers are extremely effective protection devices, significantly reducing deaths, injuries and property loss from fire. It urges that these systems should not be disconnected and it recommends that the following actions be taken:

- If you have, or are responsible for, a residential occupancy with a fire sprinkler system, contact a sprinkler contractor to check and see if there is antifreeze solution in the system.

- If there is antifreeze solution in the system, as an interim measure, drain the system and replace it with water only. Problems associated with freezing of sprinkler pipes can be mitigated by alternative measures such as insulation. NFPA hopes to provide further guidance based on additional testing before the winter freezing months.

These recommendations and any updates that the NFPA may provide as a result of the Phase II testing (see www.nfpa.org/antifreeze for any updates as they may become available) provide important guidance on the handling of antifreeze in existing residential sprinkler systems. The responsible technical committees within the NFPA consensus codes and standards development process, however, should now review where and how relevant NFPA standards might be made to address antifreeze in existing systems. Relevant committees, including the Technical Committee on Sprinkler System Installation Criteria, the Technical Committee on Residential Sprinkler Systems, the Technical Correlating Committee on Automatic Sprinkler Systems, and the Technical Committee on Inspection, Testing, and Maintenance of Water-Based Systems, should consider this question in a coordinated manner and report back to the Council no later than its October 2010 meeting with any proposed actions or recommendations.

Finally, the actions taken in this decision do not address antifreeze in non-residential commercial applications. As the Research Foundation reports suggests, commercial sprinklers and occupancies present quite different characteristics than residential sprinklers and occupancies and, as the First Research Foundation Report suggests, any analysis of antifreeze in sprinkler systems is highly dependent on the specific characteristics of the sprinkler design and setting. The current activities, driven by clear concerns identified in residential sprinkler systems, have been a necessary response to an emerging problem. Further research will likely be necessary to better understand and address the use of antifreeze in various non-residential commercial settings. The role of the relevant committees in considering further standards development activities in this area and in recommending needed research is clear, and the Council is, therefore, requesting that they begin to review and consider the use of antifreeze in non-residential contexts and report back to the Council by its October 2010 meeting with any proposed actions or recommendations.

In conclusion, the Council wishes stress the importance of fire sprinklers in safeguarding lives and property. The home in particular is the place where most fire fatalities occur, and when home sprinklers are present, the risk of dying in a home fire decreases by 83%. It is hoped that the actions of the Standards Council, the valuable contributions of the NFPA and the Research Foundation, (including the project contractors, technical panel and sponsors), and the continuing activities of the sprinkler related NFPA technical committees will all combine to help ensure the continued effectiveness and wide use of these important safety devices.

Council Member Roland Huggins recused himself during the hearings, deliberations and vote on the issue. Council Members Shane Clary and Ralph Gerdes wished to be recorded as voting negatively.

Tentative Interim Amendment

NFPA 13

Standard for the Installation of Sprinkler Systems

2010 Edition

Reference: 7.6.1
TIA 10-1
(SC 10-8-16/TIA Log #1000)

Pursuant to Section 5 of the NFPA Regulations Governing Committee Projects, the National Fire Protection Association has issued the following Tentative Interim Amendment to NFPA 13, *Standard for the Installation of Sprinkler Systems*, 2010 edition. The TIA was processed by the Technical Committee on Sprinkler System Installation Criteria and the Technical Correlating Committee on Automatic Sprinkler Systems, and was issued by the Standards Council on August 5, 2010, with an effective date of August 25, 2010.

A Tentative Interim Amendment is tentative because it has not been processed through the entire standards-making procedures. It is interim because it is effective only between editions of the standard. A TIA automatically becomes a proposal of the proponent for the next edition of the standard; as such, it then is subject to all of the procedures of the standards-making process.

1. Add a new section 7.6.1 as follows:

7.6.1 Dwelling Units. Antifreeze shall not be permitted to be used within the dwelling unit portions of sprinkler systems.

2. Renumber the remainder of the section accordingly.

Issue Date: August 5, 2010

Effective Date: August 25, 2010

(Note: For further information on NFPA Codes and Standards, please see www.nfpa.org/codelist)

Tentative Interim Amendment

NFPA 13D

Standard for the Installation of Sprinkler Systems in One- and Two-Family Dwellings and Manufactured Homes

2010 Edition

Reference: 3.3.9.1, 4.1.4, 5.2.7, 8.3.3, and A.8.3.3.1
TIA 10-1
(SC 10-8-18/TIA Log #994)

Pursuant to Section 5 of the NFPA Regulations Governing Committee Projects, the National Fire Protection Association has issued the following Tentative Interim Amendment to NFPA 13D, *Standard for the Installation of Sprinkler Systems in One- and Two-Family Dwellings and Manufactured Homes*, 2010 edition. The TIA was processed by the Technical Committee on Residential Sprinkler Systems and the Technical Correlating Committee on Automatic Sprinkler Systems, and was issued by the Standards Council on August 5, 2010, with an effective date of August 25, 2010.

A Tentative Interim Amendment is tentative because it has not been processed through the entire standards-making procedures. It is interim because it is effective only between editions of the standard. A TIA automatically becomes a proposal of the proponent for the next edition of the standard; as such, it then is subject to all of the procedures of the standards-making process.

1. Delete 3.3.9.1 and renumber remainder of subsection 3.3.9.

2. Delete entire subsection 4.1.4, Antifreeze Systems.

3. Revise 5.2.7 to read as follows:
"Joints for the connection of copper tube for wet type systems shall be soldered joints or be brazed." (delete the words "and antifreeze systems").

4. Delete Item (2) of subsection 8.3.2 and renumber (3) as (2).

5. Revise section 8.3.3.1 to read:
8.3.3.1 Antifreeze shall not be permitted in sprinkler systems.

6. Delete A.8.3.3.1.

7. Delete all subsections and accompanying Annex A paragraphs commencing with 8.3.3.2 and ending with 8.3.3.5.

Issue Date: August 5, 2010

Effective Date: August 25, 2010

(Note: For further information on NFPA Codes and Standards, please see www.nfpa.org/codelist)

Tentative Interim Amendment

NFPA 13R

Standard for the Installation of Sprinkler Systems in Residential Occupancies up to and Including Four Stories in Height

2010 Edition

Reference: 4.7 and 5.4.3
TIA 10-1
(SC 10-8-19/TIA Log #995)

Pursuant to Section 5 of the NFPA Regulations Governing Committee Projects, the National Fire Protection Association has issued the following Tentative Interim Amendment to NFPA 13R, *Standard for the Installation of Sprinkler Systems in Residential Occupancies up to and Including Four Stories in Height*, 2010 edition. The TIA was processed by the Technical Committee on Residential Sprinkler Systems and the Technical Correlating Committee on Automatic Sprinkler Systems, and was issued by the Standards Council on August 5, 2010, with an effective date of August 25, 2010.

A Tentative Interim Amendment is tentative because it has not been processed through the entire standards-making procedures. It is interim because it is effective only between editions of the standard. A TIA automatically becomes a proposal of the proponent for the next edition of the standard; as such, it then is subject to all of the procedures of the standards-making process.

1. Add new sections as follows:

4.7 Antifreeze Systems. Antifreeze shall not be permitted within the dwelling unit portions of sprinkler systems.

5.4.3 Antifreeze shall not be permitted within the dwelling unit portions of sprinkler systems.

2. Renumber 5.4.3 as 5.4.4.

Issue Date: August 5, 2010

Effective Date: August 25, 2010

(Note: For further information on NFPA Codes and Standards, please see www.nfpa.org/codelist)

Antifreeze Solutions in Home Fire Sprinkler Systems

Phase II Research Interim Report

Prepared by:
Code Consultants, Inc.

THE FIRE PROTECTION RESEARCH FOUNDATION

Research in support of the NFPA mission

FIRE RESEARCH

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FOREWORD

NFPA 13, *Standard for the Installation of Sprinkler Systems*, has included guidance on the use of antifreeze solutions in fire sprinkler systems since the 1940 edition. Recent fire incidents, analysis of available literature, and preliminary testing have identified concerns with the use of certain antifreeze solutions. Under certain conditions, solutions of glycerin and propylene glycol antifreeze have been found to ignite when discharged from automatic sprinkler systems. A literature review, preliminary testing, and a long term research plan were developed as part of Phase I of this project. This Interim Report has been prepared to outline the results of Phase II of the project, which includes further testing of propylene glycol and glycerin antifreeze solutions for a range of concentrations and operating conditions.

The content, opinions and conclusions contained in this report are solely those of the author.

THE FIRE PROTECTION RESEARCH FOUNDATION
Research in support of the NFPA mission

Project Technical Panel

Home Fire Sprinklers and Antifreeze Solutions

Phase II

Magnus Arvidson	Swedish Testing and Research Center
Elizabeth Buc	Fire and Materials LLC
Scott Futrell	Futrell Fire Design and Consult
Tonya Hoover	CAL FIRE – Office of the State Fire Marshal
Garner Palenske	Schirmer Engineering
Maurice Pilette	Mechanical Designs Inc (chair of NFPA 13D)
Noah Ryder	Packer Engineering
Joe Senecal	Kidde Fenwal
Pete Willse	XL Insurance
Jim Lake	NFPA Staff Liaison

Contractors

Steve Wolin	Code Consultants, Inc.
Kerry Bell	Underwriters Laboratories Inc.

Sponsor Representatives

Chris Dubay	NFPA
James Golinveaux	Tyco Fire Suppression and Building Products
Scott Franson	The Viking Corporation
Russ Fleming	NFSA
Roland Huggins	AFSA
Tom Multer	Reliable Automatic Fire Sprinkler Co.
Tom Wancho and Ken Swantek	Victaulic

Home Fire Sprinklers and Antifreeze Solutions
Phase II

Project Sponsors

National Fire Protection Association
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Tyco Fire Suppression and Building Products
Victaulic
The Viking Corporation

Contributing Sponsor

Reliable Automatic Fire Sprinkler Co.

Interim Report

Phase II Research
Antifreeze Solutions in Home Fire Sprinkler Systems

Prepared for:

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CCI Project No. 100138.04.001

August 11, 2010

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Executive Summary

NFPA 13, *Standard for the Installation of Sprinkler Systems*, has included guidance on the use of antifreeze solutions in fire sprinkler systems since the 1940 edition. [1] Antifreeze solutions may be used in fire sprinkler systems where the piping system, or portions of the piping system, may be subject to freezing temperatures. [2] Antifreeze solutions permitted for use in sprinkler systems connected to potable water supplies include propylene glycol and glycerin.

Recent fire incidents, analysis of available literature, and preliminary testing have identified concerns with the use of certain antifreeze solutions. Under certain conditions, solutions of glycerin and propylene glycol antifreeze have been found to ignite when discharged from automatic sprinkler systems. A literature review, preliminary testing, and a long term research plan were developed as part of Phase I of this project. This Interim Report has been prepared to outline the results of Phase II of the project, which includes further testing of propylene glycol and glycerin antifreeze solutions for a range of concentrations and operating conditions.

A test plan was developed for Phase II to investigate the potential for large-scale ignition of antifreeze solutions discharged from residential sprinklers and the influence of antifreeze solutions on the effectiveness of residential sprinkler systems in controlling a fire condition and maintaining tenable conditions for egress. Testing was conducted in two parts. Scope A consisted of fire tests using six (6) models of sprinklers at elevations of 8 ft and 20 ft to investigate the potential for large-scale ignition of antifreeze sprays at pressures ranging from 10 psi to 150 psi. Scope B consisted of room fire tests, similar to UL 1626, that were designed to investigate the effective of sprinklers discharging antifreeze solutions and their ability to maintain tenable conditions.

Results of the Scope A testing indicate that concentrations of propylene glycol exceeding 40% by volume and concentrations of glycerin exceeding 50% by volume have the potential to ignite when discharged through automatic sprinklers. The potential for ignition depends on several factors including the ignition source, sprinkler model, sprinkler elevation, and discharge pressure. Ignition of antifreeze spray increased the measured heat release rate in certain tests with 50% propylene glycol and 55% glycerin by more than 300%. For certain test conditions, the increase in heat release rate resulting from the application of 55% glycerin solution exceeded the increase in heat release rate from the application of 50% glycerin solution by a factor of 10. A similar level of sensitivity was observed between 40% and 50% propylene glycol solutions, but not between 40% and 45% propylene glycol solutions.

The results of the Scope B testing indicated that concentrations of propylene glycol not exceeding 40% by volume and concentrations of glycerin not exceeding 50% by volume have similar performance to water as compared to the UL 1626 fire control criteria. Both the 40%

propylene glycol and 50% glycerin solutions met the UL 1626 fire control criteria and demonstrated similar performance to that of water alone throughout the series of tests.

The results of this research suggest that antifreeze solutions of propylene glycol exceeding 40% and glycerin exceeding 50% by volume are not appropriate for use in home fire sprinkler systems. Consideration should be given to an appropriate safety factor for concentrations of these antifreeze solutions that are permitted by future editions of NFPA 13. In addition, based on the flammability properties outlined in Table 4, the use of solutions of diethylene glycol and ethylene glycol in home fire sprinkler systems should also be limited unless testing is conducted to establish that they are appropriate for use in home fire sprinkler systems.

I. Introduction

Recent fire incidents raised questions regarding the effectiveness of antifreeze sprinkler systems in controlling residential fire conditions. As a result, the Fire Protection Research Foundation retained Code Consultants, Inc. (CCI) to perform a literature search and develop a research plan to investigate the impact of antifreeze solutions on the effectiveness of home fire sprinkler systems [3]. The literature review included the following subjects:

1. Antifreeze sprinkler system requirements
2. Mixing and separation of antifreeze compounds commonly used in sprinkler systems
3. Flammability of antifreeze solutions commonly used in sprinkler systems
4. Factors influencing the flammability of liquids, such as dispersion in droplets
5. Characterization of residential sprinkler sprays
6. Factors influencing the potential for flash fires or explosions from liquid sprays
7. Existing fire test data on the effectiveness of antifreeze solutions at controlling fire conditions
8. Fire incident reports involving antifreeze sprinkler systems

A research plan was developed to supplement the literature review in areas where existing information was limited. In addition, CCI observed a series of preliminary fire tests (Phase I) conducted by Underwriters Laboratories, Inc. (UL) to investigate the effectiveness of antifreeze sprinkler systems in controlling certain home fire scenarios. A summary of data from the preliminary testing was also provided by UL. [4] CCI provided suggestions for further research to provide a more complete analysis of currently permitted antifreeze solutions as well as to investigate other antifreeze solutions that could be used in sprinkler systems.

The Phase I testing identified the need for additional research regarding the potential for antifreeze solutions to create a large-scale ignition of spray when discharged through automatic sprinklers onto a fire. Additional research was also needed to further investigate the impact of antifreeze solutions on a sprinkler system's ability to control a fire condition and maintain tenable conditions. As such, a Phase II test plan was created based on the Phase I information.

The Phase II test plan was separated into two scopes (A and B) which were intended to investigate additional research identified in Phase I. Scope A tested antifreeze solutions for the potential to create a large-scale ignition of the spray when discharged through sprinklers onto a fire. Scope B tested antifreeze solutions for its impact on a sprinkler system's ability to control a fire condition and maintain tenable conditions.

II. Background

Recent fire tests have indicated the potential for ignition of certain antifreeze solutions discharged from automatic sprinkler systems.[4] The potential for ignition of an antifreeze spray and the influence of antifreeze solutions on sprinkler effectiveness involves several complex and contemporary research topics. This section provides a basic summary of relevant background information; a more complete discussion can be found in the report from Phase I of this project. [3]

A. Antifreeze Solutions

NFPA 13 [5], 13D [6], and 13R [7] each include substantially similar requirements for antifreeze solutions used in sprinkler systems. Antifreeze solutions of propylene glycol and glycerin with water are each permitted in sprinkler systems connected to potable water supplies. The antifreeze solutions are intended to protect sprinkler piping that passes through areas that could be exposed to freezing temperatures. Freezing point data for propylene glycol and glycerin solutions provided in NFPA 13 is summarized in the following table.

Material	Solution with Water (by Volume)	Specific Gravity at 60 °F (15.6 °C)	Freezing Point	
			°F	°C
Glycerin (C.P. or U.S.P grade)	50% glycerin	1.145	-20.9	-29.4
	60% glycerin	1.171	-47.3	-44.1
	70% glycerin	1.197	-22.2	-30.1
Propylene glycol	40% propylene glycol	1.034	-6	-21.1
	50% propylene glycol	1.041	-26	-32.2
	60% propylene glycol	1.045	-60	-51.1

C.P.: Chemically pure. U.S.P.: United States Pharmacopoeia 96.5%

Table 1: Adapted from NFPA 13 Table 7.6.2.2 Antifreeze Solution to be Used if Potable Water is Connected to Sprinklers

Antifreeze solutions of ethylene glycol and diethylene glycol are also permitted, but only in sprinkler systems that are connected to non-potable water supplies. This research focuses on propylene glycol and glycerin antifreeze solutions, because they are believed to be much more commonly used in home fire sprinkler systems.

Antifreeze solutions of glycerin, diethylene glycol, and ethylene glycol were included in NFPA 13 starting in the Appendix of the 1940 edition, known as National Board of Fire Underwriters Pamphlet No. 13 at the time. [1] The 1953 edition of NFPA 13 included requirements for antifreeze sprinkler systems in the body of the standard and permitted the use of propylene glycol or calcium chloride solutions as well as glycerin, diethylene glycol, and ethylene glycol. [8] The antifreeze solutions and concentrations permitted by the 1953 edition of NFPA 13 are the same as those permitted by the current (2010) edition of NFPA 13, with the exception that calcium chloride is no longer permitted. [2]

Table 2 (below) illustrates the freezing point and the specific gravity values (at 25°C) for a propylene glycol-water mixture in addition to the corresponding percent volume and percent weight of propylene glycol. The difference in percent volume and percent weight of propylene glycol solutions is minimal, because its density is only slightly higher than the density of water.

Propylene Glycol Properties			
% Vol.	% Wt.*	Freezing Point (°F)	Specific Gravity at 25°C
0%	0%	32	1.000
5%	5%	26	1.004
10%	10%	25	1.008
15%	15%	22	1.012
20%	20%	19	1.016
25%	25%	15	1.020
30%	30%	11	1.024
35%	35%	2	1.028
40%	40%	-6	1.032
45%	45%	-18	1.035
50%	50%	-26	1.038
55%	55%	-45	1.040
60%	60%	-60	1.041

*% Vol. to % wt. conversion is at 25°C

Table 2: Propylene Glycol Properties [9] (Portions of data are calculated or interpolated).

Similar to Table 2 (above), Table 3 (below) depicts the freezing point and specific gravity values (at 25°C) for a glycerin-water mixture in addition to the corresponding percent volume and percent weight of glycerin. Unlike the propylene glycol properties, the values for percent volume and percent weight vary significantly, because the density of glycerin is approximately 26% higher than the density of water.

Glycerin Properties			
% Vol.	**% Wt.***	**Freezing Point (°F)**	**Specific Gravity at 25°C**
0%	0%	32	1.000
5%	6%	31	1.014
10%	12%	28	1.029
15%	18%	25	1.043
20%	24%	20	1.059
25%	29%	16	1.071
30%	35%	10	1.087
35%	40%	4	1.100
40%	45%	-2	1.114
45%	51%	-11	1.130
50%	55%	-19	1.141
55%	60%	-31	1.155
60%	65%	-46	1.168
65%	69%	-40	1.179
70%	74%	-25	1.193
75%	79%	-8	1.207
80%	83%	6	1.217
85%	87%	19	1.228
90%	92%	36	1.241
95%	96%	49	1.252
100%	100%	63	1.262

*% Vol. to % wt. conversion is at 25°C

Table 3: Glycerin Properties [10] [11] [12] (Portions of data are calculated or interpolated)

As illustrated by the v-shaped curve in Figure 1 (below), glycerin-water solutions reach their maximum freeze protection at a concentration of approximately 60% glycerin by volume. A glycerin-water mixture that contains more than approximately 60% by volume glycerin will provide the same freeze protection as a less concentrated mixture. From a freeze protection standpoint, there is no reason to use a glycerin-water mixture that contains more than 60% glycerin by volume.

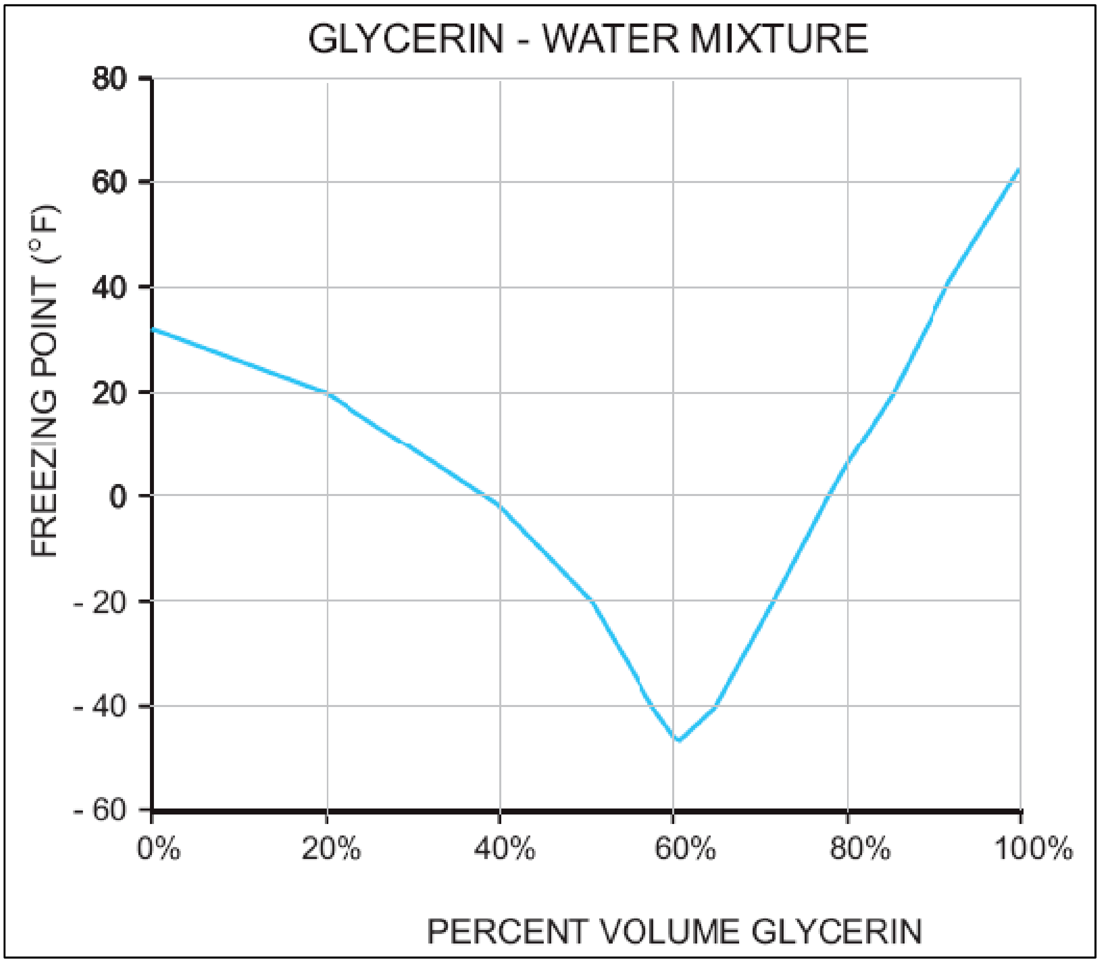

Figure 1: Freezing point of a glycerin-water mixture based on percent volume of glycerin

B. Flammability of Liquids

Liquids have many quantifiable flammability properties that vary depending on the type of liquid and the surrounding environment. The flash point is the temperature at which a liquid must be raised in order to produce sufficient vapors for flash ignition under specified test conditions. The flash point can be measured by one of many standardized test apparatus. Figure 2, below, illustrates an example of a closed-cup tester (ASTM D 93). The tester utilizes a heated stirrer (intended to maintain temperature uniformity) inserted into the test liquid. The test liquid is heated at a rate of approximately 41°F to 43°F per minute. The tester is capable of measuring the flash point of liquids between 174°F and 750°F. [13]

