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A Study of Potential Sources of Linguistic Ambiguity in Written Work Instructions

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Abstract

This report describes the results of a small experimental study that investigated potential sources of ambiguity in written work instructions (WIs). The English language can be highly ambiguous because words with different meanings can share the same spelling. Previous studies in the nuclear weapons complex have shown that ambiguous WIs can lead to human error, which is a major cause for concern. To study possible sources of ambiguity in WIs, we determined which of the recommended action verbs in the DOE and BWXT writer's manuals have numerous meanings to their intended audience, making them potentially ambiguous. We used cognitive psychology techniques to conduct a survey in which technicians who use WIs in their jobs indicated the first meaning that came to mind for each of the words. Although the findings of this study are limited by the small number of respondents, we identified words that had many different meanings even within this limited sample. WI writers should pay particular attention to these words and to their most frequent meanings so that they can avoid ambiguity in their writing.

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NOMENCLATURE

DOE	Department of Energy
SNL	Sandia National Laboratories
WI	work instruction

1. INTRODUCTION

Human error is a major concern across the nuclear weapons complex. Prior reports by Sandia and DOE on the Pantex Plant have indicated that failures to follow operating procedures can lead to potentially hazardous situations (Witmer, 2001) and are the leading cause of reportable occurrences (Brannon, Wenner, Ramos, & Stevens, 2004). The procedural errors that were observed in these studies were caused by a variety of factors, including ambiguous or easily misinterpreted procedures, conflicting procedures, reliance on "operator techniques" instead of formal procedures, and personal biases on the part of the author of the procedure. DOE Order 5480.19 on the conduct of operations requirements for DOE facilities states that "procedures should be written in such a way that they can easily be used without making mistakes." Further, it states that "procedure preparation, verification, and validation should receive high-level attention… Review, verification, and validation should be formalized for written and software procedures." The findings of the Sandia and DOE reports indicate that more work is required to meet these standards. Improvement of the processes for writing, validating, and using operating procedures could lead to a reduction in the number of occurrences at DOE facilities.

To assist with meeting these standards, the present study was conducted to assess the linguistic ambiguity of verbs that are recommended for use in written procedures and work instrictions (WIs). Through this assessment, we have identified which of the recommended verbs are consistently unambiguous and which have the potential to be unclear or misleading.

1.1. Assessing Ambiguity in Language

Ambiguity is common across all levels of the English language. On the word level, words with the same spelling and sound can have multiple meanings (homonyms). For example, the word "bank" is a homonym that can refer to the bank of a river or to a financial institution. The meanings of homonyms are often, but not always, disambiguated by their context. For example, in the sentence "I'm going to the bank," the word's meaning is still ambiguous. Some words can be used as multiple parts of speech, such as the words "control" and "bear," both of which can be a noun or a verb. The meaning of the noun and verb uses of a word may or may not be related to one another, increasing the likelihood of ambiguity.

Verbs have even more potential for ambiguity than nouns. In addition to having multiple meanings, verbs can have multiple senses. Many verbs have a range of related meanings, often extending from concrete actions to metaphorical expressions. Each of those variants is referred to as a verb sense (Hare, McRae, & Elman, 2004). The meanings of the senses of a verb are related by definition (if they were unrelated, they would be considered homonyms), but the relationships between them can be very distant. In addition, verbs can be used in a variety of grammatical structures. Each verb typically occurs on one structure more often than any other, a pattern that language researchers refer to as "verb bias" (Garnsey et al., 1997). The two most common types of verb bias (in English) are direct object bias and subordinate clause bias. Verbs with a direct object bias most commonly (and sometime obligatorily) occur in sentence structures where they take a direct object as an argument. For example, the verb "buy" has a strong direct object bias and is almost always followed by a direct object, the item that is being purchased. The verb "argue" has a strong subordinate clause bias and rarely takes a direct object. Previous research has shown that when verbs are used in structures other than their preferred structure, readers often misinterpret the meaning of the sentence (Christianson et al., 2001). For example, after

reading "While Anna dressed the baby spit up," most readers say that Anna was dressing the baby even though the correct parsing of the sentence indicates that Anna was dressing herself. Readers are highly likely to misinterpret the sentence because "dressed" has a strong direct object bias, but it is being used in a sentence with a subordinate clause. The problem of ambiguity introduced by verb bias is confounded by the fact that different senses of the same verb can have different preferred structures. The verb "claim" has a strong subordinate clause bias when it is used in the sense of making an argument, but it has a strong direct object bias when it is used in the sense of claiming a prize.