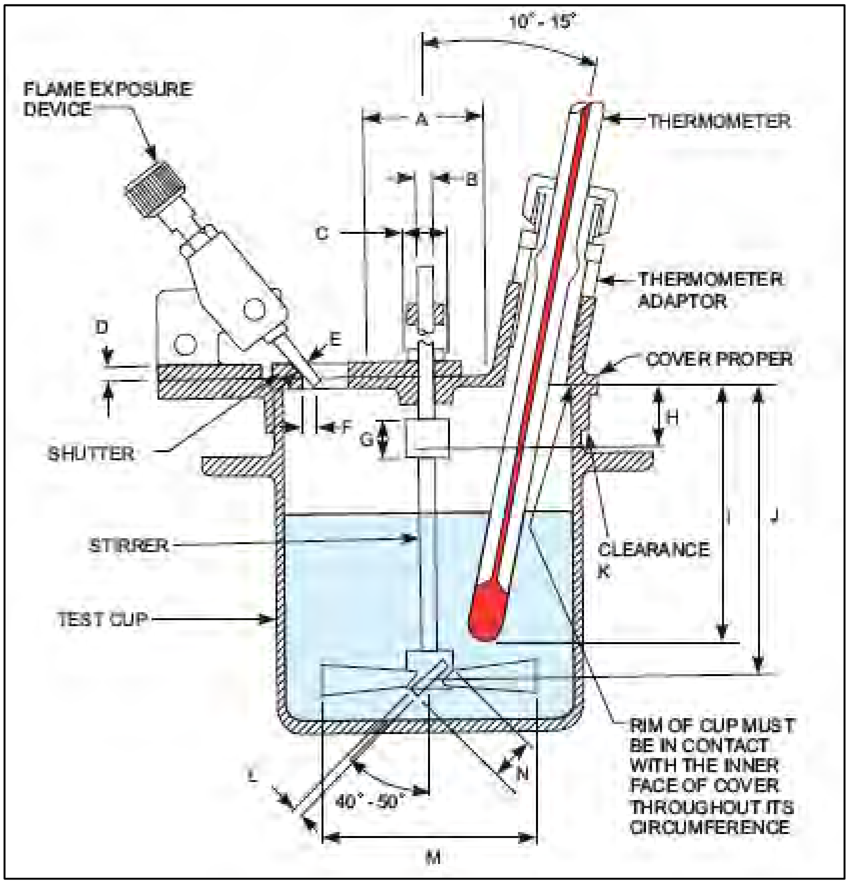

Figure 2: ASTM D 93 Pensky-Martens Closed-Cup (PMCC) Tester

Maintaining a liquid at a temperature below its measured flash point does not guarantee that ignition will be prevented. There are many factors that may influence a liquid's actual flash point. This is because the flash point of a liquid, as measured by test apparatus, is not necessarily the flash point of a liquid in its end-use environment. Liquids with flash point temperatures greater than the temperature of the environment of the liquid may sometimes be ignited by spraying, wicking or other means. Liquids that are mixtures, as opposed to pure substances, may demonstrate a tendency for vaporization of one component and not the other. The flash point of the remaining liquid may be different than that of the mixture when it was originally tested. [13]

At some temperature above a liquid's flash point temperature, an ignitable liquid's vapor can ignite without the presence of an ignition source. This is known as the autoignition temperature (AIT). There is no known relation between a liquid's flash point and its AIT. The AIT is primarily determined by a liquid's reactivity (rate of oxidation) while the flash point is determined by a liquid's volatility (rate of evaporation). Many factors may affect a liquid's AIT. Some known factors are the concentration of the vapor given off by the liquid, the shape and size of the container, the rate and duration of heating, and the test method. [13]

Figure 3 below is an example of a test method used to measure the AIT of liquids (ASTM E 659). In this method, the testing vessel is a glass flask surrounded by an electrically heated oven equipped with several thermocouples. During a test, a 0.1 mL sample of liquid is injected into the glass flask and is heated to a constant temperature while being observed for indications of ignition. Once the AIT is observed, both larger and smaller amounts of liquid are analyzed to determine the overall lowest AIT. [13]

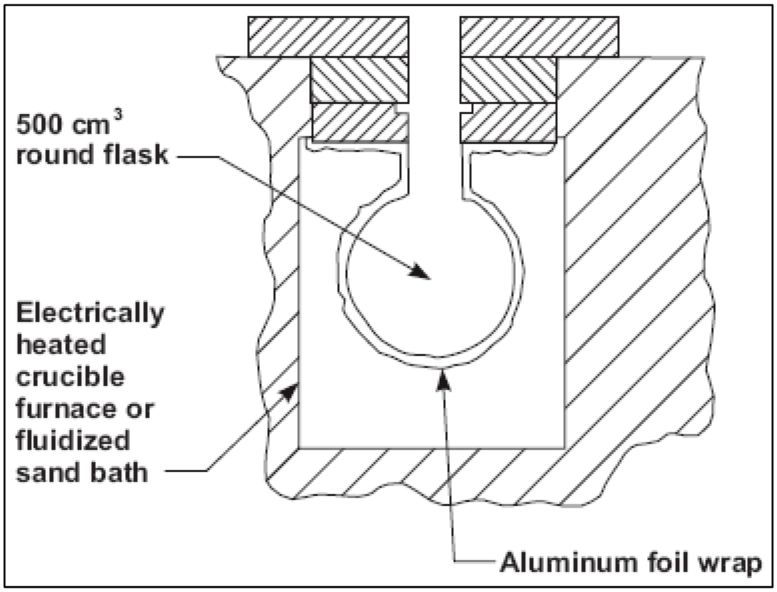

Figure 3: ASTM E 659 Autoignition Test (Setchkin Flask Test)

Flammable substances may also have an upper flammability limit (UFL) and lower flammability limit (LFL). The UFL is the highest concentration (or lowest in the case of LFL) of gas or vapor of the liquid in air capable of producing a flash fire in the presence of an ignition source.

The following table summarizes flammability properties of chemicals permitted for use in antifreeze solutions by NFPA 13.

Chemical	Flammable Limits in Air (% by volume) Lower/Upper)	Flash Point (°F)	Autoignition Temperature (°F)	Boiling Point (°F)
Propylene Glycol	2.6 / 12.5	210	700	370
Glycerin	Not Provided / Not Provided	390	698	340
Diethylene Glycol	Not Provided / Not Provided	255	435	472
Ethylene Glycol	3.2 / Not Provided	232	748	387

Table 4: Flammability Properties of Pure Antifreeze Chemicals Permitted by NFPA 13 [14]

A suspension of finely divided droplets of flammable liquid in air can yield a flammable mixture that has many of the characteristics of a flammable gas/air mixture. These droplets have the potential to burn or explode. Researchers have observed that a 10 μm diameter droplet of flammable liquid behaves like a vapor with respect to burning velocity and LFL. Droplets with diameters larger than 40 μm behave differently. [15]

Flame propagation can occur at average concentrations well below the LFL. A flammable mixture can also form at temperatures below the flash point of a liquid combustible when atomized into air. Testing shows that with fine mists and sprays (particles less than 10 μm) the combustible concentration at the lower limit is about the same as that in uniform vapor-air mixtures. However, as the droplet diameter increases, the lower limit appears to decrease. It was observed that coarse droplets tend to fall towards the flame front in an upward propagating flame, and as a result the concentration at the flame front actually approached the value found in lower limit mixtures of fine droplets and vapors. [16]

Mists made up of coarser aerosols are capable of sustaining a flame at considerably lower fuel-air ratios than fine aerosols (vapors). The reason for this lies in the ability of the droplets to move in relation to the ambient air. Mists made up of coarser aerosols prove to be more responsive to acceleration and random movement than that of finer aerosols. As such, coarser aerosols communicate flame more readily. [15]

In the case of water-glycols, flash points will not exist until the excessive water has been removed. Research indicates that a high-temperature environment is required to realize a flash point hazard with the vapors of these fluids at normal pressure conditions. [17]

In pure form, propylene glycol and glycerin are Class IIIB Combustible Liquids. As discussed above, existing research and testing suggests that the combustibility characteristics of antifreeze-water mixtures in droplet form are not completely characterized by standardized test methods for flash point or autoignition temperature. As such, these methods are not a reliable indication of the potential for ignition of a liquid dispersed into droplets. Under certain conditions, atomized antifreeze-water mixtures can combust when sprayed onto an ignition source. Increasing the concentration of the antifreeze in the antifreeze-water solution increases the combustibility of the solution.

The discussion above describes the complexity of whether a certain antifreeze solution has the potential to ignite when supplied through automatic sprinkler systems. Existing research indicates that under certain conditions the energy released during a fire condition could increase upon interaction with certain antifreeze-water mixtures currently permitted by NFPA 13, 13D and 13R. [18] [19] Recent testing conducted by UL [4] demonstrates that, under certain conditions, a large-scale sustained ignition is possible from the discharge of certain sprinkler systems containing antifreeze solutions. The intent of the Phase II testing is to more completely investigate the potential for large-scale ignition of flash fires from antifreeze solutions and to investigate the impact on a sprinkler system's ability to control a fire condition and maintain tenable conditions.

C. Sprinkler Droplet Sizes and Distributions

Droplet sizes and distributions produced by automatic sprinklers have been studied using a variety of techniques. Measurements of the droplet sizes produced by automatic sprinklers are relatively complex because the droplet size distribution measured is expected to vary with several factors including:

- Position with respect to the sprinkler in three dimensions
- Sprinkler model
- Operating pressure/flow rate
- Liquid supplied to the sprinkler, e.g. water or antifreeze solution
- Surrounding air currents, including fire induced flows

Even with all of the variables above held constant, measurements include a range of droplet sizes and not a single uniform droplet size. Additionally, it is possible for sprinklers operating with identical k-factors and pressures to have different spray patterns. Sprinklers that have identical orifice sizes (k-factor) can have varying geometric parameters such as arms, deflectors or tines. Changes in any of these geometric parameters may substantially alter the droplet size and distribution. For example, the figure below illustrates sprinkler discharge from two sprinklers with the same k-factor operating under the same pressure, but with spray distribution patterns that are significantly different.

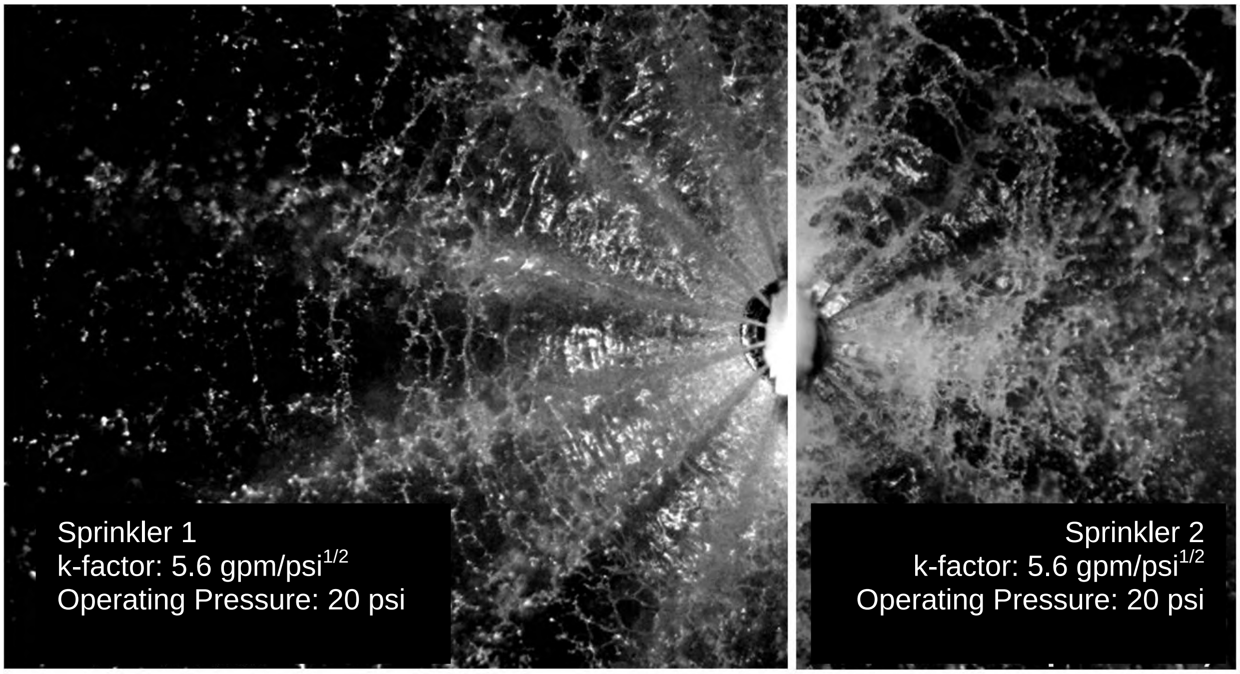

Figure 4. Spray distribution from automatic sprinklers. (Courtesy: Prof. André Marshall, University of Maryland)

Many of the existing methods are point measurement techniques that only measure data at a single point. Point measurement techniques are capable of measuring droplet size and velocity and work well for spherical droplets. However, sprinkler droplets are not always spherical.[20] In addition, point measurements must be taken at various locations in the sprinkler flow so that the results are temporally and spatially averaged. This limits measurement accuracy because fire sprinkler sprays are unsymmetrical and unsteady. Certain areas of the spray distribution are denser than others which may cause results to vary based on measurement locations. [20]

Studies of standard orifice, pendent spray fire sprinklers indicate droplet sizes between approximately 200 and 3,000 μm. [20] This approximation agreed with existing research which indicated that droplets larger than approximately 5,500 μm in diameter are unstable and break up into smaller droplets, predominantly in the range of 1,000 to 2,000 μm. [23] Previous research indicates that while a large number of very small drops are present, they comprise a small portion of the total water volume. Data indicates that 98% of the water from standard orifice fire sprinklers is contained in droplets larger than 200 μm in diameter. [16] A study of residential sprinklers measured water droplets ranging from an arithmetic mean of 200 to over 500 μm, depending on location. [21] However, droplets with diameters of less than 100 μm were measured. [21]

D. Phase I Testing

During Phase I of this project a series of preliminary tests were sponsored and conducted by Underwriters Laboratories. Tests were conducted in UL's large-scale test facility in Northbrook, IL and several of the tests were witnessed by CCI on behalf of the Foundation.

Initial tests were conducted with a small ceiling above an elevated pan of heptane using residential pendant sprinklers with nominal k-factors of 3.1 and 4.9 gpm/psi$^{1/2}$. The tests used premixed solutions of 70% glycerin and 60% propylene glycol with water. The tests indicated the potential for large-scale ignition of a 70% glycerin solution using a 3.1 k-factor sprinkler at an operating pressure of 100 psi. This large-scale ignition resulted in flames surrounding the majority of the sprinkler spray. A similar large-scale ignition did not occur for initial tests with 60% propylene glycol solutions or tests using a 4.9 k-factor sprinkler at an operating pressure of 50 psi.

Further tests were conducted in a three sided room measuring approximately 12 feet by 12 feet with a ceiling height of 8 feet. A single sprinkler with a k-factor of 3.1 was located in the center of the ceiling for each test. The majority of the room tests were conducted using a nominal 12-inch cast-iron pan with cooking oil as the initial fire source. An electric cooktop was used to heat the pan and ignite the cooking oil. One room test was conducted with a pan of heptane as the initial fire instead of the cooking oil. In various tests, the sprinkler was supplied with water only as well as premixed solutions of 70% glycerin, 50% glycerin, and 60% propylene glycol in water. Sprinkler operating pressures of 20, 100, and 150 psi were investigated.

Test results in the room configuration ranged from extinguishment of the fire to large-scale, sustained ignition of the antifreeze solution. Preliminary observations during the tests indicated that the results depend, at a minimum, on a combination of the following factors:

- Location of the initial fire with respect to the sprinkler
- Initial fire source
- Type of sprinkler and operating pressure
- Type and concentration of antifreeze solution

Large-scale, sustained ignition of the 70% glycerin solution supplied at 100 psi occurred when the initial fire was in close proximity to the sprinkler, but the initial fire was controlled using the same concentration of antifreeze at the same operating pressure when the initial fire was located farther from the sprinkler. Large-scale ignition of the 60% propylene glycol solution occurred in the room configuration during a cooking oil fire, but did not occur in the open configuration during a heptane fire. Large-scale ignition of the antifreeze solution did not occur in any of the tests with the 50% glycerin solution.

Preliminary observations during the UL testing indicate the following:

- Large-scale ignition of antifreeze solutions occurred in certain tests for 70% solutions of glycerin and 60% solutions of propylene glycol with water.
- Large-scale ignition of antifreeze solutions of 50% glycerin with water did not occur for any of the tested configurations.

Preliminary observations from the tests highlighted the need for further research into the effectiveness of currently permitted antifreeze solutions and consideration of their suitability for use in sprinkler systems.

III. Phase II Test Plan and Setup

The Phase II testing was intended to further study the potential for contribution of antifreeze solutions to fire conditions. The Phase II test plan was separated into two scopes. Scope A tested antifreeze solutions for the potential to create a large-scale ignition of the spray when discharged through sprinklers onto a fire. Scope B tested antifreeze solutions for their impact on a sprinkler system's ability to control a fire condition and maintain tenable conditions.

Tests were conducted with premixed solutions of propylene glycol and glycerin with water obtained from a single commercial distributor. Application of the test results is limited to the solutions tested and not to other formulations of antifreeze solutions that were not tested.

A. Scope A: Room Fire Tests for Spray Ignition using Sprinklers

Scope A was developed to investigate the potential for ignition of antifreeze solutions supplied by automatic sprinklers. The tests were designed to use a strong, continuous ignition source to identify whether flammable mixtures of antifreeze were created by the antifreeze spray. The tests used several models of residential sprinklers to investigate their impact of the potential for ignition.

Scope A tests were conduct without an enclosure, other than the walls and roof bounding the laboratory. As discussed in the report from Phase I of this project [3], the difference between a flash fire and an explosion is the degree of confinement of the flash fire. Because an explosion could not occur in this context without a flash fire, the flash fires themselves were used as criteria for the tests without the need to evaluate a resulting, enclosure dependant, explosion. While the test setup was designed to avoid explosions within the laboratory, the confinement of flash fires can produce over-pressurizations or explosions.

The test setup for Scope A is illustrated in Figure 5, below.

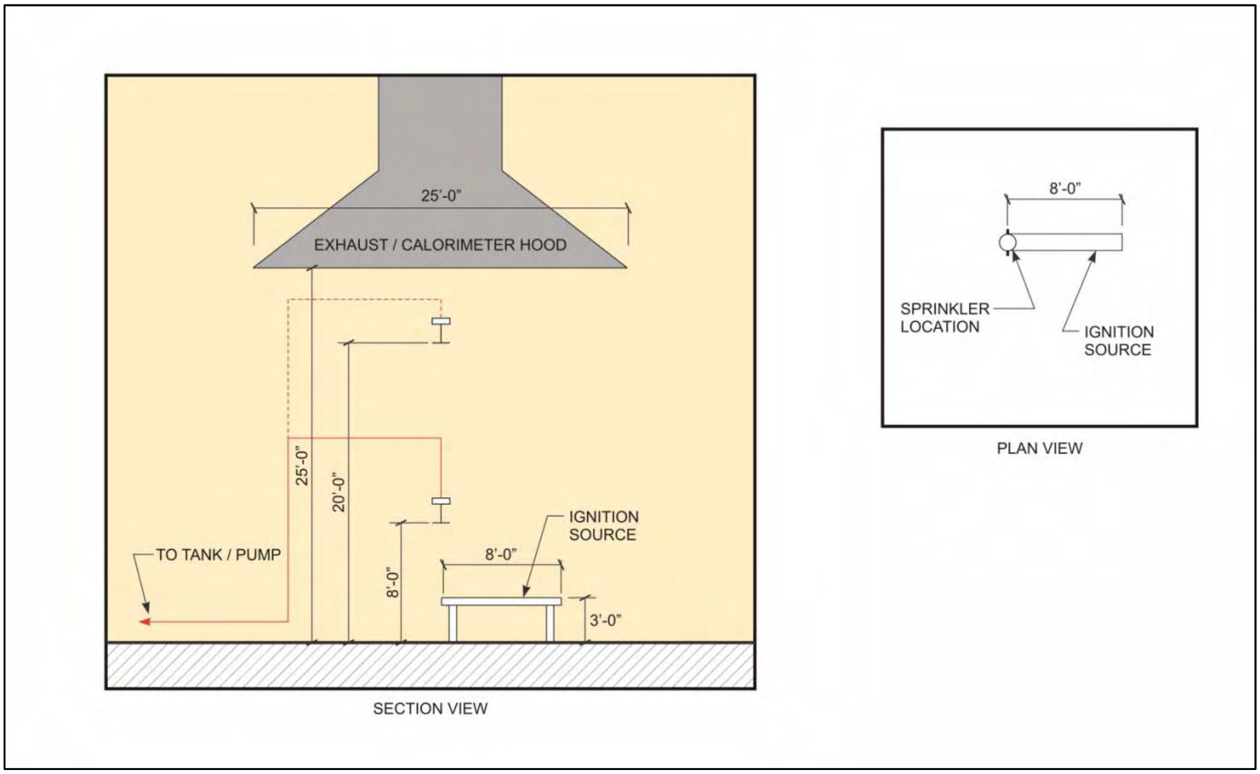

Figure 5. Scope A test setup.

The test setup included a long ignition source that was designed to extend radially from the sprinkler location. The long ignition source allowed a single test to investigate the potential for ignition over a range of locations within the spray pattern. The arrangement allowed for multiple sprinkler heights to be tested and data was collected to allow for heat release rate measurements using oxygen consumption calorimetry.

Initial testing was conducted to investigate appropriate ignition sources. Ignition sources investigated included:

- 6" wide and 12" wide rectangular pans of heptane extended radially from the point directly below the sprinkler.
- 4-nozzle heptane spray burners under a metal grate (the metal grate functions as a hot surface to vaporize antifreeze solution).
- Electric range heating elements (also functioning as a hot surface to vaporize antifreeze solutions).

Figure 6, below, illustrates each of the ignition sources investigated as part of Scope A.

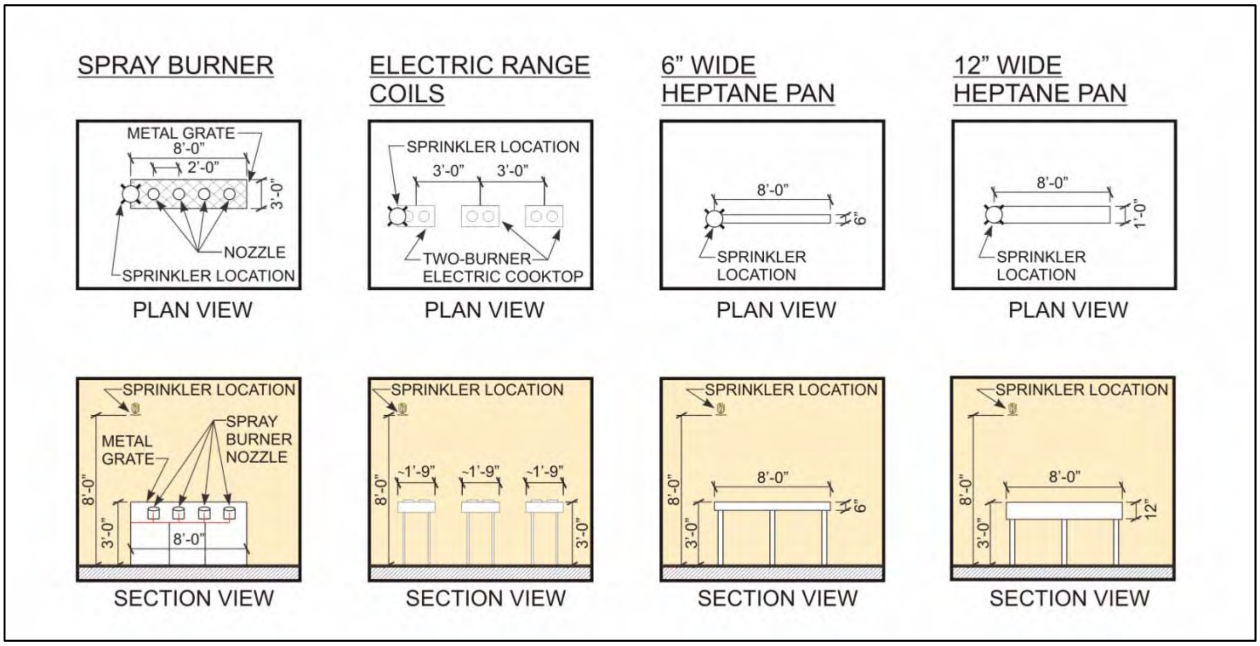

Figure 6. Scope A ignition sources.

The ignition sources are also shown in the photographs below.

6-inch Wide Heptane Pan

12-inch Wide Heptane Pan

Heptane Spray Burner Assembly

Electric Range Coils

Figure 7. Ignition source photographs.

Ignition sources were tested using solutions of 50% propylene glycol and 60% propylene glycol supplied from a residential pendant sprinkler with a k-factor of 3.1. Prior testing indicated that a 60% propylene glycol solution can be ignited when supplied from a k3.1 sprinkler. Thus, the ignition source selected should be capable of igniting the 60% propylene glycol solution supplied through a k3.1 sprinkler. It was unclear prior to the start of testing whether the 50% propylene glycol solution would be ignited.

The ignition sources selected for the Scope A testing are very unlikely to be extinguished during sprinkler activation. This is unlike most home fire conditions that would be expected to reduce in intensity upon the application of water. Some increase in heat release rate could be expected for the ignition sources, but observations of flash fires or ignition of the spray away from the fire source were considered an immediate failure. The initial testing was also intended to validate the use of a variable sprinkler operating pressure. Varying the sprinkler operating pressure allowed each test to collect data for a range of sprinkler operating pressures. This approach reduced the overall number of tests conducted and helped yield more complete results.

Following the initial testing, a series of tests was conducted to investigate the potential for ignition of select concentrations of antifreeze for the following variables:

VARIABLE	VALUES TESTED
Antifreeze concentration	• Propylene glycerol o 40%, 45%, 50%, 60% • Glycerin o 50%, 55%
Antifreeze temperature	• Ambient 80-90°F • Elevated 140°F
Sprinkler height	• 8 ft • 20 ft
Horizontal position of ignition source	Considered through the use of a long ignition source that extended radially from the sprinkler
Sprinkler operating pressure	10 to 150 psi (varied in 10 psi increments)
Sprinkler type and nominal k-factor	• Fixed deflector residential pendant (k3.1, k4.9, k7.4) • Drop-down deflector (concealed) residential pendant (k4.9, k5.8) • Residential sidewall (k4.2, k5.5)

The majority of the testing was conducted with solutions of 40%, 50%, and 60% propylene glycol as well as 50% glycerin. Select tests of 45% propylene glycol and 55% glycerin were used to evaluate the sensitivity of the results to the antifreeze concentration.

Ceiling heights of 8 ft and 20 ft were used to evaluate a range of residential applications. The 8 ft ceiling height is typical of many residential spaces and the 20 ft ceiling height is intended to account for a tall, double-height space in a residential occupancy. It was theorized prior to the initial testing that the atomization and dispersion of the droplets in the sprinkler spray would behave differently for varying ceiling heights. The initial testing confirmed that the spray distribution reaching the fire sources changes with the height of the sprinkler.

The Phase I testing demonstrated that the position of the ignition source within the sprinkler spray significantly impacted the potential for ignition of the spray. The long ignition source extending radially from below the sprinkler was used to allow a single test to generate data for a range of ignition source locations.

Data was gathered for a wide range of sprinkler operating pressures by varying the operating pressure during each test. The low pressure (10 psi) was intended to capture data near the minimum flow rates that would be permitted for the larger orifice sprinklers in the test plan. The high pressure (150 psi) was intended as a high pressure anticipated for a typical residential occupancy.

Due to the complex nature of the droplet size and sprinkler spray distribution produced during sprinkler discharge, several different types of sprinklers were selected for the Scope A testing. This approach was used to develop information on how changes in sprinkler geometry (deflector, arms and tines) and orifice size impacted the results.

B. Scope B: Room Fire Tests of Sprinkler Effectiveness

The Scope B tests were intended to investigate the effectiveness of residential sprinklers using an antifreeze solution compared with water alone. The Scope B tests were not intended to investigate the potential for large-scale ignition of the sprinkler spray.

The Scope B testing is similar to the UL 1626 fire test, with certain additional variables considered as outlined in the table below.

VARIABLE	VALUES TESTED
Antifreeze solutions	• 50% Glycerin • 40% Propylene glycol (single test) • Water alone
Ceiling height	• 8 ft

Sprinkler operating pressure/flow rate	• Minimum permitted flow based on NFPA 13D design criteria
	    o Pendant: 18 gpm one sprinkler / 13 gpm each for two sprinklers
	    o Sidewall: 24 gpm one sprinkler / 17 gpm each for two sprinklers
	• 80psi
	• 150 psi

Sprinkler type, temperature rating, and nominal k-factor	• Ordinary temperature fixed deflector residential pendant (k3.1, k4.9) • Ordinary temperature residential sidewall (k4.2)
Fire Source	• UL 1626 fuel package • Furnished living room (sofa, chair, tables)

The tests are designed to directly compare the performance of sprinkler systems supplied with antifreeze solutions to the performance of sprinkler systems supplied with water alone. The tests measured temperature at several locations within the room to evaluate tenability in accordance with the criteria specified in UL 1626. In addition, the test setup included sprinklers installed within the room that were designed to evaluate whether the fire condition would be expected to overwhelm the sprinkler system. Figure 8, below, illustrates the test setup for Scope B.

For the purposes of the Scope B testing, a ceiling height of 8 ft was used. This ceiling height was intended to represent that of a typical residential dwelling.

Similar to the Scope A tests, Scope B tests included multiple sprinkler operating pressures, but the pressure was not varied during each test. The low flow tests were intended to match the NFPA 13D criteria of 18 gpm for the activation of the first sprinkler and 13 gpm per sprinkler for the activation of two sprinklers. For the sidewall sprinklers a minimum flow rate of 24 gpm for the first sprinkler and 17 gpm per sprinkler for the activation of two sprinklers was required based on the listing of the sprinkler. Higher sprinkler operating pressures of 80 and 150 psi were also tested to evaluate their impact on the results.

A range of sprinkler types and models were tested in Scope B. Two sprinklers were located within the test room in accordance with UL 1626 to control the fire condition and a third sprinkler was located near the doorway to the enclosure, as illustrated in Figure 8, below, to investigate the potential for activation of sprinklers away from the area of fire origin. The test enclosure measured 8 ft by 16 ft by 8 ft high, which was within the listed spacing of the k4.9 and sidewall sprinklers. The enclosure was somewhat larger than the 14 ft by 14 ft listed spacing of the k3.1 sprinkler, which provided a severe test of the antifreeze solution.

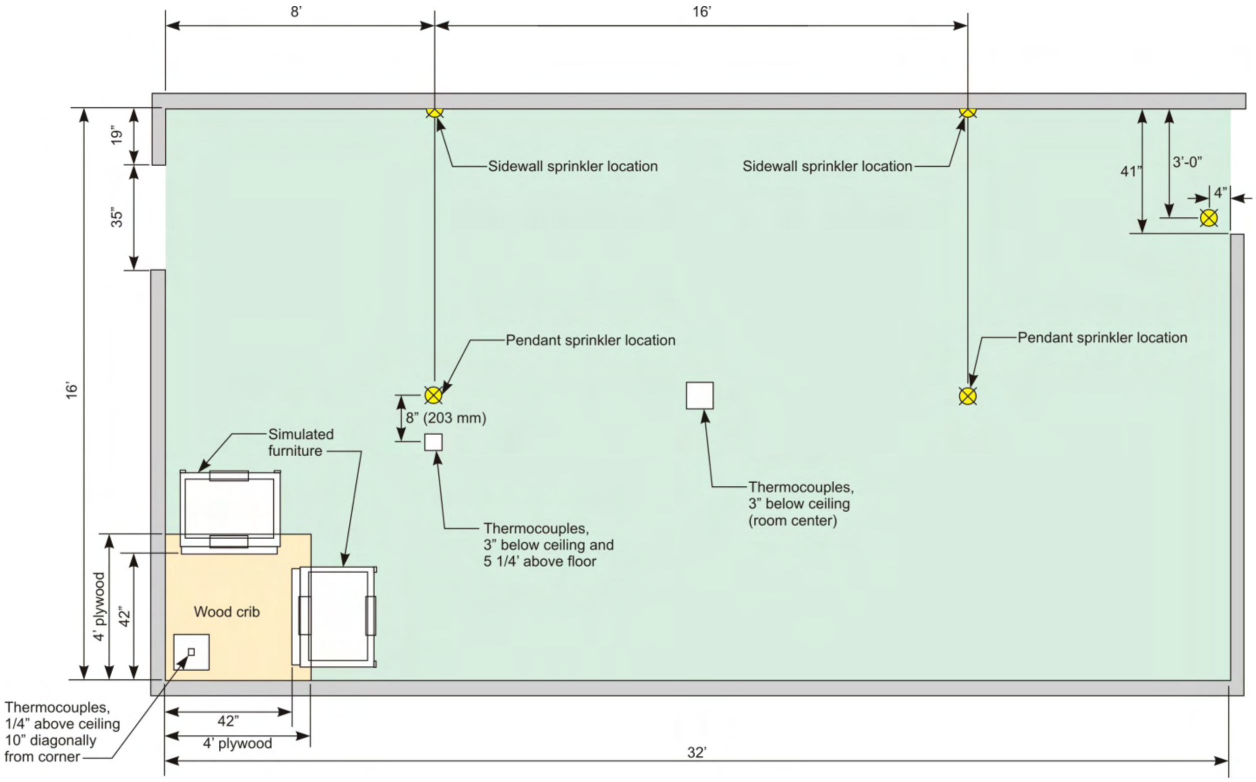

Figure 8. Scope B test setup.

The tests primarily used the fuel package specified in UL 1626 that consists of a wood crib ignited by a pan of heptane that is positioned adjacent to two simulated furniture ends. The potential for fire spread is evaluated by locating the fuel package in the corner of the room with walls covered with wood paneling. In addition to tests with the UL 1626 fuel package, a test was also conducted with a fuel package typical of a residential living room. The fuel package consisted of a sofa, chair, end table, and coffee table, along with a trash can filled with paper.

Failure criterion for the Scope B testing was based on the UL 1626 fire control criteria. Based on these criteria, residential sprinklers installed in a fire test enclosure with an 8-ft ceiling are required to control a fire for 10 minutes with the following limits:

1. The maximum gas or air temperature adjacent to the sprinkler 3 inches below the ceiling at two locations within the room must not exceed 600°F.

2. The maximum temperature 5 feet 3 inches above the floor at a specified location within the room must be less than 200°F during the entire test. This temperature must not exceed 130°F for more than a 2 minute period.

3. The maximum temperature ¼ inch behind the finished surface of the ceiling material directly above the test fire must not exceed 500°F.

4. No more than two residential sprinklers in the test enclosure can operate.

Any variation from the limits outlined above was considered an immediate failure. [24]

IV. Phase II Test Results

A. Scope A – Spray Ignition

Initial tests were conducted to investigate potential ignition sources. The tests used solutions of 50% and 60% propylene glycol to investigate the effectiveness of each ignition source in igniting antifreeze sprays. The following graph compares the increase in heat release rate due to ignition of 60% propylene glycol antifreeze spray for each of the ignition sources.

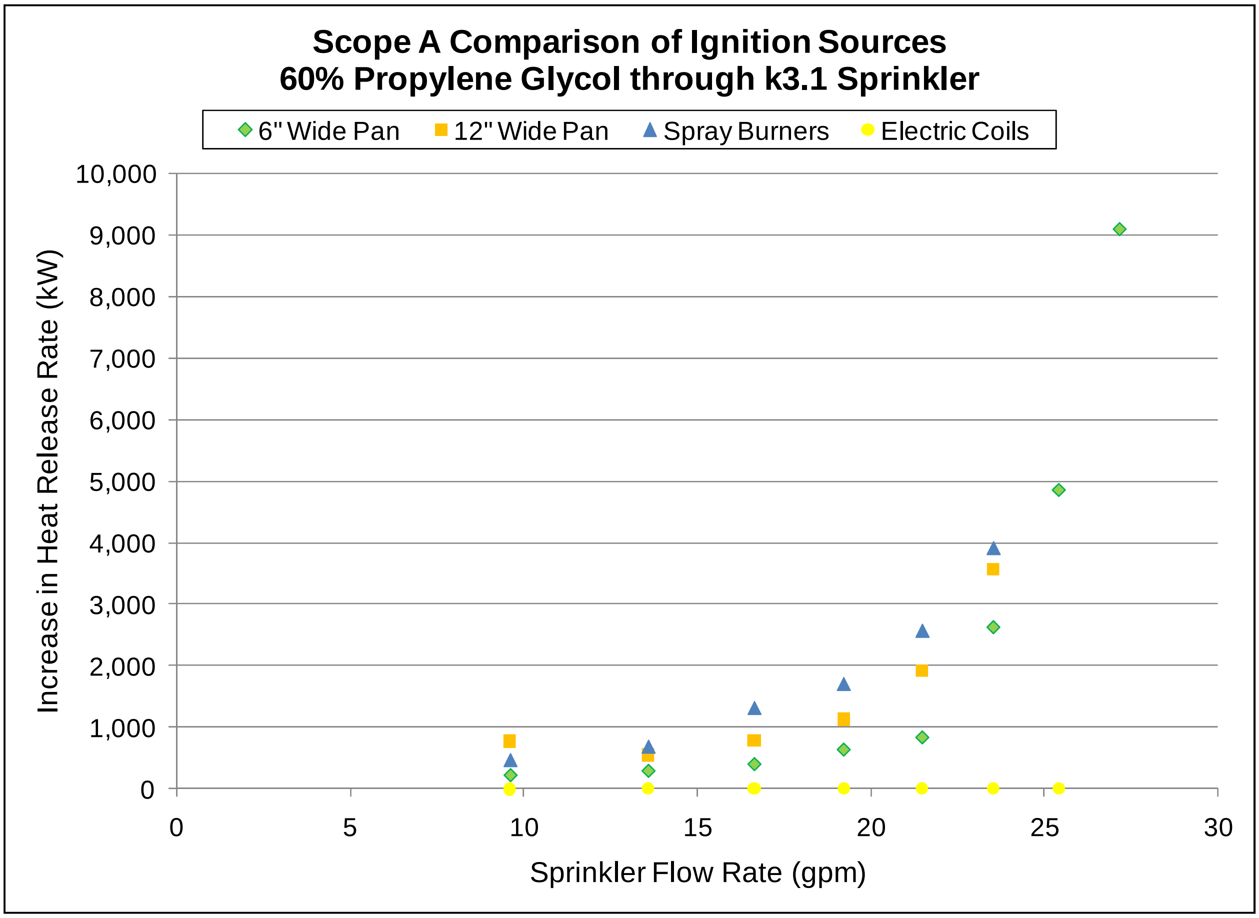

Figure 9: Scope A Comparison of Ignition Sources with 60% Propylene Glycol

Each of the ignition sources, with the exception of the electric range coils, was able to ignite the 60% propylene glycol solution. The increase in heat release rate from the spray burner assembly was somewhat higher than the other ignition sources at the same sprinkler flow rate. Note that the pan and spray burner tests were terminated early due to the size of the resulting fire condition.

Figure 10, below, shows the increase in heat release rate as a function of sprinkler flow rate for a 50% propylene glycol solution using each of the ignition sources that ignited the 60% solution.

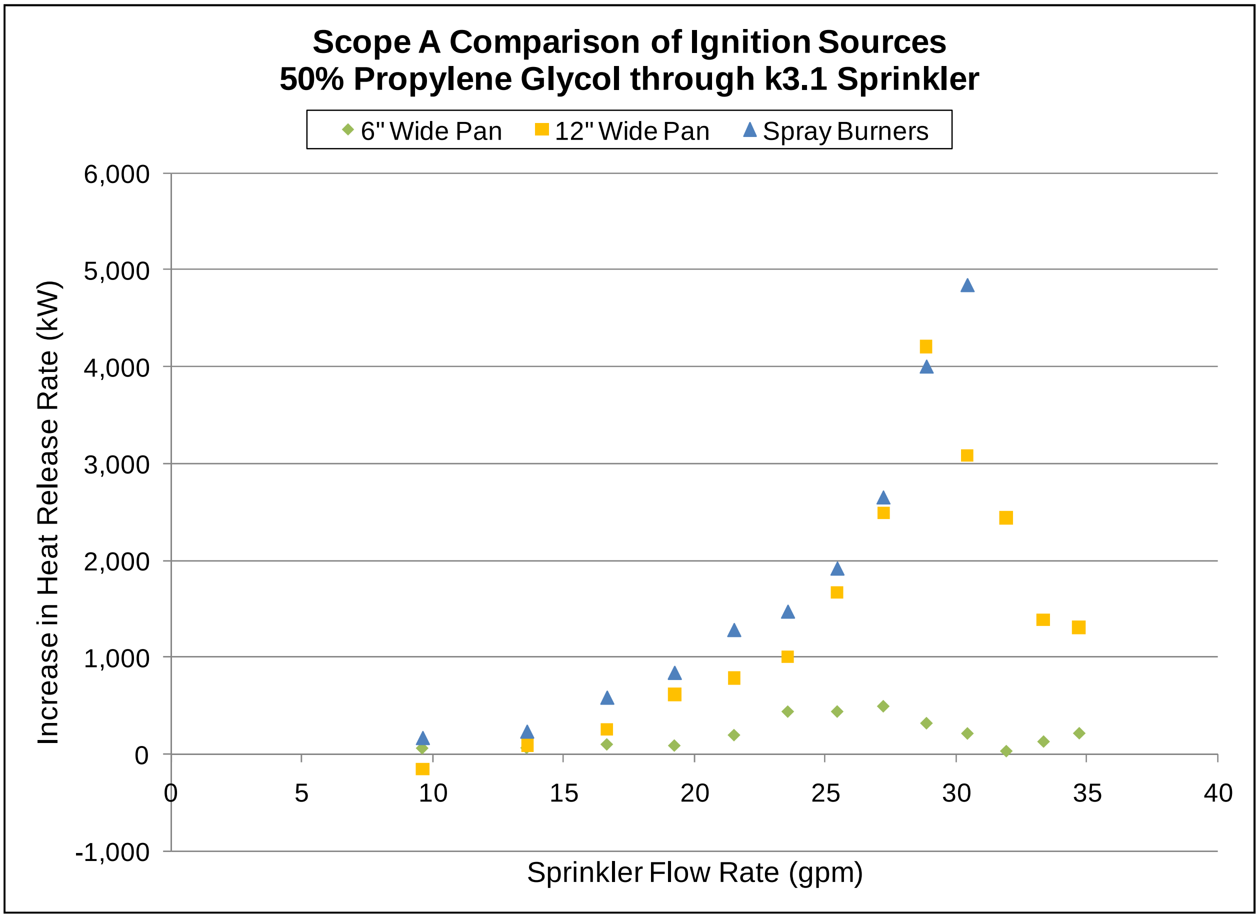

Figure 10. Scope A Comparison of Ignition Sources with 50% Propylene Glycol

The results with the 50% propylene glycol solution show significant differences between the ignition sources. There was very little increase in the heat release rate of the 6-inch wide heptane pan upon application of the antifreeze solution. The 12-inch wide heptanes pan had an initial increase in heat release rate, but higher sprinkler flow rates extinguished portions of the pan fire and reduced the heat release rate. The heat release rate of the spray burner increased throughout the test as the sprinkler flow rate increased.

The heptane spray burner was selected as the ignition source for the remaining tests based on its ability to efficiently ignite sprays of both the 50% and 60% propylene glycol solutions. As illustrated in Figure 10, above, the heptane spray burner represented the worst-case ignition source of those investigated, because it was not extinguished by the 50% propylene glycol solution. Additionally, the heptane spray burner produced a steady baseline fire size that increased the overall reproducibility and reliability of the ignition source.

Tests were conducted by lighting the heptane burners, adjusting the heptane flow rate, allowing for a 2 minutes of heating, and flowing antifreeze solution to an open sprinkler. The sprinkler operating pressure was typically varied during each test from 10 psi to 150 psi, unless the test was terminated early due to the growth of the fire condition.

The tests investigated the impact of several variables in causing ignition of antifreeze sprays.

1. Sprinkler

Tests of 50% propylene glycol solution were conducted for the full range of sprinklers investigated. The graph that follows shows the increase in heat release rate due to an antifreeze spray of 50% propylene glycol for the range of sprinklers.

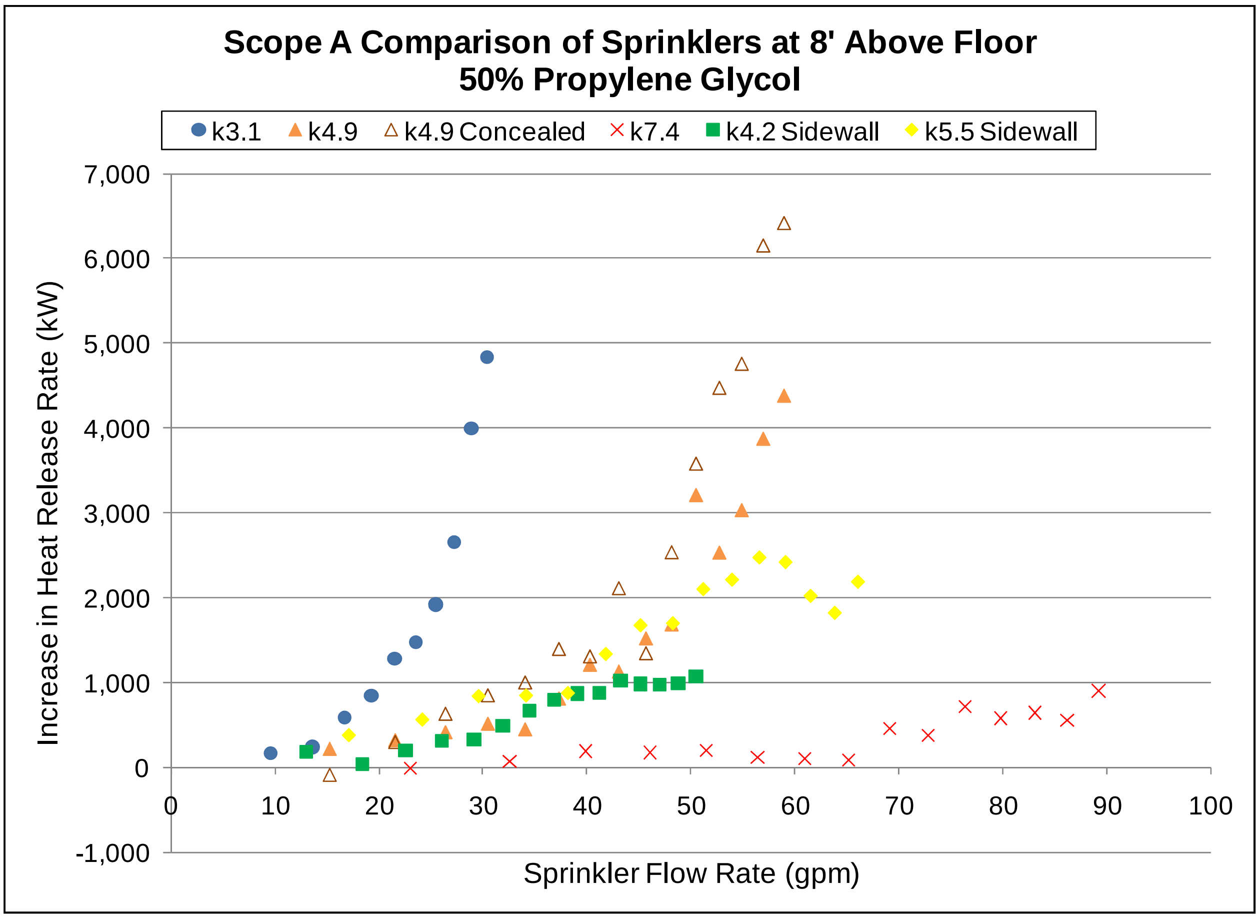

Figure 11: Comparison of Sprinklers at 8' Above Floor with 50% Propylene Glycol

The results presented in Figure 11, above, show that a 50% propylene glycol solution results in a significant increase in the size of the initial fire when supplied by certain sprinklers. Data for three of the six sprinklers tested shows an increase of more than 4,000kW or 300% in the heat release rate due to the application of 50% propylene glycol antifreeze solution depending on the operating pressure. Very little ignition of the spray was observed during the test with the k7.4 pendant sprinkler. The results for the two k4.9 pendant sprinklers show that the portion of the spray that is ignited can differ for sprinklers with the same k-factor. For example, at a flow of approximately 55 gpm the increase in heat release rate during the test with the k4.9 pendant sprinkler was approximately 3,000 kW compared with more than 4,500 kW in the test with a concealed sprinkler. Further testing primarily used the k3.1 and k4.9 concealed sprinklers based on the results outlined above.

2. Antifreeze Solution

Scope A tests were conducted for solutions of 40%, 45%, and 50% propylene glycol as well as 50% and 55% glycerin. Results of the tests are summarized in Figure 12, below, which shows the increase in heat release rate due to the application of each antifreeze solution using the same sprinkler and ignition source.

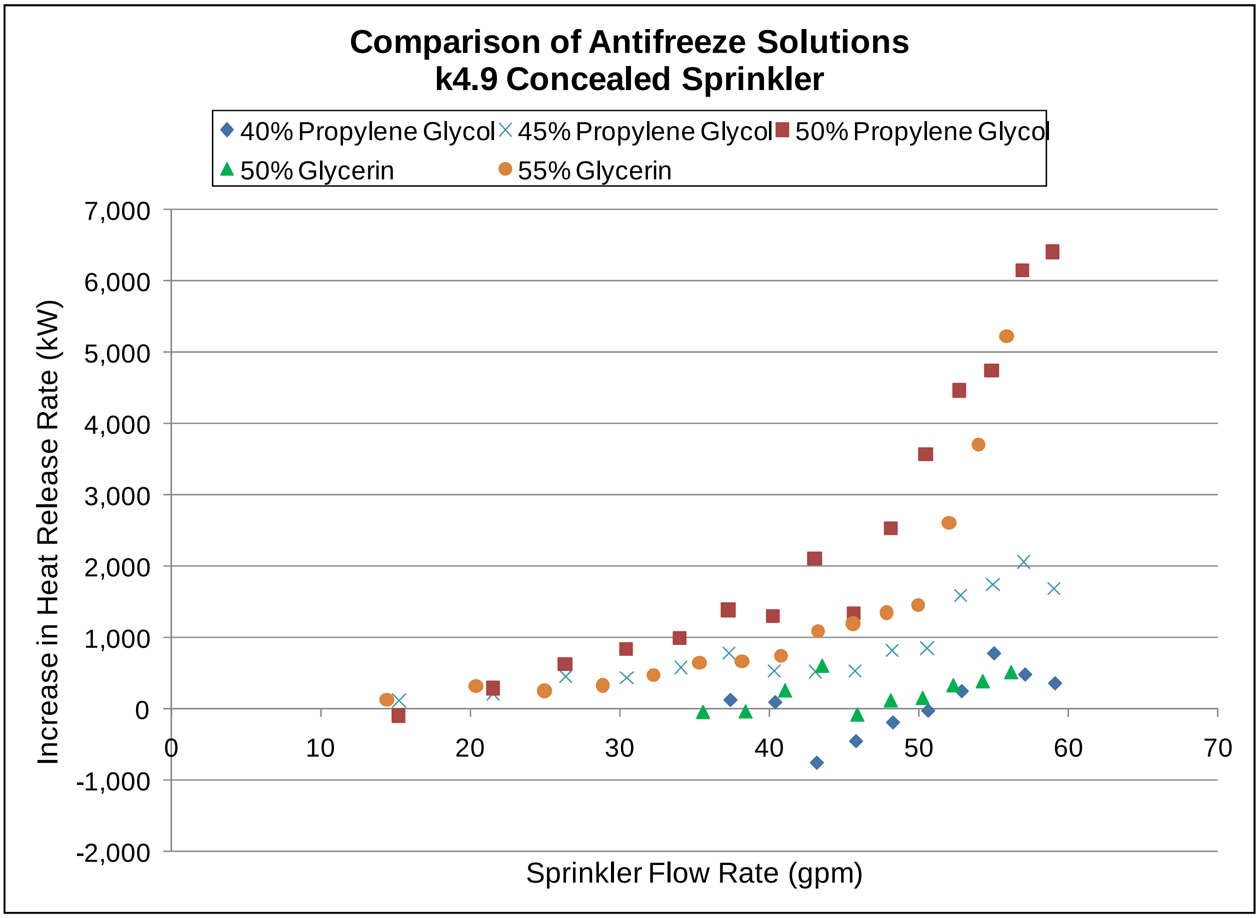

Figure 12: Increase in fire size for various antifreeze solutions.