Both DOE and BWXT Pantex have lists of verbs that are recommended for use in written procedures. However, several of those verbs have the potential to be ambiguous in one or more of the ways mentioned above. By testing the verbs for noun/verb ambiguity and for the number of senses with which they are commonly used, we aimed to alert the writers of procedures and WIs to verbs that may be problematic and help them to avoid any potential for ambiguity.

1.2. Study Methods

In language processing research, there are two standard methods for assessing the verb/noun ambiguity of a word or the number of senses and verb bias of a verb. The first involves gathering data from a large corpus, such as the archives of a newspaper, and calculating the frequencies of each type of pattern within the corpus. The second technique involves conducting a sentence completion study where people in a population of interest see a list of words and put them into sentences, using the first context that comes to mind. The structures of the sentences give researchers insight into which meanings, senses, and grammatical structures are most common for each word in the population of respondents.

In the present study, we assessed the recommended action verbs from the *BWXT Writer's Manual for Technical Procedures* and from the *DOE Standard Writer's Guide for Technical Procedures*. Due to the technical nature of the recommended verbs, most of them do not appear in the existing research corpora. In addition, the verb meanings that are most frequent for technicians reading WIs may be unusual for the general population or in non-technical contexts. Thus, it was crucial for the present study to collect new data from a target population: technicians who use WIs in their professional work.

Participants were recruited from a group of technicians at Sandia National Laboratories and were asked to do a sentence completion survey. All of the technicians work in the NW field and use WIs in their day-to-day jobs. They were asked to fill out a sentence completion survey, as described above. There were 110 words used in the survey. The word list was comprised of the 80 recommended action verbs from the *BWXT Writer's Manual for Technical Procedures*, plus an additional 30 verbs were drawn from the Action Verb List in the *DOE Standard Writer's Guide for Technical Procedures*. Fifty-three of the words appeared in both writer's guides. The verbs and their definitions (from one or both sources) are listed in Appendix A.

2. STUDY RESULTS

There were a total of six respondents to this survey, but some of the verbs were used in more then one sentence by the respondents, providing more data for analysis. A breakdown of the results is shown in Appendix B. Overall, 25 words were always used as verbs and with only one verb sense. One word was always used as a noun and with only one meaning. An additional 17 words were always used as verbs, but were used with different senses or meanings by different respondents. The remaining 67 words were used as more than one part of speech by different respondents. These results, and their implications for the potential ambiguity of the words, are discussed in more detail below.

2.1. Unambiguous Words

Of the 110 verbs used in the study, 32 could be considered unambiguous based on the survey responses. Twenty-five of those words were used as a verb and with only one verb sense across all respondents. The unambiguous verbs were: *adjust, avoid, calculate, continue, determine, disassemble, dispose, don, ensure, establish, evacuate, implement, insert, locate, notify, obtain, per, perform, purge, reduce, regulate, repair, review, rotate*, and *verify*.

One word, *sample*, was used exclusively as a noun and with only one meaning, making it unambiguous as well.

An additional five words were used as both a noun and a verb, but had different forms for each part of speech. These words are disambiguated by their written form, so they can also be considered unambiguous. The words that fall into this category are *assemble* (assembly), *calibrate* (calibration), *collect* (collection), *contaminate* (contaminant), and *inspect* (inspection). Finally, the surveyed word *operate* was used with two different noun forms and also as a verb and adjective, but it had different forms in each case (operator/operation/operate/operating).

2.2. Potentially Ambiguous Words

Seventy-eight of the words used in the survey had multiple uses that were not disambiguated by written form. In some cases, these uses were closely-related senses with only subtle differences in meaning. In other cases, the words had very different meanings, indicating that they could be ambiguous or confusing to readers who interpret the words in a different way than the author intended. For this analysis, the words were grouped based on the similarity of their uses and meanings.