The results presented above show increases in heat release rate of more than 6,000 kW or 500% for the 50% propylene glycol and 55% glycerin solutions at certain flow rates. This is due in large part to ignition of the antifreeze spray extending away from the initial fire condition. A significantly lower increase in heat release rate was measured for the 45% propylene glycol solution, which showed little ignition of the sprinkler spray away from the ignition source. The application of antifreeze solutions of 40% propylene glycol and 50% glycerin resulted in much smaller changes in heat release rate during otherwise identical test conditions. The 40% propylene glycol and 50% glycerin solutions resulted in very similar changes in the heat release rate of the fire condition. Although there was some increase in the heat release rate that was measured for both solutions at certain operating pressures, flames were not observed to extend away from the initial fire source.

Figures 13 and 14, below, illustrate the maximum increase in heat release rate caused by 50% glycerin solution for tests with sprinklers at 8 ft and 20 ft above the floor, respectively. The maximum heat release rate measured for the test at 8 ft was approximately 3,300 kW and 2,800kW for a test at 20 ft, compared with a baseline ignition source heat release rate of approximately 1,400 kW.

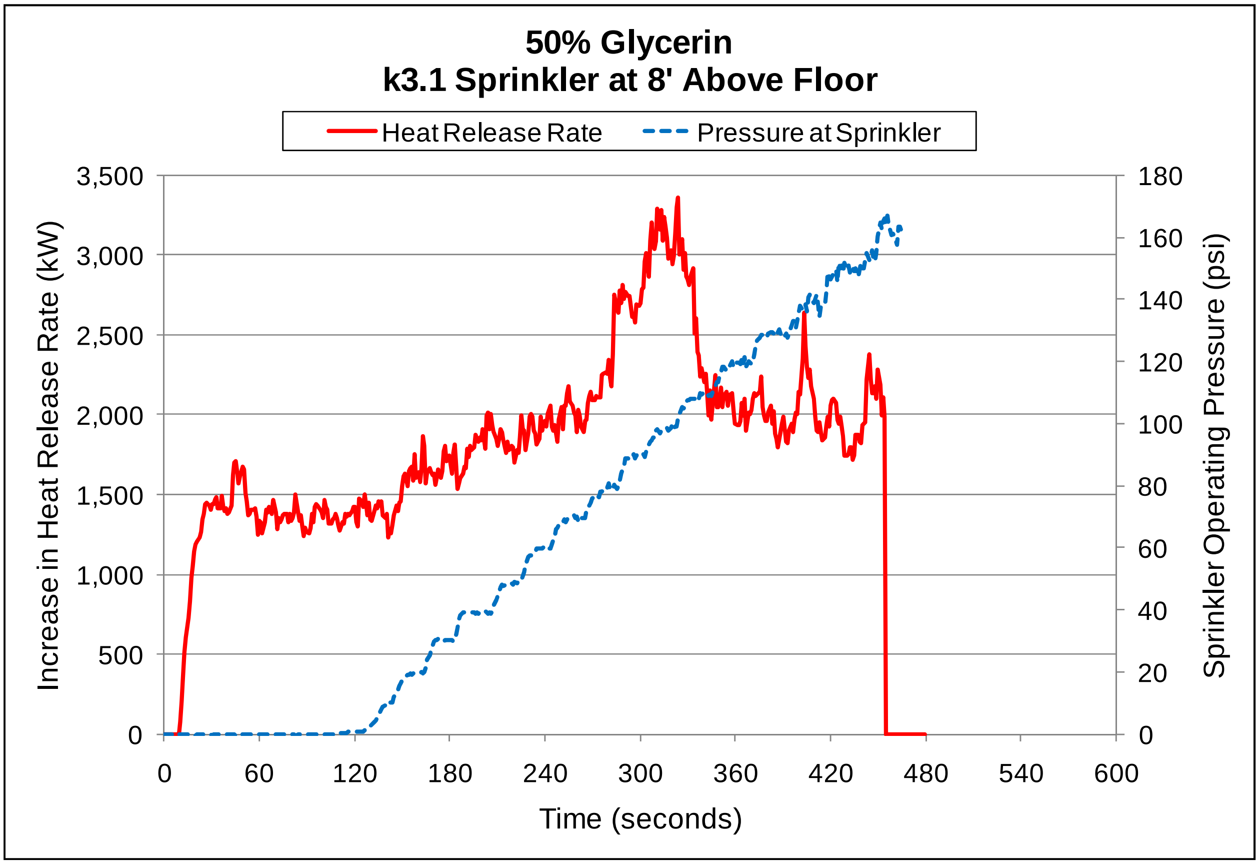

Figure 13. Detailed results for 50% glycerin supplied through k3.1 sprinkler at 8 ft.

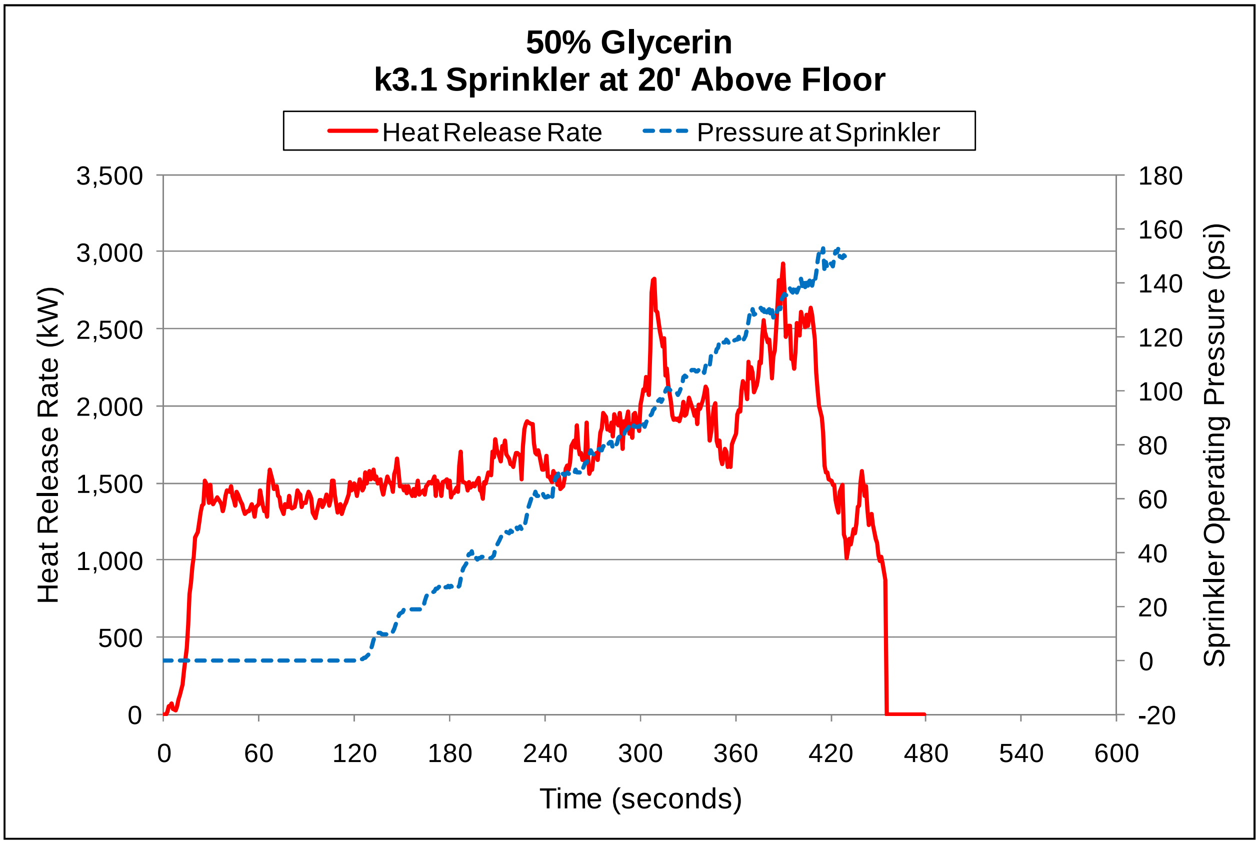

Figure 14: Detailed results for 50% glycerin supplied through k3.1 sprinkler at 20 ft.

3. Sprinkler Height

Tests were conducted for solutions of 40%, 50% and 60% propylene glycol for sprinkler heights of 8 feet and 20 feet. Results of the tests are summarized in Figure 15, below, which shows the increase in heat release rate due to the change in ceiling height for each antifreeze solution using the same sprinkler and ignition source.

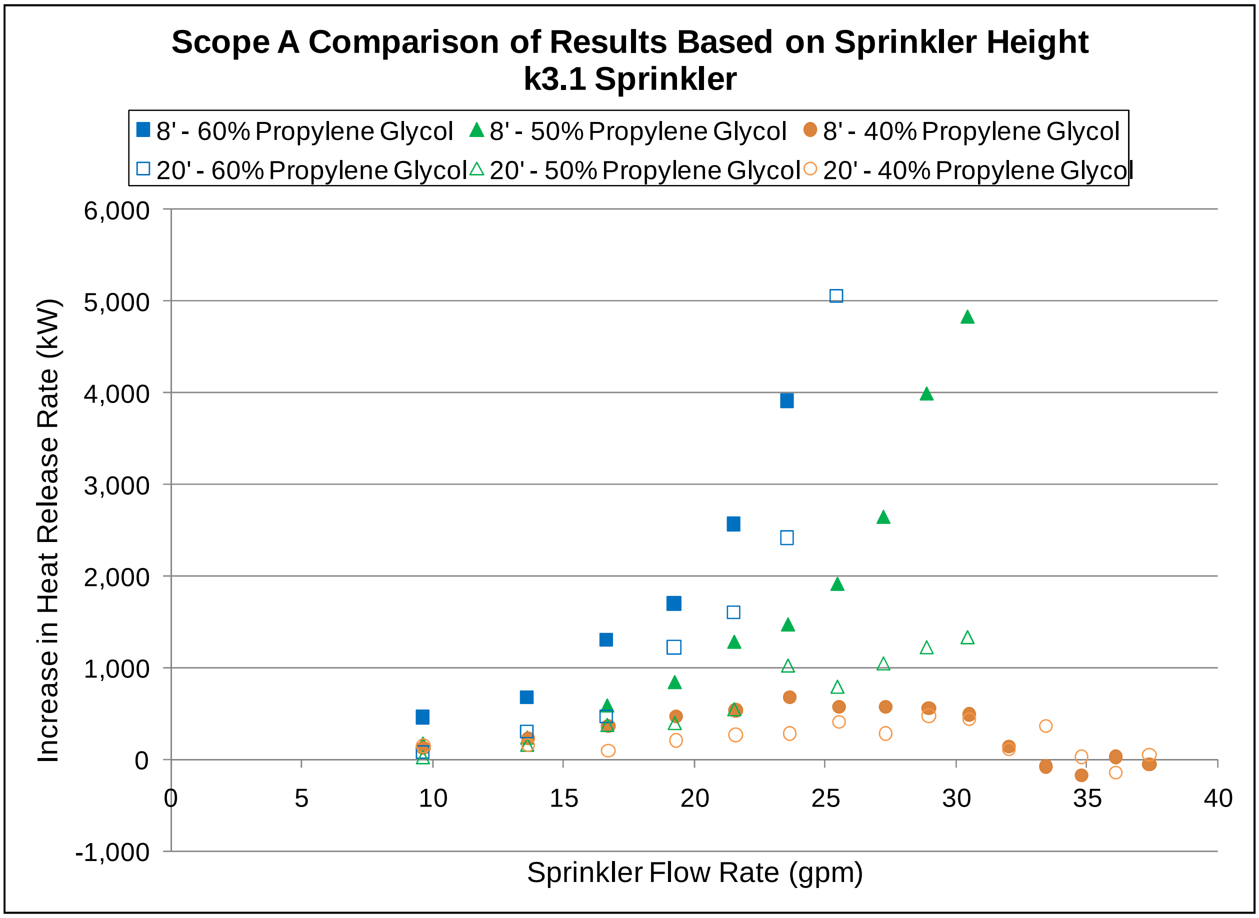

Figure 15: Comparison of Results Based on Sprinkler Height

The results presented above show that for 40% and 60% propylene glycol solutions, the height of the sprinkler had a less significant effect on the increase in heat release rate. The 40% solution resulted in very little increase in heat release rate regardless of the sprinkler height and the 60% solution resulted in a substantial increase in the heat release rate for both sprinkler heights. However, the height of the sprinkler had a significant impact on the results with the 50% propylene glycol solution, particularly at higher flow rates. The 50% propylene glycol solution discharged at a height of 8 ft had an increase in heat release rate of approximately 5,000 kW while discharge at a height of 20 ft yielded an increase in heat release rate of approximately 1,200 kW. Thus, while the sprinkler and antifreeze concentration seem to be of primary importance in determining the potential for ignition, the change in spray distribution with height can significantly impact the results for marginal solutions.

4. Temperature of Antifreeze Solution

Tests were conducted that compared the performance of glycerin solution at ambient temperature (80°F to 90°F) and glycerin solution heated to 140°F. Results of the tests are summarized in Figure 16, below, which illustrates the increase in heat release rate for heated and unheated 50% glycerin solutions.

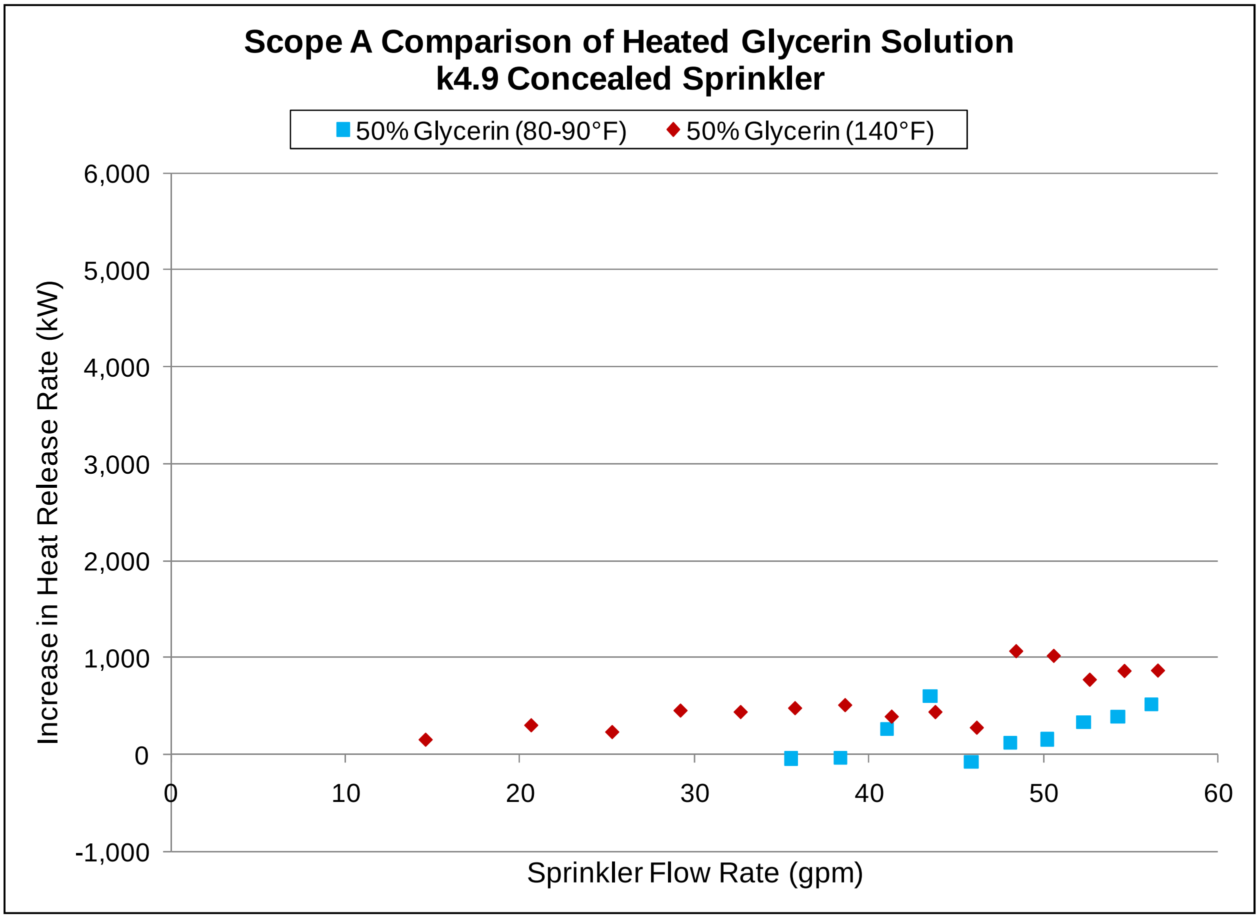

Figure 16: Comparison of Heated Glycerin Solution

The results presented above shows a minor difference in heat release rate during tests with ambient temperature and heated glycerin solutions. Each of the solutions produced a maximum increase in heat release rate of approximately 500 to 1,000kW. While there may be some difference based on temperature over the range investigated, it appears that the effect of temperature is minor compared with the impact of solution concentration.

B. Scope B – Room Fire Tests

Failure criterion for the Scope B testing was based on the UL 1626 fire control criteria. Based on these criteria, residential sprinklers were installed in a fire test enclosure with an 8-ft ceiling and are required to control a fire for 10 minutes within the limits established by the UL 1626 fire control criteria. UL 1626 includes provisions for extending the duration of the test to 30 minutes if continued burning is observed at 10 minutes, but the test duration was limited to 10 minutes for the purposes of this comparison.

1. Temperature 3 inches Below Ceiling

Tests were conducted to ensure that the maximum temperature adjacent to the sprinkler 3 inches below the ceiling did not exceed 600°F. Figure 17, below, illustrates the results of these tests.

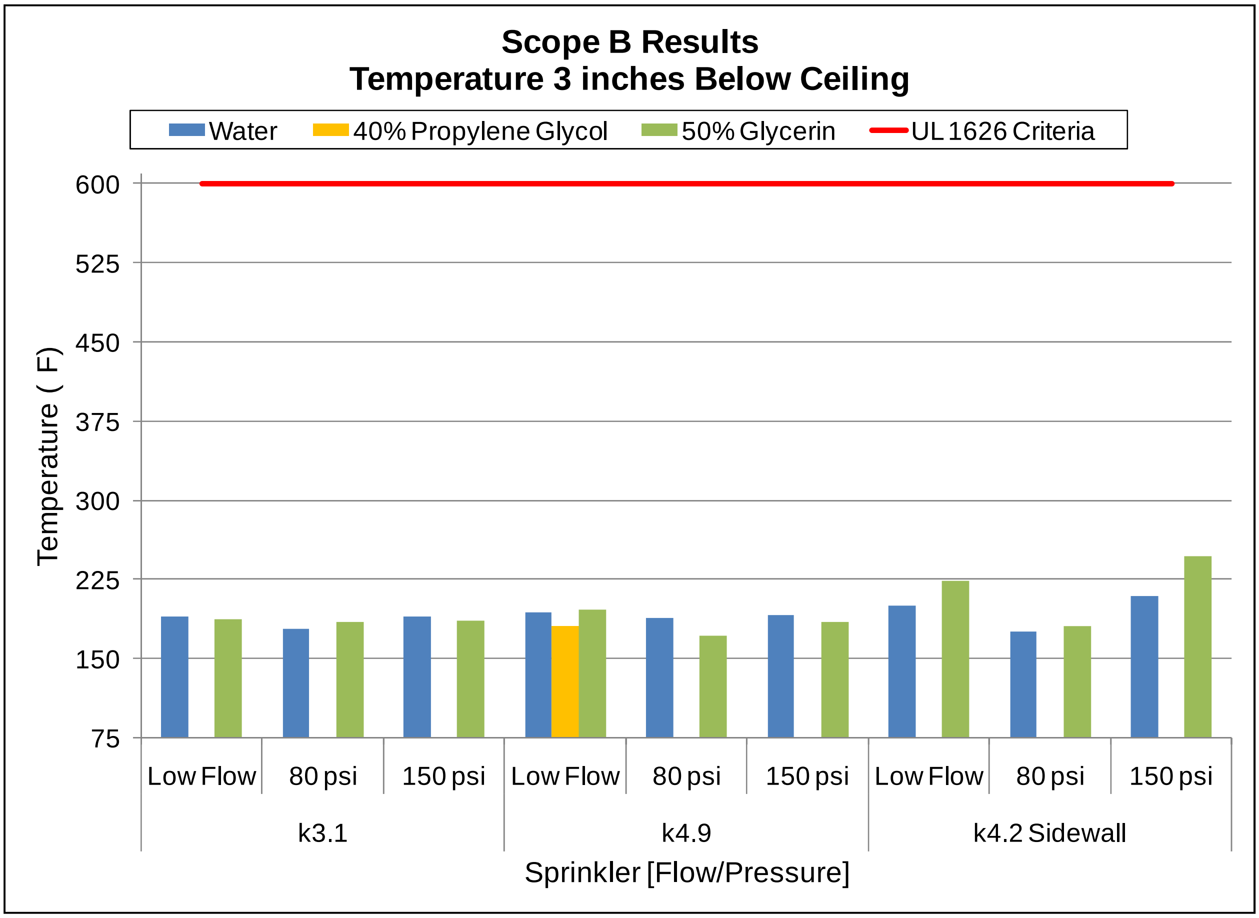

Figure 17: Scope B Results Temperature 3 inches Below Ceiling

The results in Figure 17, above, show that water, 40% propylene glycol, and 50% glycerin demonstrate similar performance. Regardless of variation in sprinkler operating pressure and k-factor, both of the antifreeze solutions and water did not exceed a measured temperature of 225°F. This is well below the maximum temperature of 600°F specified in the UL 1626 fire control criteria.

2. Temperature at 5'-3" Above Floor

Temperature results at 5'-3" above the floor are illustrated in Figures 18 and 19, below. Figure 18 shows the maximum temperature measured during the test, which is limited by UL 1626 to 200°F, and Figure 19 shows the temperature that is sustained for 2 minutes during the test, which must be less than 130°F based on the criteria in UL 1626.