2.2.1. Words that are Unlikely to be Ambiguous

The 44 words in these groups were used in multiple ways by the survey respondents, but their meanings were either closely related or could be easily disambiguated by the inclusion of written part-of-speech markings. The groupings of words that are unlikely to be ambiguous are verbs with multiple similar senses, words with closely related meanings across different parts of speech, and words with distinct meanings for different parts of speech. Each grouping is described in more detail below. While these words are unlikely to be ambiguous, writers should be aware that these words have multiple uses. Also, due to the small number of respondents in

this survey, these words may have potentially ambiguous uses that were not captured here. Writers should ensure that the context in which these words appear makes their meaning clear.

2.2.1.1. Verbs with Multiple Similar Senses

The words in this group were almost always used as verbs by the survey respondents. They were used with more than one verb sense, but those senses were closely related. The 15 words in this group are *actuate, align, apply, backfill, compress, equalize, maintain, move, observe, remove, repeat, restore, stabilize, tighten*, and *transfer*. These words are unlikely to be ambiguous because they were always used as verbs and their verb senses were very similar across different contexts. For example, the verb *stabilize* was used in a physical sense by one respondent ("You need to stabilize the load for greater weight distribution") and in a chemical sense by another respondent ("The pH level must stabilize prior to heating parts"). Because of their similarity of meaning across the different senses, these verbs are unlikely to lead to comprehension errors. The word *align* was used once as a noun but had a different written form for that usage (alignment), so it is also unlikely to be ambiguous.

2.2.1.2. Words with Closely Related Meanings across Different Parts of Speech

The words in this group were used as different parts of speech by the survey respondents and did not have different written forms to correspond to each part of speech. However, because the meanings of their noun, verb, or other forms are closely related, these words are unlikely to problematic, even if their part of speech is unclear. The 25 words in this category are *balance, bond, clamp, clean, cool, correct, exit, filter, heat, label, latch, lift, lower, open, place, press, pull, pump, push, reset, screw, squeeze, start, use*, and *vent*. The uses of all of these words were extremely closely related. For example one participant used the word *heat* as a verb in the sentence "Heat the base of the part," and another participant used *heat* as a noun in the sentence "Apply heat to the part." Even though *heat* is serving different grammatical functions in these two sentences, the meaning of the word is nearly identical in both cases.

2.2.1.3. Words with Distinct Meanings for Different Parts of Speech

The words in this group were used as different parts of speech and had meanings that were very different for each of their uses. However, the usage of these words was consistent within each part of speech. In other words, when the word was used as a verb it was always used with the same sense, and when the word was used as a noun it always had the same meaning. This pattern of distinct meanings corresponding with different parts of speech indicates that these words are unlikely to be ambiguous so long as their part of speech is clear in their written context. This can be accomplished by including grammatical markers for the different parts of speech, such as "a" or "the" before a noun and "to" before a verb.

The four words in this group are *raise, slide, stop*, and *trip*. When *raise* was used as a noun, it always referred to money, and when it was used as a verb it always referred to lifting an object. When *slide* was used as a noun, it always referred to slides in a presentation (e.g. PowerPoint), and when it was used as a verb it always used to describe a manner of motion. When *stop* was used as a noun, it referred to an emergency stop button, and when it was used as a verb it referred to halting an action. When *trip* was used as a noun it referred to traveling, and

when it was used as a verb it was used in an electrical sense ("Don't trip the breaker"). If written part of speech markers are included with these words, their meaning should be unambiguous.

2.2.2. Words with a Higher Potential for Ambiguity

The remaining 34 words that were tested in this study are more likely to be ambiguous because they were used with a wide variety of meanings and senses even in this very small sample of sentences. For these words, any one of their meanings could come to mind for a particular reader when he or she reads the word. Even if the word's meaning is later disambiguated by its context, a reader's initial interpretation of a word can alter his or her understanding of the sentence, potentially leading to errors (Christianson et al., 2001).