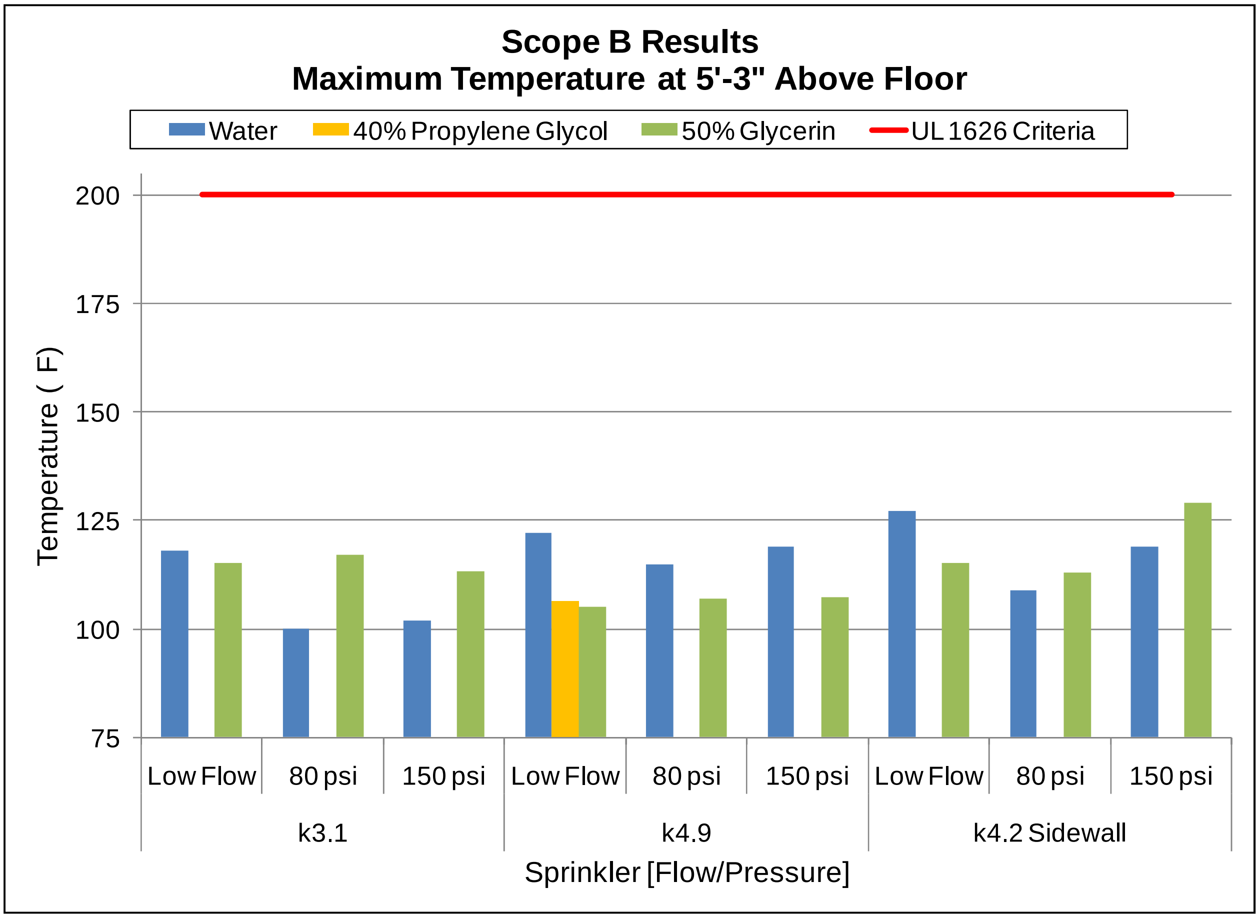

Figure 18: Maximum Temperature 5'-3" Above Floor

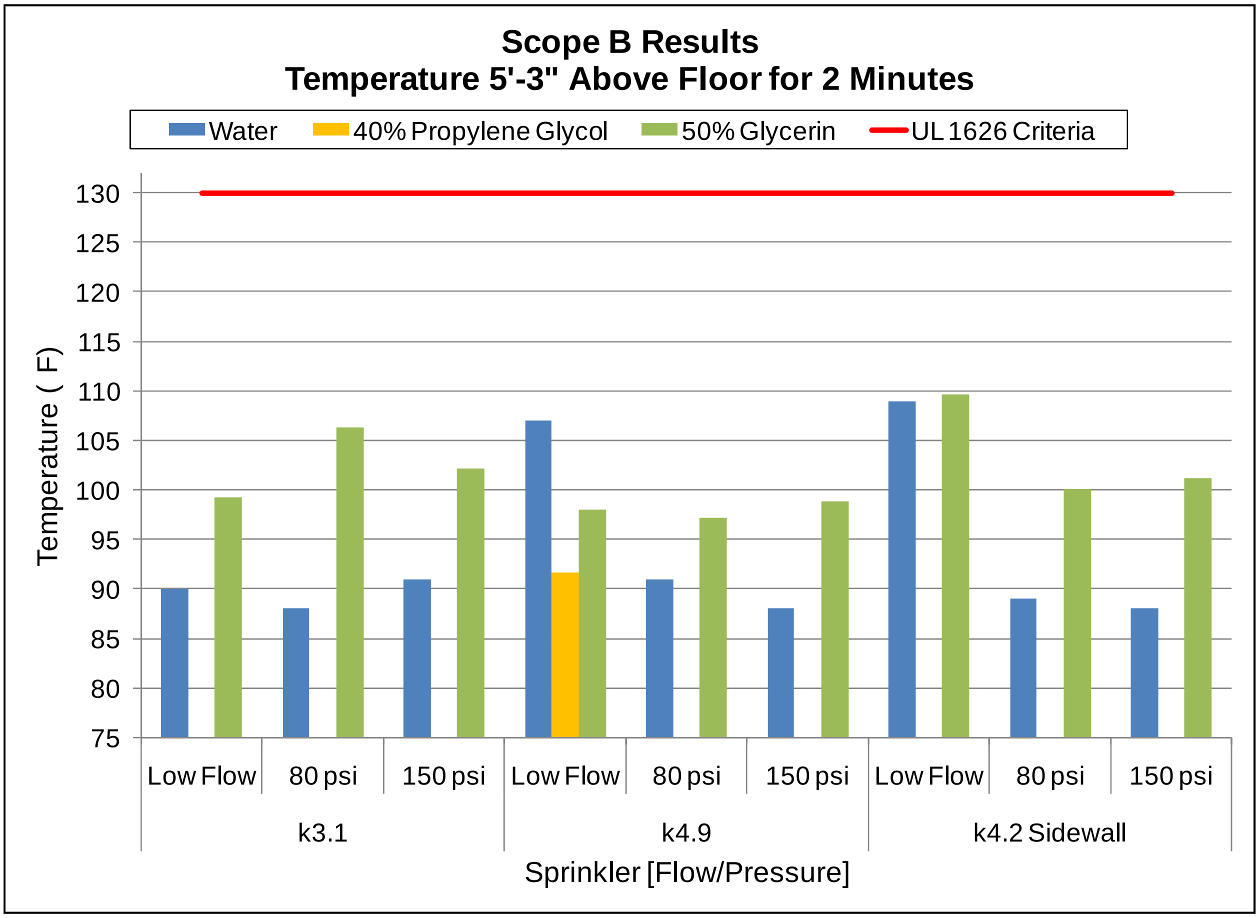

Figure 19: 2 minute Sustained Temperature at 5’-3” Above Floor

All of the tests remained well below the temperature criteria specified in UL 1626. The maximum temperature for water and 50% glycerin were each slightly higher than 125°F compared with a criteria of 200°F. For the low flow condition and the 2 minute temperature criteria, the results with the 50% glycerin solution were better than water for the test with the k4.9 sprinkler, the results with water were better for the k3.1 sprinkler, and the results with the k4.2 sidewall sprinkler were nearly the same. The results for the 2 minute temperature criteria in the tests at 80 psi and 150 psi show somewhat higher temperatures with the 50% glycerin solution compared with water. This may be due in part to the flow rate of glycerin solution being lower than the flow rate of water at the same pressure, which should be accounted for in the design of a sprinkler system. Overall, the temperature results at 5’-3” above the floor were similar with water, 40% propylene glycol, and 50% glycerin.

3. Temperature ¼-inch Behind Ceiling Surface

The temperature results at ¼-inch behind the ceiling surface above the fire are illustrated in Figure 20, below.

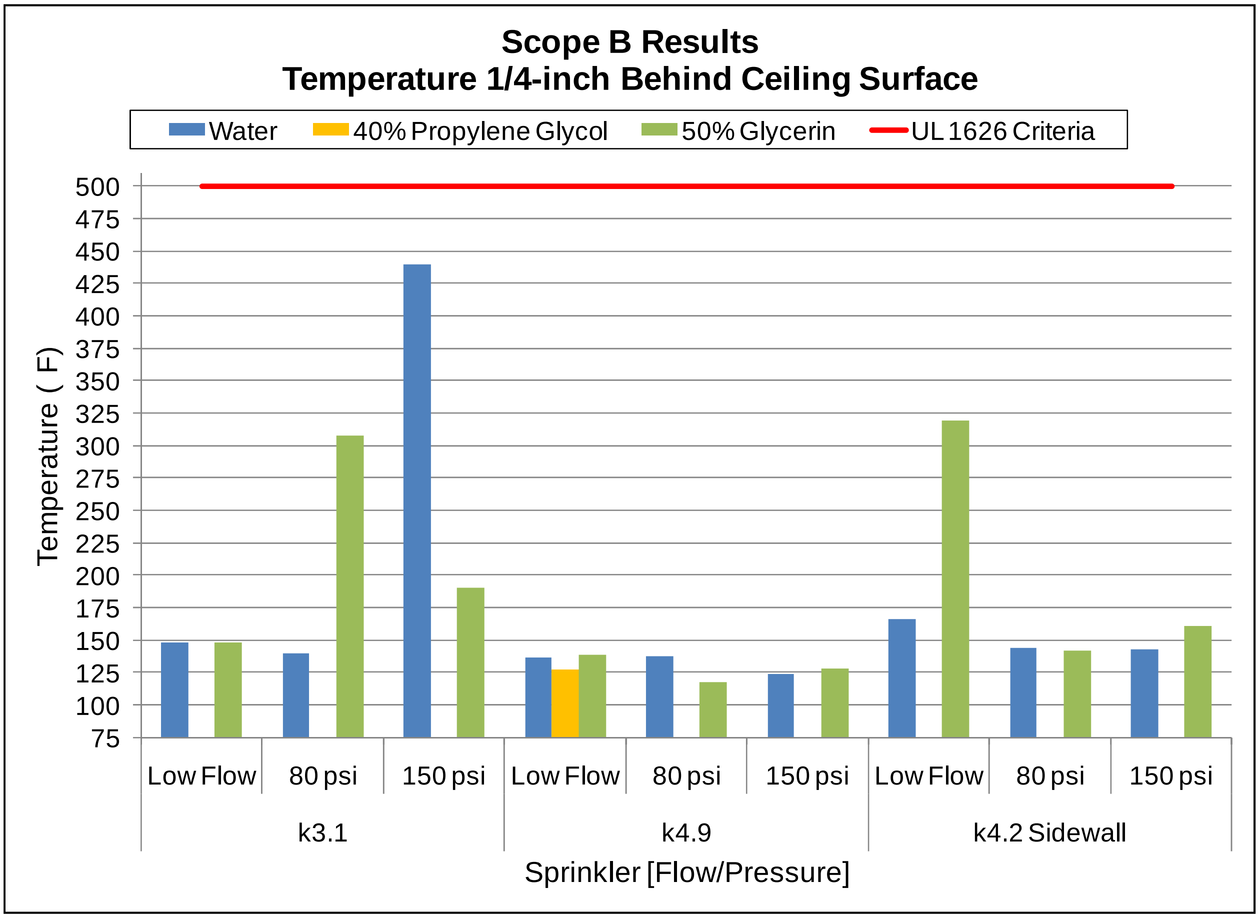

Figure 20: Temperature 1/4–inch Behind Ceiling Surface

As shown in the figure above, the majority of the tests had similar results and all of the tests remained within the criteria specified by UL 1626. In two of the configurations the test with 50% glycerin solution had significantly higher temperatures than the similar test with water and in one of the configurations the test with water had significantly higher temperatures than the similar test with glycerin solution. The highest measured temperature behind the ceiling material was during the test with the k3.1 sprinkler supplied with water at 150 psi. This result is likely due to the test room being larger than the listed protection area of the sprinkler; however, the same test configuration with 50% glycerin solution better controlled the fire condition.

4. Number of Sprinkler Activated

The UL 1626 criteria allows no more than two of the three sprinklers in the room to activate for a successful test. Figure 21, below, shows that the number of sprinklers activated met this criteria for each of the tests.

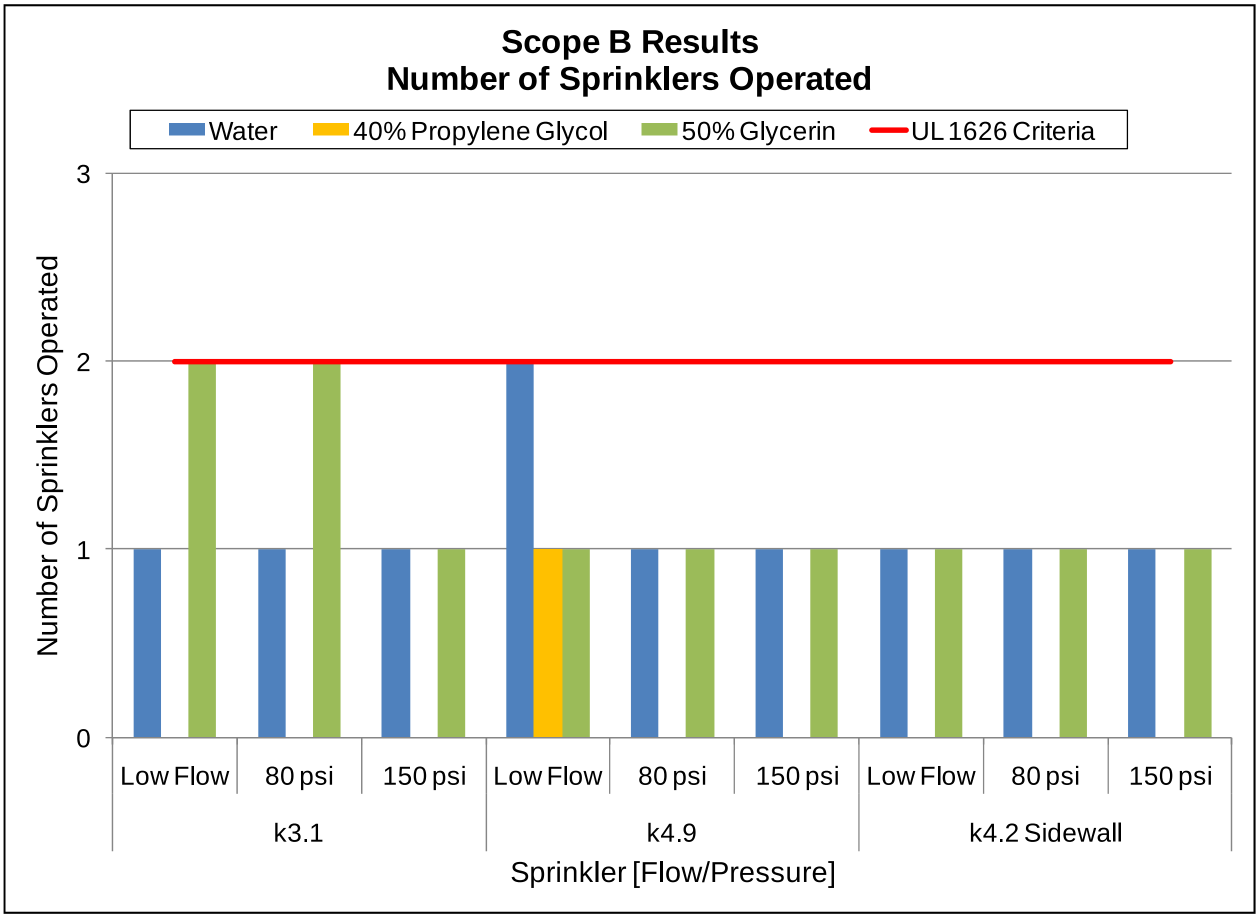

Figure 21: Scope B Results Number of Sprinklers Operated

Two sprinklers were activated in the enclosure during two of the tests with glycerin solution and one of the tests with water. For the remaining tests only a single sprinkler activated. Based on the results of these tests, as illustrated above, the UL 1626 criteria was satisfied.

5. Scope B Summary

The results for Scope B are summarized in Table 5, below, along with the UL 1626 criteria.

Sprinkler [Flow/Pressure] Solution	Temperature 3" Below Ceiling Maximum (°F)	Temperature 5'-3" Above Floor Maximum (°F)	Temperature 5'-3" Above Floor 2-Minute (°F)	Temperature Behind Ceiling Material Maximum (°F)	No. of Sprinklers Activated Maximum
UL 1626 Criteria	**600**	**200**	**130**	**500**	**2**
k3.1 Low Flow					
Water	190	118	90	148	1
50% Glycerin	188	115	99	148	2
k3.1 80 psi					
Water	178	100	88	140	1
50% Glycerin	184	117	106	308	2
k3.1 150 psi					
Water	190	102	91	440	1
50% Glycerin	186	113	102	190	1
k4.9 Low Flow					
Water	193	122	107	137	2
40% Propylene Glycol	180	106	92	127	1
50% Glycerin	196	105	98	139	1
k4.9 80 psi					
Water	189	115	91	138	1
50% Glycerin	172	107	97	117	1
k4.9 150 psi					
Water	191	119	88	124	1
50% Glycerin	185	107	99	128	1
k4.2 Sidewall Low Flow					
Water	200	127	109	166	1
50% Glycerin	223	115	110	319	1
k4.2 Sidewall 80 psi					
Water	175	109	89	144	1
50% Glycerin	180	113	100	142	1
k4.2 Sidewall 150 psi					
Water	209	119	88	143	1
50% Glycerin	246	129	101	161	1
Furniture Fire k4.9 Low Flow					
50% Glycerin	165	96	94	104	1
Without Sprinklers	**> 1,074**	**> 545**	**>130**	**> 571**	**N/A**

Table 5. Scope B Test Results

In addition to the results of tests with the UL 1626 fuel package, Table 5 also includes the results of a test conducted with living room furniture. The test used 50% glycerin solution supplied to a k4.9 sprinkler at 18 gpm. The fire was controlled by one sprinkler. The results of the test indicate that the UL 1626 fuel package is a more severe test of the sprinkler system than the living room furniture fuel package. The temperatures measured during the test with actual furniture were lower than any of the tests with the UL 1626 fuel package.

Table 5 also includes results of a UL 1626 type test conducted by Underwriters Laboratories without the use of sprinklers. The test without sprinklers was conducted as part of a prior research project and used a 12 ft by 24 ft enclosure meeting the requirements of UL 1626. The test was terminated after less than 4 minutes when the temperature in the room exceeded 1,000°F. While all of the Scope B tests with antifreeze solutions and water maintained temperatures within the UL 1626 criteria for a full 10 minutes, a similar test without sprinklers resulted in flashover of the enclosure in less than 4 minutes. The results demonstrate the effectiveness of water as well as solutions of 40% propylene glycol and 50% glycerin in controlling home fire conditions represented by UL 1626.

V. Summary

A test plan was developed for Phase II to investigate the potential for large-scale ignition of antifreeze solutions discharged from residential sprinklers. This test plan also explored the influence of antifreeze solutions on the effectiveness of residential sprinkler systems in controlling a fire condition and maintaining tenable conditions for egress.

Testing was conducted in two parts (Scope A and B). Scope A consisted of fire tests using six (6) models of sprinklers operating at pressures of 10 psi to 150 psi at elevations of eight and twenty feet. The Scope A testing was intended to investigate the potential for large-scale ignition of antifreeze sprays at pressures ranging from 10 psi to 150 psi. Scope B consisted of room fire tests, similar to UL 1626, that were designed to investigate the effective of sprinklers discharging antifreeze solutions and their ability to maintain tenable conditions.

Results of the Scope A testing indicated that concentrations of propylene glycol exceeding 40% by volume and concentrations of glycerin exceeding 50% by volume have the potential to ignite when discharged through automatic sprinklers. The potential for ignition depends on several factors including the ignition source, sprinkler model, sprinkler elevation, and discharge pressure. Ignition of antifreeze spray increased the measured heat release rate in certain tests with 50% propylene glycol and 55% glycerin by more than 300%. For certain test conditions, the increase in heat release rate resulting from the application of 55% glycerin solution exceeded the increase in heat release rate from the application of 50% glycerin solution by a factor of 10. A similar level of sensitivity was observed between 40% and 50% propylene glycol solutions, but not between 40% and 45% propylene glycol solutions.

The results of the Scope B testing indicated that concentrations of propylene glycol not exceeding 40% by volume and concentrations of glycerin not exceeding 50% by volume have similar performance to water as compared to the UL 1626 fire control criteria. Test with the 40% propylene glycol and 50% glycerin solution met the UL 1626 fire control criteria and demonstrated similar performance to water throughout many of the tests.

The results of this research suggest that antifreeze solutions of propylene glycol exceeding 40% and glycerin exceeding 50% by volume are not appropriate for use in home fire sprinkler systems. Consideration should be given to an appropriate safety factor for concentrations of antifreeze solutions that are permitted by future editions of NFPA 13. In addition, based on the flammability properties outlined in Table 4, the use of solutions of diethylene glycol and ethylene glycol in home fire sprinkler systems should also be limited.

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Appendix A

Scope A Test Matrix

Test No.	Solution	Ignition Source	Sprinkler Height (feet)	Sprinkler Pressure (psi)	Sprinkler (k-Factor)
A1	60% propylene glycol	6" wide heptane pan	8	10-80	Residential pendent fixed deflector (k3.1)
A2	60% propylene glycol	12" wide heptane pan	8	10-60	Residential pendent fixed deflector (k3.1)
A3	60% propylene glycol	spray burner assembly	8	10-60	Residential pendent fixed deflector (k3.1)
A4	50% propylene glycol	spray burner assembly	8	10-100	Residential pendent fixed deflector (k3.1)
A5	50% propylene glycol	12" wide heptane pan	8	10-120	Residential pendent fixed deflector (k3.1)
A6	50% propylene glycol	6" wide heptane pan	8	10-140	Residential pendent fixed deflector (k3.1)
A7	60% propylene glycol	electric range tops	8	10-150	Residential pendent fixed deflector (k3.1)
A8	60% propylene glycol	spray burner assembly	20	10-100	Residential pendent fixed deflector (k3.1)
A9	50% propylene glycol	spray burner assembly	20	10-150	Residential pendent fixed deflector (k3.1)
A10	50% propylene glycol	spray burner assembly	20	10-150	Residential pendent fixed deflector (k4.9)
A11	50% propylene glycol	spray burner assembly	8	10-150	Residential pendent fixed deflector (k4.9)
A12	50% propylene glycol	spray burner assembly	8	10-150	Residential pendent fixed deflector (k7.4)
A13	50% propylene glycol	spray burner assembly	20	10-150	Residential pendent fixed deflector (k7.4)
A14	50% propylene glycol	spray burner assembly	20	10-150	Residential pendent drop down deflector (k4.9)
A15	50% propylene glycol	spray burner assembly	8	10-150	Residential pendent drop down deflector (k4.9)
A16	50% glycerin	spray burner assembly	8	60-150	Residential pendent drop down deflector (k4.9)
A17	40% propylene glycol	spray burner assembly	8	60-150	Residential pendent drop down deflector (k4.9)
A18	water	spray burner assembly	8	10-150	Residential pendent drop down deflector (k4.9)
A19	50% propylene glycol	spray burner assembly	5	10-150	Residential sidewall sprinkler (k4.2)
A20	50% propylene glycol	spray burner assembly	5	10-150	Residential sidewall sprinkler (k5.5)
A21	50% propylene glycol	spray burner assembly	8	10-150	Residential sidewall sprinkler (k5.5)
A22	50% propylene glycol	spray burner assembly	8	10-150	Residential sidewall sprinkler (k4.2)
A23	40% propylene glycol	spray burner assembly	8	10-150	Residential pendent fixed deflector (k3.1)
A24	40% propylene glycol	spray burner assembly	8	10-150	Residential pendent fixed deflector (k4.9)
A25	40% propylene glycol	spray burner assembly	20	10-150	Residential pendent fixed deflector (k3.1)
A26	40% propylene glycol	spray burner assembly	8	10-150	Residential pendent fixed deflector (k4.9)
A27	50% glycerin	spray burner assembly	8	10-150	Residential pendent fixed deflector (k3.1)
A28	50% glycerin	spray burner assembly	20	10-150	Residential pendent fixed deflector (k3.1)
A29	50% glycerin	spray burner assembly	20	100	Residential pendent fixed deflector (k3.1)
A30	50% glycerin	spray burner assembly	8	10-150	Residential pendent fixed deflector (k4.9)
A31	50% glycerin	spray burner assembly	8	100	Residential pendent drop down deflector (k4.9)
A32	55% glycerin	spray burner assembly	8	10-150	Residential pendent drop down deflector (k4.9)
A33	45% propylene glycol	spray burner assembly	8	10-150	Residential pendent drop down deflector (k4.9)
A34	45% propylene glycol	spray burner assembly	20	120	Residential pendent fixed deflector (k3.1)
A35	50% glycerin heated to 140°F	spray burner assembly	8	10-150	Residential pendent drop down deflector (k4.9)

Scope B Test Matrix

Test No.	Solution	Fuel Package	Sprinkler Pressure/Flow Rate	Sprinkler (k-Factor)
B1	water	UL1626	18 gpm first sprinkler 13 gpm each for two sprinklers	Residential pendent fixed deflector (k3.1)
B2	water	UL1626	18 gpm first sprinkler 13 gpm each for two sprinklers	Residential pendent fixed deflector (k4.9)
B3	water	UL1626	80 psi	Residential pendent fixed deflector (k4.9)
B4	water	UL1626	80 psi	Residential pendent fixed deflector (k3.1)
B5	water	UL1626	150 psi	Residential pendent fixed deflector (k3.1)
B6	water	UL1626	150 psi	Residential pendent fixed deflector (k4.9)
B7	water	UL1626	150 psi	Residential sidewall sprinkler (k4.2)
B8	water	UL1626	80 psi	Residential sidewall sprinkler (k4.2)
B9	water	UL1626	24 gpm first sprinkler 17 gpm each for two sprinklers	Residential sidewall sprinkler (k4.2)
B10	40% propylene glycol	UL1626	18 gpm first sprinkler 13 gpm each for two sprinklers	Residential pendent fixed deflector (k4.9)
B11	50% glycerin	UL1626	18 gpm first sprinkler 13 gpm each for two sprinklers	Residential pendent fixed deflector (k4.9)
B12	50% glycerin	UL1626	18 gpm first sprinkler 13 gpm each for two sprinklers	Residential pendent fixed deflector (k3.1)
B13	50% glycerin	UL1626	150 psi	Residential pendent fixed deflector (k3.1)
B14	50% glycerin	Furnished living room	18 gpm first sprinkler 13 gpm each for two sprinklers	Residential pendent fixed deflector (k4.9)
B15	50% glycerin	UL1626	150 psi	Residential pendent fixed deflector (k4.9)
B16	50% glycerin	UL1626	80 psi	Residential pendent fixed deflector (k4.9)
B17	50% glycerin	UL1626	80 psi	Residential pendent fixed deflector (k3.1)
B18	50% glycerin	UL1626	24 gpm first sprinkler 17 gpm each for two sprinklers	Residential sidewall sprinkler (k4.2)
B19	50% glycerin	UL1626	80 psi	Residential sidewall sprinkler (k4.2)
B20	50% glycerin	UL1626	150 psi	Residential sidewall sprinkler (k4.2)

Antifreeze Solutions in Home Fire Sprinkler Systems

Literature Review and Research Plan

Prepared by:
Code Consultants, Inc.