Some of the words have multiple technical uses while others have one technical use and other nontechnical uses that are unlikely to appear in WIs. Writers should pay particular attention to the words with multiple technical uses, as those are the most likely to lead to confusion. However, even words with nontechnical uses could lead to errors if the context is not sufficient to disambiguate them or if the nontechnical meaning of a word is much more salient to a reader than its technical meaning.

2.2.2.1. Words with Technical and Nontechnical Meaning

There were nine words in the survey that were used with one technical meaning and one or more nontechnical meanings. Those words are *bleed, bypass, depressurize, discharge, limit, record, select, stroke*, and *twist*. The technical and nontechnical uses of these words are listed in Table 1.

Table 1. Words Used with Technical and Nontechnical Meanings

Word	Technical Meanings	Nontechnical Meanings
Bleed	Verb: Release pressure/water/air	Noun: Blood Verb: Person bleeding
Bypass	Noun: A part (e.g. exhaust bypass) Verb: Skip or go around	Adj. or Noun: Road
Depressurize	Verb: Release pressure	Verb: Relax
Discharge	Verb: Discharge electricity Verb: Vent gas	Verb: Fire an employee
Limit	Verb: Minimize or confine	Noun: Speed limit
Record	Noun: Notation Verb: Keep a record or make notations	Verb: Set a record
Select	Verb: Choose Verb: Highlight on computer screen	Adj: Elite
Stroke	Adj: Referring to an engine Verb: Motion of an engine part	Noun: Brain injury Idiom: Stroke of luck
Twist	Noun: Turn Verb: Turn	Verb: Dance

As mentioned above, writers should use these words carefully and ensure that their context disambiguates their meaning.

2.2.2.1. Words with Multiple Technical Meanings

Twenty-five of the words included in the survey were used with multiple unrelated or loosely related meanings by the survey respondents. The words in this group are *charge, clear, close, control, cover, cut, cycle, doff, follow, ground, guide, hold, isolate, log, monitor, pass, plot, plug, reference, release, secure, set, strip, tear*, and *turn*. Of the words tested in this study, these words are the most likely to be ambiguous in WIs and should be used with caution. Writers should consider the different interpretations of each word and ensure that the context makes the intended meaning clear. The respondents' uses of each word and specific recommendations for avoiding ambiguity are discussed below.

Charge. The survey respondents used *charge* as both a noun and a verb to refer to charging or using batteries. It was used as a noun in another electrical sense to refer to charge on a capacitor. In addition, it was used to refer to charging a project on a timecard and to refer to rushing "Do not charge ahead... go slowly." When using *charge* in the electrical sense, writers should make sure that the object of the verb is clearly specified. *Charge* should only be used in its financial sense when the context makes this meaning unambiguous.

Clear. The word *clear* was used as a verb to mean "remove" as in "Clear all excess parts from the desk." It was also used as an adjective to mean "transparent" as in "The liquid should appear clear." Finally, it was used as an adjective to mean "distinct" as in "There will be a clear change." All of these meanings would be plausible in the context of work instructions. To reduce the potential for ambiguity, it would be preferable to avoid using *clear* altogether or to use it only as an adjective in the sense of "transparent." In place of the other meanings of *clear*, using "remove" or "distinct" instead would reduce the likelihood of ambiguity.

Close. When *close* was used as a verb, it was always used in the sense of "to shut" as in shutting a lid or a door. However, *close* was also used as adjective to mean "near" in describing the position of an object and as an adverb in the construction "watch closely." These uses could lead to ambiguity, because an instruction like "Pull the closer handle" could refer to the handle nearer the user or the handle that closes something. To avoid this situation, *close* should not be used as an adjective in work instructions, and "shut" should be used instead of the verb use of *close* whenever possible.

Control. When *control* was used as a verb in the surveys, it was used in the sense of maintaining control over a process ("Control the flow at all times") or in the related sense of adjusting or changing something as desired ("You can control the temperature using this knob"). *Control* was also used as a noun in a related sense ("The process is out of control"). As a noun, *control* had two other loosely related senses, which were referring to a device that controls a process ("Set the control to 22 PSI") and referring to a rule or regulation ("The process control has to be followed..."). To disambiguate these meanings, the noun form of *control* should be modified with an adjective whenever possible in order to pinpoint its meaning ("the temperature control," "the process control," etc.).

Cover. This word was used with several different senses and meanings by the survey respondents. As a noun, *cover* referred to lids on containers, protective shielding ("lower the cover to protect the parts"), and protective garments ("please don tyvek covers"). As a verb, *cover* referred to going over material ("In this class, we will cover all the topics") and spreading

something over a surface ("Cover the table with paper"). The likelihood of ambiguity for this word can be reduced by using "lid" for containers and by using adjectives to specify the referent of the noun form of the word.

Cut. In the survey responses, *cut* was most often used as a verb to refer to opening a package. Some of the sentence contexts implied specific manners of cutting (sawing, cutting with a knife, cutting with scissors, etc), while others did not. *Cut* was also used to refer to a cut on someone's skin. Specifying the instrument of cutting would help to reduce the potential for ambiguity for the verb uses of *cut*.

Cycle. *Cycle* was generally used as a noun, but had several different meanings. It was used to refer to engines, a sequence of steps in a process, the life cycle of a product, and "cycle counts." As a verb, *cycle* was used to describe repeating the same action multiple times. Avoiding the verb use of *cycle* and specifying the type of cycle for the noun use would reduce ambiguity.

Doff. Only three of the six survey respondents wrote a sentence containing *doff*. This indicates that the other respondents did not know the meaning of the word. *Doff* should be avoided altogether and replaced with "take off" or "remove."

Follow. *Follow* was used as both a verb and an adjective (following) and was used to refer to the order of actions in a series, following a leader, obeying a rule, and using a specific procedure for completing a task. It is most likely to be ambiguous if a reader confuses the "order of actions" meaning with the "follow the procedure" meaning. The "order of actions" meaning (e.g. "Follow the assembly operation with a thorough cleaning") should be avoided when possible.

Ground. The electrical sense of *ground* was the most common in the survey responses, in adjective ("Use a grounded cable"), noun ("Verify the ground plane"), and verb ("Ground the part") forms. However, *ground* was also used in reference to grinding or wear ("Be sure the probe does not get ground down."). These two meanings could be highly confusing. Special attention should be paid to making sure that the non-electrical meaning of *ground* will not be misinterpreted.

Guide. The word *guide* was used as a verb to mean "lead" in both a physical ("The tracks guide the vehicle") and an abstract sense ("The trainer will guide you through the process"). It was used as a noun to refer to a book ("A training guide") and a tool ("Use the guide to ensure proper alignment."). Writers should take care to differentiate these two noun meanings of *guide*.

Hold. This word was used as a noun to refer to waiting ("Put the product on hold until it is analyzed"). As a verb, *hold* referred to holding an electric charge, hosting an event, physically grasping an object, hanging on to something important, and keeping an item in a specific location. The many verb meanings of *hold* could make it ambiguous if there is not enough contextual information to differentiate them.

Isolate. *Isolate* was always used as a verb by the study respondents, but it was used with several different meanings. It was used in an electrical sense ("Isolate the equipment from ground"), in the sense of searching for something ("Isolate the cause of the problem"), and in the sense of separating groups of items ("Please isolate parts for the engineers"). It was also used to refer to being alone. To minimize the chance for ambiguity, it would help to use *isolate* only in its electrical sense. "Find" and "separate" can be used in place of the other meanings of *isolate*.

Log. When *log* was used as a noun, it referred to a log book or record book. When it was used as a verb, it referred to entering data ("Log your data into Oracle"), logging on to a

computer system, and logging in to a building. Replacing *log* with "enter" for its data entry meaning would help to reduce the potential for ambiguity.

Monitor. As a noun, *monitor* always referred to a computer monitor. As a verb, it referred to being aware ("Monitor what is going on around you"), security monitoring ("I need to monitor the VTR"), checking on something ("Monitor the chart periodically to ensure a proper run") and searching or watching for something ("Monitor the system for any anomalies"). To disambiguate the verb meanings of *monitor*, writers should try to limit its use to the security monitoring sense. "Watch," "observe," "examine," or "check" could substitute for the other meanings of *monitor* in most cases.