THE FIRE PROTECTION RESEARCH FOUNDATION
Research in support of the NFPA mission

FIRE RESEARCH

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FOREWORD

Automatic sprinkler systems significantly limit the potential for loss of life and property in residential occupancies. When portions of automatic sprinkler systems must be located in spaces subject to freezing and temperatures cannot reliably be maintained at or above 40°F, NFPA 13 requires the use of dry pipe, preaction, or antifreeze sprinkler systems, or other systems specifically listed to protect against freezing. Recent fire incidents have raised questions regarding the effectiveness of sprinkler systems with certain antifreeze solutions in controlling residential fire conditions.

This report describes the results of a literature search on the impact of antifreeze solutions on the effectiveness of home fire sprinkler systems. Suggestions for further research are provided to provide a more complete analysis of currently permitted antifreeze solutions as well as to investigate other antifreeze solutions that could be used in sprinkler systems.

The content, opinions and conclusions contained in this report are solely those of the author.

Home Fire Sprinklers and Antifreeze Solutions Literature Review

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Literature Review and Research Plan

Antifreeze Solutions in Home Fire Sprinkler Systems

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Executive Summary

NFPA 13, *Standard for the Installation of Sprinkler Systems*, has included guidance on the use of antifreeze solutions in fire sprinkler systems since the 1940 edition.[1] Antifreeze solutions may be used in fire sprinkler systems where the piping system, or portions of the piping system, may be subject to freezing temperatures.[2]

Two compounds, glycerin and propylene glycol, are permitted by NFPA 13 for use as antifreeze solutions with water in sprinkler systems supplied by either potable or nonpotable water connections.[3] This report primarily address glycerin and propylene glycol antifreeze solutions, because they are the only solutions permitted by NFPA 13 for use in sprinkler systems connected to potable water supplies. Both compounds are fully miscible in water, meaning that they will form a solution with water in all proportions. Once in solution, both compounds will remain in solution and do not exhibit settling or separation from the solution.[4]

Propylene glycol and glycerin, in pure form, are Class IIIB Combustible Liquids having flashpoints of 210°F (99°C) and 390°F (199°C), respectively.[5] Depending on concentration, the addition of water limits the flammability of each compound.[6] Flashpoint, however, is not a reliable indication of the potential for ignition of a liquid when it is divided into droplets.[7]

The potential for ignition of an antifreeze solution spray depends on the type and concentration of antifreeze as well as the size and mass concentration of the droplets.[8] The majority of water from a standard automatic sprinkler is expected to be contained in droplets ranging from 200 to 3,000 micrometers (μm).[9] In referenced studies, measurements of water droplets from residential sprinklers range from an arithmetic mean of 200 to over 500 μm, depending on location. However, droplets with diameters of less than 100 μm were measured.[10] Existing data on droplet sizes expected from residential sprinklers using antifreeze solutions has not been identified; test data for large-orifice sprinklers indicates that antifreeze solutions with higher viscosities than water have little impact on the spray pattern distribution, which contradicts theoretical predictions.[11] Future investigations should address either explicitly or implicitly the influence of antifreeze solutions on the drop size distribution produced.

Combustible liquids in a spray or mist have been found to ignite at temperatures less than their flashpoint.[7] Research on the ignition of mists indicates that droplets of less than 10 μm behave in a similar manner to a vapor of the same concentration.[7,8] Droplets larger than 40 μm may ignite at concentrations below the Lower Flammability Limit (LFL) for an equivalent concentration of vapor.[7,8] The potential for ignition of a solution of propylene glycol or glycerin and water is limited by the need to evaporate water from the solution prior to ignition.[6,7] Limited data has been identified on the ignition potential of droplets of antifreeze solution at concentrations permitted by NFPA 13.[6] However, it is clear from the available literature that the use of antifreeze solutions in concentrations exceeding those permitted by NFPA 13 must be avoided.

Existing laboratory test data was identified regarding the effectiveness of sprinklers when discharging antifreeze solutions of propylene glycol or glycerin.[11,44,45,46] For certain test conditions, an increase in energy released of 18 to 76% has been measured during the time of antifreeze application compared with water alone.[11,44] These tests included antifreeze solutions at concentrations permitted by NFPA 13 that were found to contribute to the energy released during a fire condition.

NFPA 13 recognizes that the potential combustibility of antifreeze solutions may be mitigated, because antifreeze solutions will only be discharged for a limited duration upon activation of a sprinkler system and will be followed by the application of water.[3] NFPA 13, however, does not provide guidance on the duration of antifreeze solution discharge that is considered acceptable or limit the size of antifreeze sprinkler systems. It is also unclear from the existing research how water spray densities in excess of the minimum required to control a fire condition would impact the contribution of antifreeze solutions to the energy released.

A series of preliminary tests was recently funded and conducted by Underwriters Laboratories to provide initial investigations of antifreeze sprinkler systems in residential applications. A complete report outlining the results of the test series was not available prior to this report being issued, because the tests are very recent. A detailed analysis of the test results should be conducted when the data is available. CCI witnessed several of the tests on behalf of the Foundation. Initial observations from the test series indicate that solutions of 70% glycerin or 60% propylene glycol in water may be ignited when discharged through sprinkler systems, resulting in a substantial fire event. This large-scale ignition of the antifreeze solution results in flames surrounding the majority of the sprinkler spray. Large-scale ignition of the antifreeze solutions did not occur in all of the 70% glycerin or 60% propylene glycol test configurations, or in any of the tests using a 50% glycerin in water solution. Observations from the tests indicate that the potential for large-scale ignition of an antifreeze solution depends on a several factors including, but not limited to, the type of sprinkler, sprinkler operating pressure, initial fire condition, location of the initial fire condition with respect to the sprinkler, and the type and concentration of antifreeze solution. Further investigation of glycerin and propylene glycol antifreeze solutions is necessary to more thoroughly investigate the appropriateness of glycerin and propylene glycol solutions for use in automatic sprinkler systems; however, the preliminary tests conducted by UL indicate the potential for substantial fire events to result from the use of 70% glycerin and 60% propylene glycol solutions in water.

Two fire incident reports have been obtained where the discharge of antifreeze from a sprinkler system was alleged to have contributed to a fire condition.[12,13] The discharge of antifreeze solution from a fire sprinkler system was alleged to result in a flash fire in one of the incidents[13] and an explosion in the other incident.[12] The flash fire incident was located in an outdoor restaurant seating area and the explosion incident occurred in an indoor residential kitchen. Confinement of a flash fire can lead to an overpressure or what is commonly termed an explosion.[14] Although the consequences of a flash fire and an explosion can be significantly different, the occurrence of either a flash fire or an explosion should be avoided, since a flash fire by itself can be hazardous and under the correct conditions can become an explosion.

Although the prior research did not indicate that a flash fire or explosion would be expected to occur for antifreeze solutions at concentrations permitted by NFPA 13[11,44,45,46], the recent tests observed at UL indicate that a flash fire and sustained large-scale ignition of antifreeze solution is possible at certain antifreeze concentrations permitted by NFPA 13. Thus, immediate consideration and additional research is recommended to investigate the appropriateness of antifreeze solutions that are currently permitted to be used in sprinkler systems.

I. Introduction

Automatic sprinkler systems significantly limit the potential for loss of life and property in residential occupancies.[15] When portions of automatic sprinkler systems must be located in spaces subject to freezing and temperatures cannot reliably be maintained at or above 40°F, NFPA 13 requires the use of dry pipe, preaction, or antifreeze sprinkler systems, or other systems specifically listed to protect against freezing.[3]

Antifreeze sprinkler systems may be preferable to dry pipe or preaction sprinkler systems in residential applications based on cost, complexity, and reliability. NFPA statistics indicate that wet pipe sprinkler systems, including antifreeze sprinkler systems, operate effectively in a higher fraction of fire conditions where they are present than dry pipe sprinkler systems.[15] In addition, NFPA 13 requires that residential sprinklers used in dry pipe systems must be specifically listed for dry pipe applications;[3] a listed residential sprinkler for dry pipe applications is not currently available.[16] Thus, antifreeze sprinkler systems have had an important role in protecting people and property in instances where portions of sprinkler systems must be located in spaces subject to freezing.

A recent fire incident[12] raised questions regarding the effectiveness of antifreeze sprinkler systems in controlling residential fire conditions. The Fire Protection Research Foundation retained Code Consultants, Inc. (CCI) to perform a literature search and develop a research plan to investigate the impact of antifreeze solutions on the effectiveness of home fire sprinkler systems. The literature review has included the following subjects:

1. Antifreeze sprinkler system requirements
2. Mixing and separation of antifreeze compounds commonly used in sprinkler systems
3. Flammability of antifreeze solutions commonly used in sprinkler systems
4. Factors influencing the flammability of liquids, such as dispersion in droplets
5. Characterization of residential sprinkler sprays
6. Factors influencing the potential for flash fires or explosions from liquid sprays
7. Existing fire test data on the effectiveness of antifreeze solutions at controlling fire conditions
8. Fire incident reports involving antifreeze sprinkler systems

A research plan was developed to supplement the literature search in areas where existing information was limited. In addition, CCI observed a series of fire tests conducted by Underwriters Laboratories, Inc. (UL) to investigate the effectiveness of antifreeze sprinkler systems in controlling certain home fire scenarios. Observations of the preliminary UL testing (as witnessed by CCI) are included in this report. Suggestions for further research are provided to provide a more complete analysis of currently permitted antifreeze solutions as well as to investigate other antifreeze solutions that could be used in sprinkler systems.

II. Definitions

Antifreeze Sprinkler System – *A wet pipe sprinkler system employing automatic sprinklers that are attached to a piping system that contains an antifreeze solution and that are connected to a water supply. The antifreeze solution is discharged, followed by water, immediately upon operation of sprinklers opened by heat from a fire.*[3]

Autoignition Temperature (AIT) – *The minimum temperature required to initiate or cause self-sustained combustion of a solid, liquid, or gas independently of the heating or heated element.*[17]

Automatic Sprinkler – *A fire suppression or control device that operates automatically when its heat-actuated element is heated to its thermal rating or above, allowing water to discharge over a specific area.*[3]

Combustible Liquid – *Any liquid that has a closed-cup flash point at or above 100°F (37.8°C), as determined by the test procedures and apparatuses set forth in Section 4.4 [of NFPA 30].*[18]

Deflagration – *Propagation of a combustion zone at a velocity that is less than the speed of sound in the unreacted medium.*[19]

Detonation – *Propagation of a combustion zone at a velocity that is greater than the speed of sound in the unreacted medium.*[19]

Dry-pipe Sprinkler System – *A sprinkler system employing automatic sprinklers that are attached to a piping system containing air or nitrogen under pressure, the release of which (as from the opening of a sprinkler) permits the water pressure to open a valve known as a dry pipe valve, and the water then flows into the piping system and out the opened sprinklers.*[3]

Explosion – *The sudden conversion of potential energy (chemical or mechanical) into kinetic energy with the production and release of gases under pressure, or the release of gas under pressure. These high-pressure gases then do mechanical work such as moving, changing, or shattering nearby materials.*[20]

Flammable Liquid – *Any liquid that has a closed-cup flash point below 100°F (37.8°C), as determined by the test procedures and apparatus set forth in Section 4.4 [of NFPA 30], and a Reid vapor pressure that does not exceed an absolute pressure of 40 psi (276 kPa) at 100°F (37.8°C), as determined by ASTM D 323, Standard Test Method for Vapor Pressure of Petroleum Products (Reid Method).*[18]

Flash Fire – *A fire that spreads rapidly through a diffuse fuel, such as dust, gas or the vapors of an ignitable liquid, without the production of damaging pressure.*[20]

Flash Point – *The minimum temperature of a liquid at which sufficient vapor is given off to form an ignitable mixture with the air, near the surface of the liquid or within the vessel used, as determined by the appropriate test procedure and apparatus specified in Section 4.4 [of NFPA 30].*[18]

Flashover – *A transition phase in the development of a compartment fire in which surfaces exposed to thermal radiation reach ignition temperature more or less simultaneously and fire spreads rapidly throughout the space, resulting in full room involvement or total involvement of the compartment or enclosed space.*[20]

Gas – *The state of matter characterized by complete molecular mobility and unlimited expansion; used synonymously with the term vapor.*[19]

Hygroscopic – *Descriptive of a substance that has the property of adsorbing moisture from the air.*[21]

Lower Flammability Limit (LFL) – *The lowest concentration of a gas or vapor that will just support the propagation of flame away from a pilot ignition source.*[19]

Miscibility – *The ability of a liquid or gas to dissolve uniformly in another liquid or gas.*[21]

Preaction Sprinkler System – *A sprinkler system employing automatic sprinklers that are attached to a piping system that contains air that might or might not be under pressure, with a supplemental detection system installed in the same areas as the sprinklers.*[3]

Residential Sprinkler – *A type of fast-response sprinkler having a thermal element with an RTI of 50 (meters-second)$^{1/2}$ or less, that has been specifically investigated for its ability to enhance survivability in the room of fire origin, and that is listed for use in the protection of dwelling units.*[3]

Solution – *A uniformly dispersed mixture at the molecular or ionic level, of one or more substances (the solute) in one or more other substances (solvent).*[21]

Upper Flammability Limit (UFL) – *The highest concentration of a vapor or gas that will ignite and burn with a flame in a given atmosphere*[19]

Vapor – *The gas phase of a substance, particularly of those that are normally liquids or solids at ordinary temperatures.*[20]

Water-Miscible Liquid – *A liquid that mixes in all proportions with water without the use of chemical additives, such as emulsifying agents.*[18]

Wet Pipe Sprinkler System – *A sprinkler system employing automatic sprinklers attached to a piping system containing water and connected to a water supply so that water discharges immediately from sprinklers opened by heat from a fire.*[3]

III. Background

This section summarizes relevant background information from the literature search, including NFPA 13 requirements, chemical data on propylene glycol and glycerin, relevant chemistry, residential sprinklers, and factors influencing the flammability of liquids and explosions.

A. NFPA 13 Requirements for Antifreeze Systems

The following are the current versions of NFPA 13 that address the installation of sprinkler systems:

- NFPA 13 — *Standard for the Installation of Sprinkler Systems (2010 edition)*
- NFPA 13D — *Standard for the Installation of Sprinkler Systems in One- and Two-Family Dwellings and Manufactured Homes (2010 edition)*
- NFPA 13R — *Standard for the Installation of Sprinkler Systems in Residential occupancies up to and Including Four Stories in Height (2010 edition)*

NFPA 13R requires antifreeze systems to be installed in accordance with NFPA 13,[3,22] and NFPA 13D includes substantially similar requirements for antifreeze solutions as those found in NFPA 13.[3,23] Thus, the discussion in the report will be based on NFPA 13, but also addresses NFPA 13D and NFPA 13R.

The purpose of NFPA 13 is, "to provide a reasonable degree of protection for life and property from fire through standardization of design, installation, and testing requirements for sprinkler systems. . . ."[3] The purpose of NFPA 13D is, "to provided a sprinkler system that aids in the detection and control of residential fires and thus provides improved protection against injury and life loss."[23] The purpose of NFPA 13R is, "to provide a sprinkler system that aids in the detection and control of residential fires and thus provides improved protection against injury, life loss, and property damage."[22] Automatic sprinkler systems that contain antifreeze-water mixtures have been addressed in NFPA 13 for more than 60 years.[1] Automatic sprinkler systems that incorporate antifreeze solutions are classified as wet pipe systems.

The intent of antifreeze sprinkler systems is to protect sprinkler piping that passes through areas that could be exposed to freezing temperatures. For example, antifreeze sprinkler systems may be used in freezers, loading docks, elevator penthouses, or elevator shafts in commercial buildings. Antifreeze sprinkler systems may also be used in residential areas that are not protected against freezing temperatures.[2] This could include sprinklers protecting unconditioned areas of a residential building or sprinklers serving a conditioned area of a residential building where the pipe passes through an unconditioned area such as an attic.

NFPA 13 outlines several requirements for the proper design and installation of antifreeze sprinkler systems. The requirements are designed to, “minimize the concentration of the solution and, therefore, minimize the potential effect on the extinguishment capabilities of the solution.”[2]

The use of antifreeze solutions in fire sprinkler systems is required to conform to state and local health regulations. NFPA 13 only permits the use of nontoxic antifreeze solutions when the system is connected to a public water supply. NFPA 13 also differentiates antifreeze solution requirements between sprinkler systems supplied by potable and non-potable water connections.

NFPA 13 permits glycerin-water and propylene glycol-water mixtures for use in antifreeze sprinkler systems connected to either potable or nonpotable water supplies.[3] The following tables illustrate the antifreeze solution requirements for potable and non-potable water connections:

Material	Solution with Water (by Volume)	Specific Gravity at 60 °F (15.6 °C)	Freezing Point	
			°F	°C
Glycerin (C.P. or U.S.P grade)	50% glycerin	1.145	-20.9	-29.4
	60% glycerin	1.171	-47.3	-44.1
	70% glycerin	1.197	-22.2	-30.1
Propylene glycol	40% propylene glycol	1.034	-6	-21.1
	50% propylene glycol	1.041	-26	-32.2
	60% propylene glycol	1.045	-60	-51.1

C.P.: Chemically pure. U.S.P.: United States Pharmacopoeia 96.5%

Table 1: Adapted from NFPA 13 Table 7.6.2.2 Antifreeze Solution to be Used if Potable Water is Connected to Sprinklers

Material	Solution with Water (by Volume)	Specific Gravity at 60 °F (15.6 °C)	Freezing Point	
			°F	°C
Glycerin	See Table 1 (NFPA 13 Table 7.6.2.2)			
Diethylene glycol	50% diethylene glycol	1.078	-13	-25.0
	55% diethylene glycol	1.081	-27	-32.8
	60% diethylene glycol	1.086	-42	-41.1
Ethylene glycol	39% ethylene glycol	1.056	-10	-23.3
	54% ethylene glycol	1.063	-20	-28.9
	49% ethylene glycol	1.069	-30	-34.4
	53% ethylene glycol	1.073	-40	-40.0
Propylene glycol	See Table 1 (NFPA 13 Table 7.6.2.2)			

Table 2: Adapted from NFPA 13 Table 7.6.2.3 Antifreeze Solution to be Used if Non-potable Water is Connected to Sprinklers

Antifreeze solutions of glycerin, diethylene glycol, and ethylene glycol were included in NFPA 13 starting in the Appendix of the 1940 edition, known as National Board of Fire Underwriters Pamphlet No. 13 at the time.[1] The 1953 edition of NFPA 13 included requirements for antifreeze sprinkler systems in the body of the standard and permitted the use of propylene glycol or calcium chloride solutions as well as glycerin, diethylene glycol, and ethylene glycol.[24] The antifreeze solutions and concentrations permitted by the 1953 edition of NFPA 13 are the same as those permitted by the current (2010) edition of NFPA 13, with the exception that calcium chloride is no longer permitted.

The exclusive use of premixed antifreeze solutions is not required by NFPA 13; however, it may be required for certain specially listed equipment or systems. The Annex to NFPA 13 cautions against the use of antifreeze solutions that are mixed on-site. When antifreeze solutions are mixed on-site, the concern exists that the antifreeze-water mixture in the fire sprinkler system may not be homogenous. As discussed in detail later in this report, fully mixed antifreeze solutions of miscible liquids, such as glycerin or propylene glycol and water, will not separate on standing. NFPA 13 references NFPA 25 for regular inspection, testing and maintenance requirements of antifreeze sprinkler systems to verify that an antifreeze sprinkler system has the proper concentration of antifreeze solution.[2] NFPA 13D requires antifreeze sprinkler systems to be emptied each year and the specific gravity of the solution to be measured before refilling the system.[23]

NFPA 13 and NFPA 25 require the specific gravity of antifreeze solutions to be tested annually by hydrometer or refractometer as an indication of the concentration and freezing point of the mixture. An antifreeze solution must be prepared with a freezing point below the expected minimum temperature for the locality. Furthermore, the minimum concentration of antifreeze solutions must be limited for the anticipated minimum temperature. High concentrations may increase the potential that the final solution will have a negative effect on the suppression characteristics of the solution.[2] In addition, high concentrations may also increase the freezing point for some antifreeze solutions.

The definition of an antifreeze system in NFPA 13 requires that the system discharge water following the antifreeze solution, and recommends that systems supplied only with antifreeze solution should only be used after consideration of, "issues such as the combustibility of the antifreeze solution and the friction loss in the piping during cold conditions."[3] Thus, NFPA 13 recognizes that in some instances antifreeze solutions may contribute to a fire condition, but that the supply of water following the antifreeze solution mitigates the contribution to the fire.

B. Antifreeze Solutions

Various antifreeze solutions are available that are designed specifically for use in antifreeze sprinkler systems. The chemicals and concentrations of these products vary by manufacturer; however, there are two main differences: premix (ready-to-go) and concentrate solutions. An example of the properties of several premix antifreeze solutions are illustrated in Table 3:[25]

Chemical	LFL/UFL in Air (% by volume)	Flash Point (°F)	Autoignition Temperature (°F)	Boiling Point (°F)
propylene glycol <75%, dipotassium phosphate <10%	2.4/17.4	228	700	222
propylene glycol <50%, dipotassium phosphate <10%	2.4/17.4	228	700	217
1,2,3-Propanetriol (Glycerin Based)	N/A	350	750	554
propylene glycol, dipotassium phosphate	2.4/17.4	228	700	370

Table 3: Sample Properties of Premix Antifreeze Solutions[26,27,28,29]

The following disclaimer is included in the MSDS for one of the premix antifreeze solutions:

> *Fire and Explosion Hazards – Heat from fire can generate flammable vapor. When mixed with air and exposed to ignition source, vapors can burn in open or explode if confined. Vapors may travel long distances along the ground before*

> *igniting and flashing back to vapor source. Fine sprays/mists may be combustible at temperatures below normal flash point. Aqueous solutions containing less than 95% propylene glycol by weight have no flash point as obtained by standard test methods. However aqueous solutions of propylene glycol greater than 22% by weight, if heated sufficiently, will produce flammable vapors. Always drain and flush systems containing propylene glycol with water before welding or other maintenance.*[29]

The disclaimer (above) identifies the potential for vapors of aqueous solutions that contain certain concentrations of propylene glycol to combust. It is important to consider this potential for combustion when dealing with aqueous solutions that contain flammable liquids (e.g. propylene glycol and glycerin). Furthermore, the disclaimer identifies that fine sprays/mists may be combustible at temperatures below their normal flash point. This concept is discussed in detail later in the report.

The premix antifreeze solutions (above) are either propylene glycol or glycerin based. The solutions that contain propylene glycol have a flash point of 228°F and the solution that is glycerin based has a flash point of 350°F. The flash point of the glycerin based solution is more than 100°F higher than that of the propylene glycol based solution.

Another notable difference among the premix solutions is the range in boiling point. The glycerin based solution has a boiling point of approximately 200 to 300°F higher than that of the propylene glycol based solution. The glycerin solution has a higher flash point and boiling point compared to the propylene glycol based solution.

An example of the properties of concentrate antifreeze solutions are illustrated in Table 4:

Chemical	LFL/UFL in Air (% by volume)	Flash Point (°F)	Autoignition Temperature (°F)	Boiling Point (°F)
1,2,3-Propanetriol (Glycerin Based)	N/A	350	750	554
propylene glycol >95%, water <3%, dipotassium hydrogen phosphate <3%	2.6/12.5	219	700	306

Table 4: Sample Properties of Concentrate Antifreeze Solutions[30,31]

Similar to the examples of the premix antifreeze solutions from Table 3, the concentrate solutions are either propylene glycol or glycerin based. The glycerin based solution has a higher flash point than the propylene glycol based solution by over 100°F. The boiling point of the glycerin solution is approximately 200°F higher than that of the propylene glycol based solution.

C. Chemistry of Solutions

Common antifreeze compounds used in fire sprinkler systems, such as propylene glycol and glycerin, form a solution with water. In chemistry, a solution is a homogenous (uniform throughout) mixture of at least two components. The particles in a solution can be characterized as having diameters in the range of 0.0001 to 0.002 µm, the size of a typical ion or small molecule. Other types of mixtures, such as colloids and suspensions, can be characterized by larger particle diameters. An important property of solutions is that they do not separate on standing. [4]

The component of a solution in the greater proportion is known as the solvent (the dissolving medium) while the lesser component is known as the solute (the substance being dissolved). For example, a gram of salt completely dissolved in a glass of water illustrates a solution that consists of two components; the solute (salt) and the solvent (water).[4]

Solutes and solvents can be mixed in a variety of concentrations. A solution is said to be concentrated if it contains a relatively large amount of solute per unit volume of solution. For mixtures of certain substances, however, there is a limit to the amount of solute that can be dissolved in any given solvent. This is known as solubility.

The solubility of a substance in a given solvent is a physical property characteristic of that substance. For a liquid-liquid mixture, the solubility depends on the chemical make-up of the substances involved and whether they will dissolve in each other. Two liquids are said to be miscible if they are mutually soluble in all proportions and will remain mixed under normal conditions. For example, propylene glycol and glycerin are miscible in water.[32,33]

The molecular structures of glycerin and propylene glycol are illustrated in Figure 1, below. Both glycerin and propylene glycol include hydroxyl (OH) groups that bond with water. Thus, in addition to being miscible with water, they are also hygroscopic and bond even with water from the surrounding air.[21]

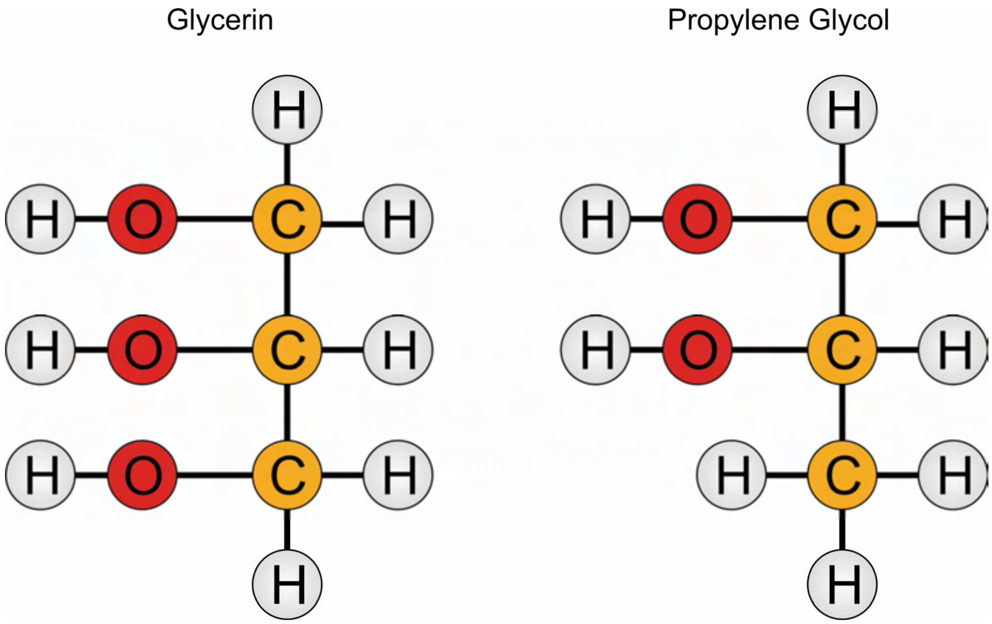

Figure 1: Molecular Structures of Glycerin and Propylene Glycol

Liquid-liquid mixtures may be miscible (capable of being mixed), partially miscible or immiscible (not capable of being mixed). Changes in temperature and pressure may change the solubility of liquids partially miscible in one another; however, miscible liquids are expected to be mutually soluble in all proportions over a complete range of temperatures and pressures. [4]

Because both glycerin and propylene glycol are miscible in water, antifreeze solutions of water mixed with either glycerin or propylene glycol would form solutions at any proportions. For example, solutions can be formed of 99% glycerin and 1% water, 1% glycerin and 99% water, or any other combination of glycerin and water. Note that density differences between either glycerin or propylene glycol and water do not prevent them from forming a solution. Because both propylene glycol and glycerin form solutions with water, any such mixture of propylene glycol or glycerin and water would not separate on standing.

D. Residential Sprinkler Systems

Automatic sprinkler systems have been used in industrial and commercial occupancies for more than 100 years. However, the use of automatic sprinkler systems in residential occupancies is not very common in the United States. According to recent research, 80% of U.S. fire deaths occur in residences. [34]

New developments in residential sprinkler system technology continually reduce the cost of installation while maintaining the effectiveness and reliability of the system. These new developments are intended to increase the number of residential sprinkler systems installed in the U.S. It is estimated that less than three percent of all residential occupancies in the U.S. have fire sprinkler systems installed.[35]

The impact that fire sprinkler systems have on reducing deaths and injuries in residential fires was assessed by the United States Fire Administration (USFA) from 1979 into the late 1990s.[36] The USFA worked in conjunction with NFPA, UL, and Factory Mutual Research Corporation (FM). Together with the USFA, these organizations evaluated the design, installation, practical use, water discharge rate, response sensitivity and design criteria of residential sprinkler systems.[36] Research concluded that sprinklers with higher sensitivity (lower RTI) performed better than lower sensitivity (higher RTI) sprinklers in residential fire applications. This research conducted by FM suggested that a more sensitive sprinkler would respond faster to both smoldering and fast-developing home fires. As a result, the quick-response sprinkler was developed to quickly control fires and help prevent the development of lethal conditions in small home compartments.[36]

In addition to fast-response characteristics, residential sprinklers have special water distribution patterns. The spray pattern is designed to deliver a portion of the water high on walls to prevent a fire from getting “above” the sprinklers and to cool gases at the ceiling level.[37]

The upper spray distribution delivers water close to the ceiling not only to protect the area of the wall close to the ceiling but also to increase the capacity of the spray to cool hot layer gases at the ceiling level. The cooling of these gases helps reduce the probability of excessive sprinkler activations. Excessive sprinkler activation may overload the hydraulic design of the sprinkler system and reduce the water density of the spray distribution. As a result, this could limit the ability of the sprinkler system to suppress a fire.

Unlike traditional sprinklers, the quick-response sprinkler expanded the goal of sprinklers to protect not just property but also to increase life safety. Design parameters for quick-response sprinklers were studied by the applicable NFPA technical committees and were used to establish criteria for the 1980 edition of NFPA 13D *Standard for the Installation of Sprinkler Systems in One- And Two-Family Dwellings and Manufactured Homes*.

Similar to NFPA 13D, NFPA 13R *Standard for the Installation of Sprinkler Systems in Residential Occupancies up to and Including Four Stories in Height* is designed with respect to life safety and property protection. NFPA 13R is designed to be more conservative than NFPA 13D, because there is greater risk associated with multifamily occupancies.[36]

The purpose of NFPA 13R is to provide a sprinkler system that aids in the detection and control of residential fires. Therefore providing improved protection against injury, life loss and property damage.[22]

The minimum requirements for spacing, location and position of sprinklers are based on the following principles:

1. Sprinklers must be installed throughout the premises (certain areas are permitted to remain unsprinklered).

2. Sprinklers must be located so as not to exceed maximum protection area per sprinkler.

3. Sprinklers must be positioned and located so as to provide satisfactory performance with respect to activation time and distribution.

E. Approval Standards for Residential Sprinklers

Due to their differences compared to standard pendent sprinklers, residential sprinklers are listed using a different standard. Product evaluation organizations have developed specialized standards such as UL 1626, *Standard for Safety for Residential Sprinklers for Fire-Protection Service*. FM global developed Approval Standard FM 2030, *Research Approval Standard for Residential Automatic Sprinklers*, for residential sprinklers. Both standards include a plunge test with specific sensitivity requirements. In addition, both standards include a distribution test that checks the spray pattern in the vertical and horizontal planes. Both UL 1626 and FM 2030 also include a fire test that is intended to simulate a residential fire in the corner of a room containing combustible materials representative of a living room environment. [36]

The UL 1626 test procedures include a fuel package with three varying test configurations. The fuel package is composed of several different components: a wood crib, two simulated furniture ends covered with foam, two sheets of ¼ inch Douglas fir plywood, a pan with heptane, and two heptane-soaked cotton wicks. The various test configurations are used to test pendent, upright, flush, recessed pendent, concealed and sidewall sprinklers. [36]

To meet the UL 1626 fire control criteria, residential sprinklers, installed in a fire test enclosure with an 8-ft ceiling, are required to control a fire for 10 minutes with the following limits:

1. The maximum gas or air temperature adjacent to the sprinkler 3 inches below the ceiling at two locations within the room must not exceed 600°F.

2. The maximum temperature 5 feet 3 inches above the floor at a specified location within the room must be less than 200°F during the entire test. This temperature must not exceed 130°F for more than a 2 minute period.

3. The maximum temperature ¼ inch behind the finished surface of the ceiling material directly above the test fire must not exceed 500°F.

4. No more than two residential sprinklers in the test enclosure can operate. [36]

To meet the UL 1626 water distribution requirements, the water spray distributions are collected in both the vertical and horizontal planes. The quantity of water collected on both the horizontal and vertical surfaces is measured and recorded. Sprinklers being tested are required to discharge a minimum of 0.02 gpm/ft^2 over the entire horizontal design area, with the exception that a limited area is permitted to be less than 0.02 gpm/ft^2 as long as it is at least 0.015 gpm/ft^2. The sprinklers must also wet the walls of the test enclosure to a height not less than 28 inches below the ceiling with one sprinkler operating. Each wall surrounding the coverage area is required to be wetted with a minimum of five percent of the sprinkler flow. [36]

F. Sprinkler Droplet Sizes and Distributions

Droplet sizes and distributions produced by automatic sprinklers have been studied using a variety of techniques including Phase Doppler Interferometry (PDI) and Particle Tracking Velocimetry and Imaging (PTVI). New research techniques are being developed to analyze the atomization (e.g. sheet breakup locations and initial drop sizes) and dispersion (e.g. volume density and local drop size profiles) in sprinkler sprays. This research primarily focuses on droplet sizes greater than 200 μm but may focus on smaller droplet sizes in the future.[38] Measurements of the droplet sizes produced by automatic sprinklers are relatively complex, because the droplet size distribution measured is expected to vary with several factors including:

1. Position with respect to the sprinkler in 3-dimensions
2. Sprinkler model
3. Operating pressure/flow rate
4. Liquid supplied to the sprinkler, e.g. water or antifreeze solution
5. Surrounding air currents, including fire induced flows

Even with all of the variables above held constant, measurements include a range of droplet sizes and not a single uniform droplet size. In addition, very limited information is available on the droplet distributions for sidewall sprinklers.

Putorti analyzed existing fire sprinkler droplet size and velocity measurement methods and identified limitations of the existing methods.[9] Putorti's research included the development of the PTVI technique to provide large-scale, simultaneous, non-intrusive measurement of droplet size and velocity in two phase flows.

The PTVI testing apparatus used by Putorti illuminates a 0.5 m by 0.5 m region of the spray field with two consecutive laser sheet pulses of different wavelengths. Dyes in the water fluoresce in two different colors, resulting in two differentiable color images for each drop, which are recorded by high-speed camera. Drop velocity is determined from the distance traveled in the time between the pulses, and size from the areas of the droplet images.

Putorti found that droplet sizes from standard orifice, pendent spray fire sprinklers are between approximately 200 and 3,000 µm with velocities on the orders of 1 m/s and 10 m/s. This approximation agreed with existing research which indicated that droplets larger than approximately 5,500 µm in diameter are unstable and break up into smaller droplets, predominantly in the range of 1,000 to 2,000 µm[39]. Putorti had already discovered from previous research that while a large number of very small drops are present, they comprise a small portion of the total water volume. Data indicates that 98% of the water from standard orifice fire sprinklers is contained in droplets larger than 200 µm in diameter. [40]

The PTVI method enabled Putorti to measure droplet size and velocity distributions with a low level of uncertainty. Unlike the PDI technique, which only measured data at a single point, the PTVI method allowed data measurement over a larger area (0.5m x 0.5m) simultaneously. Based on this data, large scale unsteady behaviors could be studied and directly compared with water sheet breakup predictions to verify droplet trajectories predicted by computer modeling.[9]

The PDI technique measures drop size and velocity. Droplets are illuminated by two incident laser beams and the scattered light signals are detected and analyzed. The scattered light signals form fringe patterns. The spatial frequencies of the fringe patterns are inversely related to the drop diameter. This measurement technique works well for spherical droplets. However, sprinkler droplets are not always spherical.[9]

Widmann used the PDI technique to measure droplet size distributions from a residential sprinkler.[10] The sprinkler investigated had a k-factor of 5.6 gpm/psi$^{1/2}$ and was supplied with water at a pressure of 19 psig ± 1 psig during the testing. Measurements were taken at 1.12 m below the sprinkler and the results were found to vary depending on if measurements were taken near or far from the axis of the sprinkler. Measurements of water droplet sizes ranged from an arithmetic mean of 200 to over 500 µm, depending on location. However, droplets with diameters of less than 100 µm were measured near the axis of the sprinkler.

The PDI technique involves point measurements made at various locations in the sprinkler flow (results are temporally and spatially averaged). This technique for determining attributes of sprays from fire sprinklers is limited by several factors. First, sprays generated by fire sprinklers are unsymmetrical and unsteady. Certain areas of the spray distribution are denser than others. Furthermore, some areas of the spray distribution contain different drop sizes than the statistical average. Since the PDI technique involves point measurement, the results obtained by this method may vary dependent on where the point measurements are taken within the spray distribution. These limitations are relevant to all point measurement techniques.[9]

Factory Mutual (FM) studied the spray distribution characteristics of antifreeze-water solutions for use in Early Suppression Fast Response (ESFR) sprinklers.[11] Specifically, FM sought to determine if a fluid, with a greater density and viscosity, had a significantly different spray distribution than that of water. Theoretical analyses were conducted followed by experimental analyses.

FM theorized that the mean drop size is directly dependent on the orifice diameter of the sprinkler type in addition to the system pressure and fluid properties of the solution being discharged. Specific fluid properties included surface tension, dynamic viscosity and density. According to the report, droplet formation is governed by surface tension, which causes the breakdown of water sheets into droplets. FM further predicted that fluid viscosity is directly related to a droplet's oscillation activity. Droplets with high oscillation activity and low fluid viscosity tend to break apart and form smaller droplets. Inversely, liquids with high oscillation activity and high fluid viscosity tend to not break apart. This dampening in oscillations will theoretically lessen the probability that larger droplets will breakdown into smaller droplets.

It is important to note that sprinkler spray patterns entrain large amounts of air which carry small drops toward the inner spray axis. It can be observed in this phenomenon that the majority of larger droplets fly towards the outer regions of the spray pattern. This correlation suggests that high viscosity fluids (antifreeze) will have fewer small drops and a lower spray density near the inner spray axis.

Following their theoretical predictions, FM conducted experimental tests for water and antifreeze fluids that included: 60% potassium lactate, 60% potassium acetate, and 28.5% calcium chloride. Spray distribution was observed for each fluid at ambient temperature. A single K-25 ESFR sprinkler was supplied with approximately 175 gpm of fluid. The antifreeze fluids had higher densities than that of water and higher pressures at the sprinkler were required to achieve the same volumetric flow rates.

The spray patterns were observed both photographically and visually. A series of two tests were performed for each fluid. FM concluded that the spray patterns for both the water and antifreeze fluids were virtually identical. This observation contradicts the theoretical predictions that antifreeze fluids with higher viscosities would have distinctively different spray patterns to that of water alone. Further research is required to characterize the effect of the fluid characteristics on droplet size distributions from residential sprinklers.

G. Flammability of Liquids

Liquids are substances whose vapor pressure at a reference temperature (commonly 25°C) is less than 1 atm. However, the actual state of a substance (gas, solid or liquid) is dependent on both its pressure and its temperature. For example, nitrogen is a gas at room temperature;

however, it is commonly sold in liquid form. This phenomenon occurs when nitrogen gas is compressed in a container. In this example, the liquefaction of nitrogen occurs when nitrogen gas is compressed.

NFPA 30, *Flammable and Combustible Liquids Code,* defines a liquid as any material that (1) has a fluidity greater than that of 300 penetration asphalt when tested in accordance with ASTM D 5, *Standard for Penetration of Bituminous Materials,* or (2) is a viscous substance for which a specific melting point cannot be determined but that is determined to be a liquid in accordance with ASTM D 4359, *Standard Test for Determining Whether a Material is a Liquid or a Solid.*

Liquids have many quantifiable properties that vary depending on the type of liquid and the environment it is exposed to. An example of these properties are a liquid's upper flammability limit (UFL) and lower flammability limit (LFL). These properties of a liquid stem from the phenomenon of concentration gradients around liquids in an open container. For liquids in containers open to the atmosphere, there is a continuous loss of liquid through evaporation. As such, a concentration gradient may exist above the liquid. This concentration gradient will vary based on factors such as height, pressure and air motion. Essentially, the UFL is the highest concentration of a gas or vapor in air capable of producing a flash fire in the presence of an ignition source. The LFL is the lowest concentration capable of producing a flash fire.[7]

If an ignition source is brought near an open vessel of a flammable liquid, ignition will only be possible at certain distances from the surface of the liquid. At distances far from the surface of the liquid, the concentration of vapors will be below the LFL. As the ignition source approaches the surface of the liquid, there will be a region where ignition is possible because the concentration of vapors is between the UFL and LFL. Finally, as an ignition source is brought even closer to the surface of the liquid, ignition will no longer be possible again. At this point, the concentration of vapors will be above the UFL.[7]

The flash point is the temperature at which a liquid must be raised in order to produce sufficient vapors for flash ignition. The flash point can be measured by one of many standardized test apparatuses. These devices are usually characterized as open-cup or closed-cup arrangements.[7]

Maintaining a liquid at a temperature below its measured flash point does not guarantee that ignition will be prevented. There are many factors that may influence a liquid's actual flash point. This is because the flash point of a liquid, as measured by test apparatus, is not necessarily the flash point of a liquid in its end-use environment. Liquids with flash point temperatures greater than the temperature of the environment of the liquid may sometimes be ignited by spraying, wicking or other means. Liquids that are mixtures, as opposed to pure substances, may demonstrate a tendency for vaporization of one component and not the other. The flash point of the remaining liquid may be different than that of the mixture when it was originally tested.[7]

At some temperature above a liquid's flash point temperature, an ignitable liquid's vapor (that accumulates in a closed space) can ignite without the presence of an ignition source. This is known as the autoignition temperature (AIT). There is no known relation between a liquid's flash point and its AIT. The AIT is primarily determined by a liquid's reactivity (rate of oxidation) while the flash point is determined by a liquid's volatility (rate of evaporation). Many factors may affect a liquid's AIT. Some known factors are the concentration of the vapor given off by the liquid, the shape and size of the container, the rate and duration of heating and the testing method.[7]

Critical to this report is the combustion of atomized liquids (mists, vapors or sprays) produced during the operation of an automatic sprinkler system. Typically in a condensed mist, the diameter of most of the droplets is less than 10 µm. Aerosols that have been produced by the atomization of a liquid by mechanical force typically have a droplet diameter of greater than 100 µm.[8] As indicated above, testing shows that 98% of the droplet sizes from standard orifice pendent spray fire sprinklers are between approximately 200 and 3,000 µm in diameter.

A suspension of finely divided droplets of flammable liquid in air can yield a flammable mixture that has many of the characteristics of a flammable gas/air mixture. These droplets have the potential to burn or explode. Researchers have observed that a 10 µm diameter droplet of flammable liquid behaves like a vapor with respect to burning velocity and LFL. Droplets with diameters larger than 40 µm behave differently.[8]

Flame propagation can occur at average concentrations well below the LFL. A flammable mixture can also form at temperatures below the flash point of a liquid combustible when atomized into air. Testing shows that with fine mists and sprays (particles less than 10 µm) the combustible concentration at the lower limit is about the same as that in uniform vapor-air mixtures. However, as the droplet diameter increases, the lower limit appears to decrease. It was observed that coarse droplets tend to fall towards the flame front in an upward propagating flame, and as a result the concentration at the flame front actually approached the value found in lower limit mixtures of fine droplets and vapors. [41]

Mists made up of coarser aerosols are capable of sustaining a flame at considerably lower fuel-air ratios than fine aerosols (vapors). The reason for this lies in the ability of the droplets to move in relation to the ambient air. Mists made up of coarser aerosols prove to be more responsive to acceleration and random movement than that of finer aerosols. As such, coarser aerosols communicate flame more readily. [8]

In the case of water-glycols, flash points will not exist until the excessive water has been removed. Research indicates that a high-temperature environment is required to realize a flash point hazard with the vapors of these fluids at normal pressure conditions.[6]

H. Factors Required for an Explosion

In a fuel-air cloud, flame can propagate in two modes: a deflagration or a detonation. A deflagration involves subsonic flame speeds from a few meters per second up to 1,000 m/s. This magnitude of flame speed results in overpressures from near zero up to several bar. A detonation involves supersonic (relative to the speed of sound in the unburned gas ahead of the wave) combustion waves. In this case, the shock wave and combustion wave are coupled. These waves will propagate at a velocity of 1,500 to 2,000 m/s and cause explosion pressures with magnitudes of 15-20 bar. [14]

If ignition occurs before a fully mixed fuel-air cloud has been formed, a flash fire or deflagration will occur instead of a detonation. Furthermore, it is important to understand that when a cloud of flammable vapor (fuel-air) burns, the combustion may or may not give rise to an overpressure. In a flash fire, there is no overpressure. In an explosion, there is overpressure.[8]

Large combustible premixed fuel-air clouds that have been formed in the presence of an ignition source are the most dangerous. If ignition occurs, the pressure generated by the combustion wave is directly related to the speed of flame propagation and the nature of pressure expansion away from the fuel-air cloud. This relationship is governed by confinement.[14]

The pressure build up associated with gas explosions is a relation of the pressure generation by the flame and the relief of the pressure, through venting. Furthermore, an explosion in a compartment is a very complex process that involves several parameters that include: type of fuel, size and concentration of the fuel cloud, ignition and geometrical layout (i.e. confinement, venting and obstructing objects). In a small compartment with no to very little venting, even slow burning can cause pressure build up. In extreme cases, it has been observed that a slow flame can cause pressures up to 8 bar in a compartment that remains closed. Vent openings are of major importance in keeping explosion pressure down.[14]

I. Existing Approval Standards and Test Methods for Ignition Properties of Liquids

Flammability characteristics of liquids are measured using a variety of test methods. The following are common measures of the flammability of a liquid.

Flash Point

Several test standards exist for measuring flash point. The Cleveland open-cup test method, ASTM D 92, is commonly used for products that have a flash point between approximately 174°F and 750°F. The test uses a cup with 70mL of test liquid. Temperature uniformity across the bottom of the cup is regulated by a metal plate. The metal plate can be heated by either a gas burner or an electric resistance heater. The test liquid is heated at a rate of approximately 41°F to 43°F per minute. The purpose of the test is to measure the flash point of the test liquid.[7]

Another method to test a liquid's flash point is the Pensky-Martens closed-cup (PMCC) tester, ASTM D 93, is limited to testing substances with a viscosity greater than 5.5 cSt at 104°F. The tester utilizes a heated stirrer (intended to maintain temperature uniformity) inserted into the test liquid. The test liquid is heated at a rate of approximately 41°F to 43°F per minute. The PMCC is used to measure the flash point of liquids between 174°F and 750°F.[7]

Autoignition Temperature

The AIT is highly dependent on the test method used. Some of the variables known to affect the AIT are the shape and size of the testing volume, the concentration of the gas or vapor in the mixture and the duration and rate of heating, based on the ignition source. Since there are many different testing methods that have been developed to measure the AIT of liquids, it is not uncommon to find different AIT values for the same material.[7]

ASTM E 659 is an example of a test method used to measure AIT of liquids. In this method, the testing vessel is a glass flask surrounded by an electrically heated oven equipped with several thermocouples. To conduct a test, a 0.1 mL sample of liquid is injected into the glass flask. The flask is heated to a constant temperature and is observed for 10 minutes (in a fully darkened room) for indications of ignition. If ignition does not occur, the temperature of the electric oven is raised and the process is repeated. Once the AIT is observed, both larger and smaller amounts of the liquid are analyzed to determine the overall lowest AIT.[7]

ASTM E 659 replaced older versions of ASTM AIT tests such as ASTM D 286 and ASTM D 2155 (both withdrawn from ASTM recommended testing methods). Results obtained from ASTM E 659 are typically lower than that from ASTM D 2155, and the differences are greater for more volatile fuels. Similar to ASTM E 659, ASTM D 2155 involves the heating of the sample liquid in a glass vessel. This vessel is observed for AIT for only five minutes (five minutes less than ASTM E 659). ASTM D 286 did not allow for visual observation of AIT and, as such, the apparatus was criticized on a practical basis.[7]

Flammability of Fluid Sprays

As discussed above, flash point measurements are not a reliable indication of the potential for ignition of a liquid dispersed into droplets. FM Global Class Number 6930 *Approval Standard for Flammability Classification of Industrial Fluids*[42], was developed to evaluate the ignition potential of industrial fluid sprays. For example, in industrial applications the failure of a pressurized hose could allow potentially combustible fluids to spray onto nearby ignition sources. Approval Standard 6930 classifies the flammability of industrial fluids based a series of tests that are design to characterize the spray flame hazard of an industrial fluid.[43] Because the potential for ignition of a liquid spray differs from a pool of the same liquid, Approval Standard 6930 may provide a more reliable method of characterizing the flammability of antifreeze solutions used in sprinkler systems than more common measurements such as flash point.

The approval standard requires industrial fluids to be screen tested to determine a flash point or verify that the fluid will boil prior to obtaining a flash point. The screening test required by this approval standard is the Cleveland open-cup test, ASTM D92.

Industrial fluids submitted for testing (having a flash point) must satisfy each of the following performance criteria to be eligible for FM Approval:

- Determination of the flash point by Cleveland open-cup;
- Determination of the chemical heat release rate (HRR) of a highly atomized spray of the industrial fluid;
- Determination of the industrial fluid density per ASTM D1480 or ASTM D4052;
- Calculation of the critical heat flux for ignition of the industrial fluid;
- Calculation of the Spray Flammability Parameter of the industrial fluid.

The Spray Flammability Parameter (SFP) calculated as part of the approval process is intended as an indication of the potential for ignition of a hydraulic fluid dispersed as droplets. The value of the SFP combines the chemical heat release rate from spray fires and the volatility of fluids in terms of a critical heat flux for ignition.[43] The chemical heat release rate used in the equation is measured from the FMRC Fire Products Collector and fluid spray setup. In this test, fluids are sprayed vertically upward in the open from an 80 degree hollow cone nozzle with an exit diameter of 0.38 mm. The tip of the nozzle is in the same plane as a propane ring burner. All of the combustion products (along with the ambient air) are captured in a sampling duct that is equipped with instrumentation for oxygen consumption calorimetry. In the sampling duct measurements are made for the total volumetric flow rate of the mixture of fire products and air; gas temperature; generation rates of carbon monoxide and carbon dioxide; and the consumption rate of oxygen. The chemical heat release rate used to calculate the SFP is the average steady state values measured by the calorimeter.[43]

The value of the SFP depends on the initial temperature of the fluid, the degree of atomization, and the temperature of air entrained into the jet. The SFP is a measure of the degree of spray flame hazard for hydraulic fluids. Fluids associated with higher SFP values have a higher burning rate while fluids with lower SFP values have lower burning rates.[43]

Additional requirements exist for industrial fluids that do not have a flash point. Since propylene glycol and glycerin both have measured flash points, the other requirements are not outlined in this report.

IV. Existing Fire Incident Reports

Two existing fire incident reports have been obtained that involve fires related to automatic sprinkler systems containing antifreeze solutions. After a fire incident, fire investigators are often called to the scene to conduct a fire analysis. Investigators collect data, analyze the data and develop a hypothesis based on the research conducted. A fire investigator's hypothesis outlines the suspected cause of the fire and identifies other critical factors relating to the fire incident. It is important to note that while a fire investigator's hypothesis is based on the best available information and evidence, it is not necessarily a truly provable hypothesis.[20]

A. Monmouth Beach, NJ

In October of 2001, a fire occurred in a restaurant located in Monmouth Beach, New Jersey. The fire originated in an outside enclosed deck/porch area at the ceiling level. The Fire Marshal of the County of Monmouth conducted the fire investigation and prepared the investigation report dated March 14, 2002.[13]

According to the report, the restaurant was protected by an automatic sprinkler system that contained an antifreeze-water solution (propylene glycol-water). Located on the ceiling of the porch were nine Sun Pak Heaters rated at 25,000 Btu each. The heaters were natural gas fired and in use at the time of the incident. Located on the wall to the rear of the row of ceiling heaters were sidewall mounted sprinkler heads. The sidewall sprinklers installed had an activation temperature of 155°F, which are recommended for locations with a maximum temperature of 100°F.

After analysis of the incident, it was the opinion of the investigator that the heaters caused the ceiling temperature in the outdoor porch area to rise above the nominal temperature rating of the sidewall sprinklers, thus causing sprinkler activation. Upon activation, the vapors from the sprayed propylene glycol-water solution (contained in the sprinkler system) resulted in a flash fire upon interaction with the heaters. This flash fire resulted in flames that traveled across the ceiling and continued into the inside of the restaurant. When all of the propylene glycol-water solution had been discharged, the plain water followed and the fire was extinguished. The building sustained very limited fire damage and several restaurant patrons received medical treatment for smoke inhalation and thermal skin burns.

B. Truckee, CA

On August 18, 2009, a fire and explosion occurred at the Henness Flats Apartment Complex in Truckee, California.[12] The following information is from a report developed by Stephen Hart. Mr Hart was asked by the California Office of the State Fire Marshal (OSFM) to assist as a subject matter expert through the local government request for fire investigation assistance from the OSFM.

The Henness Flats Apartment Complex is a 92-unit multi-building apartment complex. There are 12 individual apartment buildings within the complex. Building #6, where the fire and explosion occurred, was a 2-story structure that consisted of 12 apartment units. The unit where the fire and explosion occurred was located on the first floor and was on the east end of the building.

The automatic fire sprinkler system riser, which served the 12-unit apartment building, was located on the exterior wall adjacent to this unit. According to Mr. Hart's observations, the force of the explosion caused window glass in the unit to be blown more than 86 feet across the adjacent parking area and caused an interior door frame and attached door to an adjacent bathroom to be separated by approximately 3 inches.

Mr. Hart's report notes that, according to the submitted fire sprinkler drawings, the overhead fire sprinkler piping was supplied by a 4-inch main that runs the length of the building and stubs up with a 2-1/2-inch riser that feeds the two units on the first and second floor levels. The report also notes that the fire sprinkler drawings indicate that the antifreeze sprinkler system had a capacity of 256.2 gallons and used a 50% solution of glycerin and water designed to have a freezing point of -20.9°F.

It is the opinion of Mr. Hart that the tenant was cooking onions in a frying pan over the electric stove when the contents of the pan caught fire. The tenant turned around (180 degrees) to the kitchen sink with the flaming frying pan to put water on the fire and the fire sprinkler activated directly over him. Upon sprinkler activation, a discharge of glycerin based antifreeze was ignited by the flames coming from the burning onions in the frying pan and an explosion resulted. As a result of the fire and explosion, it was noted that eight of the ten residential sprinklers within the unit activated. The fire sprinkler over the kitchen sink was reported to be a residential pendant sprinkler with a k-factor of 4.9 gpm/psi$^{1/2}$ and an activation temperature of 155°F.

V. Prior Research

Research studies have been conducted by SP Technical Research Institute of Sweden (SP), Factory Mutual (FM), and Underwriters Laboratories (UL) to evaluate the use of antifreeze solutions in sprinkler systems. This section summarizes the prior research and testing as it relates to the use of antifreeze solutions in residential sprinkler systems.

A. SP Research

SP investigated the effect of antifreeze-water mixtures upon interaction with intermediate-scale wood crib fires.[44] The tests analyzed antifreeze-water mixtures of calcium chloride, potassium acetate, ethanol, urea, methanol, propylene glycol and glycerin. The tests specifically focused on the potential contribution of the combustion energy of such agents to a fire.

The fire tests were conducted in an intermediate scale. The fire source was a burning wood crib (approximately 730 x 730 x 360 mm). A liquid fuel was applied to the crib that upon ignition would last for three minutes. It was measured that after the igniter fluid was consumed, the free-burn chemical heat release rate of the fire quickly reached a steady heat release rate (HRR) of approximately 800 kW. Furthermore, at four minutes after ignition the antifreeze solution was evenly distributed with spray nozzles (volumetric flow rate of 2.95 L/min) above the wood crib. The antifreeze solution was applied for ten minutes at which time the test was terminated.

The application rate was selected so that the heat release rate of the fire was reduced, but the fire was never actually extinguished with water. The test report notes that antifreeze solution was completely vaporized and consumed in the flames with little runoff of liquid.

Table 5: SP Test Results, below, outlines the SP test results for propylene glycol, glycerin, and water.

Agent	Freezing Point (°F)	Mass Fraction (%)	Density @ 20°C (kg/L)	Total Chemical Energy Released (MJ)
Water	32	---	0.998	357
Propylene Glycol	5	33.5	1.039	493
Glycerin	5	39.0	1.098	545
Glycerin	-22	57.0	1.146	596
Propylene Glycol	-22	49.0	1.062	629

Table 5: SP Test Results

The conclusions of the SP Report are as follows:

- The contribution of energy to a fire by the antifreeze solution may be a factor that needs to be considered for some sprinkler system applications.
- Antifreeze agent solutions of propylene glycol and glycerin resulted in a significant increase in the heat release rate of the fire relative to the water only tests.

B. FM Research

FM's research was, in part, a continuation of research conducted by SP. FM conducted a series of tests similar to those of SP. The FM tests compared the effectiveness of various antifreeze-water mixtures by steadily dripping a small of amount of these mixtures onto a well established wood crib fire. Similar to the SP experiments, the reduction in the fire's heat release rate was recorded.

The wood cribs were approximately 600 grams and were consumed in approximately 10 minutes under free-burn conditions. The cribs were ignited by 50 grams of acetone (igniter fluid) and allowed to free-burn for 4.75 minutes before the antifreeze-water mixture was applied via four drip nozzles (total rate of 0.522 ml/s). The test report notes that there was negligible antifreeze-water runoff while the cribs were burning.

Table 6: FM Test Results, below, summarizes the results of these experiments. The results were later analyzed to evaluate whether antifreeze solutions could be used with ESFR sprinkler systems. Data from the SP fire tests is also included in the table.

Agent	FM Data		SP Data
	Crib Moisture Content (%)	Avg. HRR 285-570 s (kW)	Avg. HRR (kW)
Free Burn	3.7	10.18	800
Water	5.4	7.72	600
50% Propylene Glycol	5.8	10.18	1050
35% Propylene Glycol	3.3	9.12	825

Table 6: FM Test Results

The conclusions of the FM Report were as follows:

- Accounting for the moisture content of the cribs, a 50% propylene glycol solution with water mixture raised the fire's HRR above that of the free-burn fire.

- A 35% propylene glycol solution with water has a neutral effect during the time in which it is replaced by water (roughly comparable to the air initially supplied by a dry pipe system).

- This suggests that a 35% propylene glycol solution with water should theoretically perform comparable to a dry pipe sprinkler system.

- Propylene glycol antifreeze solutions were found to be unacceptable for use in ESFR fire sprinkler systems due to their performance compared to water.

C. UL Research

1. ESFR Sprinkler Protection of Cold Storage

UL conducted a series of tests to evaluate the effectiveness of ESFR sprinklers in suppressing fires involving Standard Class II commodity using antifreeze solutions.[45] Tests were conducted under a 40 ft ceiling with rack storage heights ranging from 30 to 35 feet. A 50% solution of propylene glycol in water was used in all tests.

Unlike the prior SP and FM research efforts, the UL tests used actual sprinklers and set criteria based on suppression of the fire, instead of comparing the performance of the antifreeze agent to the performance of water. The results of the tests are summarized in the following table.

Test	**Sprinkler k-factor (gpm/psi$^{1/2}$)**	**Discharge Rate (gpm)**	**Storage Height (feet)**	**Result**
1	14.0	119	30	Uncontrolled
2	25.2	160	30	Suppressed
3	25.2	160	35	Suppressed

Table 7: UL ESFR Cold Storage Test Results

The UL Report indicates the following:

- It is believed that the discharge rate of the sprinkler system must be sufficient to compensate for the combustion energy released by the antifreeze mixture.

- Suppression of the Standard Class II commodity fire with antifreeze solution was achieved by increasing the flow rate of the sprinkler system.

2. Manufactured Home Sprinkler Protection

UL conducted a series of tests for the Federal Emergency Management Agency to investigate sprinkler protection of manufactured (mobile) homes and rural housing.[46]

The research focused on controlling fire conditions using limited water supplies. Total available water supplies of 50 and 100 gallons were investigated. This research was conducted with a sprinkler having a nominal K-factor of 2.0 gpm/psi$^{1/2}$.

The project considered the impact of 6% wetting agent, 0.3% Class A foam, and 50% glycerin on the effectiveness of a residential sprinkler system. Although rarely used in residential sprinkler systems, the wetting agent and Class A foam were investigated for their ability to improve the effectiveness of the sprinkler system, because faster extinguishment of a fire could reduce the quantity of water needed. Certain tests added glycerin alone or in combination with the wetting agent or foam to investigate the impact of antifreeze on the effectiveness of the sprinkler system for conditions where the water supply may be located in spaces subject to freezing.

Ten fire tests were conducted in a living room/kitchen area measuring 13 feet by 23 feet with a vaulted ceiling. The room was protected with six residential style sprinklers.

A UL 1626 residential fuel package was located in a corner of the room and consisted of a 12 to 13 lb. wood crib with dimensions of 12-inches by 12-inches by 12-inches along with simulated furniture using two 3-inch thick foam cushions measuring 36 inches by 40 inches over wood frames. Instrumentation included the following:

- Temperature at 12 locations throughout the home;
- Activation times of each sprinkler;
- Sprinkler system inlet pressure;
- Smoke density; and
- Carbon monoxide and carbon dioxide concentrations.

Test results were evaluated based on number of sprinklers operated, temperature, carbon monoxide, and carbon dioxide, as well as the following criteria based on UL 1626:

- The maximum temperature 3 inches below the ceiling directly above the wood crib not exceeding 600°F;
- The temperature 63 inches above the floor and 46 inches from the end wall closest to the wood crib not exceeding 200°F at any time and 130°F continuously for more than 2 minutes; and

- The temperature measured ¼-inch behind the ceiling surface, directly above the wood crib not exceeding 500°F.

The results of the UL Manufactured Home tests are outlined in the table below.

Test	Solution		Sprinkler		Measurements in Center of Room of Origin during first 5 minutes				Observations
	Type	Quantity (gallons)	Temp. Rating (°F)	Operating Times (mm:ss)	Max. Temp. (°F)	Max. CO Conc. (ppm)	Max. CO_2 Conc. (ppm)	Light Transmission (%)	
1	Water	100	286	0:59	127	450	9,750	40	Suppressed
2	Water	100	286	1:07	144	300	9,000	32	Suppressed
3	Water	50	175	1:04	92	1,400	11,450	47	Not suppressed
4	50% Glycerin	100	286	0:55	145	1,000	20,000	0	Suppressed, unsteady sprinkler pressure due to pump
5	0.3% Class A Foam/50 % Glycerin	50	286	1:10, 1:27, 1:50, 2:05	375	4,600	52,000	0	Not suppressed, test discontinued at 2:15
6	6% Wetting Agent/50 % Glycerin	50	286	1:09	N/A	N/A	N/A	N/A	Not suppressed
7	0.3% Class A Foam	50	175	1:26	98	715	N/A	90	Suppressed
8	0.3% Class A Foam	50	286	1:03	105	400	4,900	62	Suppressed
9	6% Wetting Agent	50	286	0:57	115	1,150	10,750	58	Suppressed
10	6% Wetting Agent	50	286	1:02	135	440	8,000	41	Suppressed

Table 8: Results of UL Manufactured Home Tests[46]

The conclusions of the UL Manufactured Home test report are as follows:

- Acceptable test results were obtained for tests using 100 gallons of water and the test using 100 gallons of 50% glycerin solution.
- Unacceptable test results were obtained for the test using 50 gallons of water.
- Acceptable tests results were obtained for tests using 50 gallons of 6% wetting

agent and 0.3% Class A foam solution.

- The addition of glycerin to the wetting agent and Class A foam solutions produced unacceptable results.
- It appeared that the glycerin did not permit the wetting agent and Class A foam solutions to spread and penetrate the fire surface as well as in the tests without glycerin.

The following observations are based on comparing the results of the test with a 50% concentration of glycerin in water (Test 4) to the two equivalent tests with water alone (Tests 1 and 2):

- All three tests met the performance criteria for the project.
- Unsteady pump pressures were noted during the test with glycerin that may or may not influence the results.
- The test with glycerin has a measured temperature in the center of the room of fire origin that was comparable to one of the tests with water alone.
- The test with glycerin had measured carbon monoxide and carbon dioxide concentrations in the center of the room of fire origin that were more than double those measured during the tests with water alone.
- The test with glycerin had a measured light transmission near zero, while the two comparable tests with water alone each had a measured light transmission of more than 30 percent.

VI. Research Plan and Near-Term Testing

A research plan was developed to investigate the effectiveness of glycerin and propylene glycol antifreeze solutions in residential fire sprinkler systems. The research plan focuses on three primary areas of concern:

1. The impact of various concentrations of propylene glycol and glycerin antifreeze solutions on the effectiveness of residential sprinkler systems over a range of system pressures and residential fire scenarios.

2. The potential for a flash fire from residential sprinklers supplied with propylene glycol or glycerin under rare conditions.

3. The development of alternative antifreeze solutions for conditions where glycerin and propylene glycol are not found to be suitable.

Fire tests were conducted by Underwriters Laboratories during the development of this report that preliminarily investigated the first two items. Observations from the UL tests and recommendations for future testing are provided below.

A. Near-term Testing on Sprinkler Effectiveness with Antifreeze Solutions

A series of preliminary tests were sponsored and conducted by Underwriters Laboratories during the development of this report. Tests were conducted in UL's large scale test facility in Northbrook, IL and several of the tests were witnessed by CCI on behalf of the Foundation. This report provides a general summary of observations from the test series. A complete report of the testing is not available at this time and further analysis of the test results should be conducted when the test report is available.

Initial tests were conducted with a small ceiling above an elevated pan of heptane using residential pendant sprinklers with nominal k-factors of 3.1 and 4.9 gpm/psi$^{1/2}$. The tests used premixed solutions of 70% glycerin and 60% propylene glycol with water. The tests indicated the potential for large-scale ignition of a 70% glycerin solution using a 3.1 k-factor sprinkler at an operating pressure of 100 psi. This large-scale ignition resulted in flames surrounding the majority of the sprinkler spray. A similar large-scale ignition did not occur for initial tests with 60% propylene glycol solutions or tests using a 4.9 k-factor sprinkler at an operating pressure of 50 psi. Analysis of the contribution, if any, of antifreeze solutions to each fire condition should be conducted when the test data is available.

Further tests were conducted in a three sided room measuring approximately 12 feet by 12 feet with a ceiling height of 8 feet. A single sprinkler with a k-factor of 3.1 was located in the center of the ceiling for each test. The majority of the room tests were conducted using a nominal 12-

inch cast-iron pan with cooking oil as the initial fire source. An electric cooktop was used to heat the pan and ignite the cooking oil. One room test was conducted with a pan of heptane as the initial fire instead of the cooking oil. In various tests, the sprinkler was supplied with water only as well as premixed solutions of 70% glycerin, 50% glycerin, and 60% propylene glycol in water. Sprinkler operating pressures of 20, 100, and 150 psi were investigated.

Test results in the room configuration ranged from extinguishment of the fire to large-scale, sustained ignition of the antifreeze solution. Preliminary observations during the tests indicate that the results depend, at a minimum, on a combination of the following factors:

- Location of the initial fire with respect to the sprinkler
- Initial fire source
- Type of sprinkler and operating pressure
- Type and concentration of antifreeze solution

Large-scale, sustained ignition of the 70% glycerin solution supplied at 100 psi occurred when the initial fire was in close proximity to the sprinkler, but the initial fire was controlled using the same concentration of antifreeze at the same operating pressure when the initial fire was located farther from the sprinkler. Large-scale ignition of the 60% propylene glycol solution occurred in the room configuration during a cooking oil fire, but did not occur in the open configuration during a heptane fire. Large-scale ignition of the antifreeze solution did not occur in any of the tests with the 50% glycerin solution. Further investigation of the contribution, if any, of the antifreeze solutions to each fire condition should be conducted when the test data is available.

Preliminary observations during the UL testing indicate the following:

- Large-scale ignition of antifreeze solutions occurred in certain tests for 70% solutions of glycerin and 60% solutions of propylene glycol with water.
- Large-scale ignition of antifreeze solutions of 50% glycerin with water did not occur for any of the tested configurations; further investigation should be conducted for a variety of initial fire sources and test configurations.

Further analysis of the tests should be conducted when the results are available. Preliminary observations from the tests highlight the need for further research into the effectiveness of currently permitted antifreeze solutions and consideration of their suitability for use in sprinkler systems.

B. Future Research

Potential Contribution of Antifreeze Solutions to Fire Conditions

The existing research as well as the recent near-term testing conducted by UL indicate the urgent need for further research into the effectiveness of currently permitted antifreeze solutions. This is based on two concerns:

1. The potential for large-scale ignition of antifreeze solutions; and

2. The potential for antifreeze solutions to reduce the effectiveness of sprinkler systems.

The potential for the large-scale ignition of antifreeze solutions supplied by sprinkler systems involves the following research topics:

- Droplet combustion of a solution of water and propylene glycol or glycerin.
  - Impact of the droplet size distribution, concentration, and spatial distribution on the potential for ignition.
  - Impact of ignition sources on the potential for ignition.
  - Influence of concentration on the potential for ignition and the need to remove water from the solution.
- Residential sprinkler droplet distributions over a range of locations, sprinkler types, liquid types, and operating pressures.
- Potential for an explosion resulting from a flash fire in a confined space.

Existing research into each of these topics has been identified and summarized as part of the literature search. From the discussion above, it is clear that each of the topics is a complicated and contemporary research topic on its own.

Because antifreeze sprinkler systems are currently in use, a practical approach is needed to investigate the potential for large-scale ignition of antifreeze solutions without waiting for the development of each of the research topics identified above.

Although rare, existing research demonstrates the possibility that a large-scale ignition of antifreeze solution may occur under certain circumstances. Factors to be considered include:

- The impact of antifreeze type and concentration.
- Sprinkler type and operating pressures.
- The type, location and duration of the ignition source.
- Potential for an explosion resulting from a flash fire in a confined space.

FM Global Class Number 6930, *Approval Standard for Flammability Classification of Industrial Fluid,* is intended to investigate the suitability of industrial fluids. This includes an investigation of the flammability of liquid sprays. This standard test method could provide an indication of the potential for ignition of propylene glycol and glycerin antifreeze solutions at various concentrations.

More detailed research specifically addressing the analysis of sprays from residential sprinklers could also be developed, although no standard test method exists for that purpose. The testing program should include an actual residential sprinkler over a range of operating pressures and antifreeze concentrations. This would simulate the range of droplet size distributions and concentrations provided by residential sprinklers. Based on observations from the testing at UL, it is important to test minimum system pressures and higher system pressures due to the complexities in the spray distribution patterns.

Testing should also investigate the impact of antifreeze solutions on maintaining tenable conditions during a fire condition. Standard test methods such as UL 1626, the *Standard for Safety for Residential Sprinklers for Fire-Protection Service*, could be used to provide criteria for future testing. The testing plan should include a range of operating pressures, sprinklers, and antifreeze concentrations.

A strong ignition source should be used to increase the potential for ignition and the ignition source should be moved to a variety of locations with respect to the sprinkler. Care should be taken in conducting such testing, as the purpose of the testing is to investigate whether a flash fire or deflagration could occur. Multiple ignition sources should be considered including, solid fuel fires, combustible liquids and hot surfaces (e.g. electric burners and heaters).

Other Antifreeze Solutions Permitted by NFPA 13

Antifreeze solutions other than propylene glycol and glycerin were not included in this literature review. However, NFPA 13 also permits the use of diethylene glycol and ethylene glycol in certain sprinkler systems. These additional antifreeze solutions have similar properties to those of propylene glycol and glycerin.

Table 9, below, outlines properties of all of the antifreeze solutions permitted by NFPA 13. One notable comparison is the flashpoint of diethylene glycol (255°F) to that of propylene glycol (210°F) and glycerin (390°F). It was observed during the recent preliminary fire tests conducted by UL that a solution of 70% glycerin with water under certain circumstances may result in large-scale ignition of the antifreeze solution. Given that the flash point of diethlyene glycol is less than the flash point of glycerin, additional research should be conducted to analyze the combustibility of diethylene glycol solutions supplied through sprinkler systems.

Another notable comparison is that the autoignition temperature of diethylene glycol (435°F) is significantly lower than that of the other antifreeze solutions permitted by NFPA 13. Because the flash points and autoignition temperatures of diethylene glycol and ethylene glycol are similar to those of propylene glycol and glycerin, additional research should be conducted to analyze the combustibility of diethylene glycol and ethylene glycol solutions supplied through sprinkler systems.

Chemical	Flammable Limits in Air (% by volume) Lower/Upper)	Flash Point (°F)	Autoignition Temperature (°F)	Boiling Point (°F)
Propylene Glycol	2.6 / 12.5	210	700	370
Glycerin	Not Provided / Not Provided	390	698	340
Diethylene Glycol	Not Provided / Not Provided	255	435	472
Ethylene Glycol	3.2 / Not Provided	232	748	387

Table 9: Properties of Pure Antifreeze Solutions Permitted by NFPA 13[47]

Alternative Antifreeze Solutions

In consideration of the potential limitations of antifreeze solutions currently permitted by NFPA 13, alternative antifreeze solutions should be researched as a potential replacement for the existing options. Ideally, the new antifreeze solution would be non-combustible, provide an adequate freezing point, be non-toxic, not be cost prohibitive, and not have material compatibility issues.

VII. Summary

NFPA 13, 13D and 13R permit the use of antifreeze solutions in fire sprinkler systems that are exposed to freezing conditions. In pure form, propylene glycol and glycerin (both permitted by NFPA 13, 13D and 13R) are Class IIIB Combustible Liquids. A literature search has been conducted to investigate impact of antifreeze solutions on the effectiveness of residential sprinkler systems.

Existing research and testing suggests that the combustibility characteristics of antifreeze-water mixtures in droplet form are not completely characterized by standardized test methods for flash point or autoignition temperature. Under certain conditions, atomized antifreeze-water mixtures can combust when sprayed onto an ignition source. Increasing the concentration of the antifreeze in the antifreeze-water solution increases the combustibility of the solution. Additionally, existing research indicates that under certain conditions, the energy release rate of some fires increases upon interaction with antifreeze-water mixtures.

Recent testing conducted at UL indicates that under certain conditions a large-scale ignition is possible from the discharge of a sprinkler system containing solutions of 70% glycerin or 60% propylene glycol in water onto certain ignition sources. This result is dependent on the characteristics of the fuel source, the spray distribution pattern of the antifreeze-water mixture, the pressure of the system, the type of sprinkler, the location of the fire relative to the sprinkler and the concentration of the antifreeze solution in the mixture. Future testing is recommended to analyze the ignition of antifreeze-water mixtures in droplet form. This is important due to the unique combustibility characteristics of antifreeze-water mixtures when atomized during sprinkler discharge.

Research is also recommended to investigate the combustibility of diethylene glycol and ethylene glycol solutions with water (antifreeze solutions also permitted by NFPA 13, 13D and 13R). The flash points and autoignition temperatures of diethylene glycol and ethylene glycol are comparable to those of propylene glycol and glycerin. As such, the combustibility of these solutions should also be addressed.

Existing research indicates that under certain conditions the energy released during a fire condition could increase upon interaction with certain antifreeze solutions currently permitted by NFPA 13, 13D and 13R. Further research is recommended to investigate the effectiveness of antifreeze solutions used in sprinkler systems. Specifically, the ability of antifreeze solutions to control a fire and maintain tenable conditions should be investigated. Additionally, the recent testing conducted by UL demonstrates that, under certain conditions, a large-scale sustained ignition is possible from the discharge of certain sprinkler systems containing antifreeze solutions. Further testing is required to more completely investigate the potential for large-scale ignition or flash fires from antifreeze solutions. Based on the known characteristics of ethylene glycol and diethylene glycol, additional research should also address their suitability for use in sprinkler systems. An alternative antifreeze solution should also be investigated for conditions where the solutions that are currently permitted are not found to be suitable.

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