Pass. When *pass* was used as a noun, it referred to a "pass through" or to a pass criteria for a test. As a verb, it referred to meeting the pass criteria for a test ("You must pass the test with 80% or greater"), moving on to the next step ("Pass on parts to the next sequence"), or handing an item to someone else ("Pass the butter"). Writers should be careful to distinguish the test criteria usage of *pass* from the other, physical meanings.

Plot. The word *plot* had two meanings that both appeared in noun and verb form. *Plot* could either refer to a graph or chart, or to creating a plan ("Plot the course for our trip"). This word could be disambiguated by using "graph" or "chart" instead of *plot*.

Plug. The word *plug* also had two meanings, both of which appeared in noun and verb form. *Plug* was used to refer to both a stopper sealing a container ("Be sure the plug is in position so no chemicals can escape") and to an electrical plug ("Check to make sure the machine is plugged in"). Even within the small set of survey responses, there were sentences that were ambiguous with respect to which of these two meanings was intended ("The plug is broken"). Writers should be very cautious with this word and ensure that its intended meaning is clear in a particular context.

Reference. When *reference* was used as a verb, it was always used to describe referring to written documents ("Reference the correct procedures"). It was also used as an adjective to describe the documents themselves ("Mark all reference copies in red") and to physical reference points ("Establish a reference point for base pressure"). These uses are closely related to one another, but they indicate that this word could be ambiguous with respect to whether the readers should consult existing material or whether they establish a reference or comparison point as a part of their current task. Writers should ensure that this is clear.

Release. This word was used as a noun to refer to mold release ("We use mold release to get this out of the mold"). It was also used as a verb to mean letting go of something ("Release the lever"), removing something from a container ("Release gas slowly") or providing material or information ("The job planner must release parts before they can get done"). Contextual information should always be provided to indicate which of these meanings is intended.

Secure. *Secure* was used as an adjective to describe something that is safely closed ("Ensure that the latch is secure") and to describe behavior ("Be safe and secure"). *Secure* was also used as a verb to refer to safely closing a latch, to security procedures ("Secure your computer before leaving it"), and in the sense of adhesion ("Five minute epoxy will secure the joint"). To reduce the likelihood of ambiguity, the adhesion sense of *secure* should be avoided. The other two meanings uses of *secure* are likely to be disambiguated by their context.

Set. The word *set* had numerous uses both as a noun and as a verb. As a noun, *set* referred to a small number of items ("They will have to establish the set of rules in the future"), objects that are used as a group ("I need a new set of golf clubs"), to a parameter ("Verify the setting is set at 6+/-5"), and to control settings ("We need to adjust the settings"). As a verb, *set*

described the use of controls ("Set the control to 22 PSI"), putting something into a particular state ("Set the temperature to 70 degrees"), setting a bond ("Align tab A to slot B then set the bond"), putting things in place in preparation for an activity ("Set up the equipment per the OP"), selecting something ("Please set the correct menu before starting the program") and to setting a record. All of these uses of *set* are very common, making them difficult to avoid. Writers should be aware of the many different uses of *set* and should choose more specific verbs (such as "adjust") whenever possible.

Strip. The word *strip* was used as a noun to refer to a piece of something ("Remove the strip of paper from the edge"). It had several uses as a verb, including removing clothes ("Strip and jump in the emergency shower"), removing materials ("Strip the tape off the parts"), stripping wires, and stripping screws. In general, "remove" should be used except in the cases where *strip* has a specific technical meaning, as with stripping wire and stripping screws.

Tear. *Tear* was used by almost all of the participants in the sense of "rip" ("Don't tear the paper"). However, it is mentioned in this section because one participant confused *tear* with "tare," writing "Tear the balance prior to weighing the parts."

Turn. The word *turn* was used with many different meanings in the survey responses. As a noun, it was used to indicate taking a turn ("It's your turn"). As a verb, it was used to refer to twisting or rotating something ("Turn the knob"), turning lights on or off, shutting down equipment ("Turn off the motor"), and changing state ("Heat the base of the part... until the tube turns a bright purple"). The "turn on/off" uses of *turn* are unlikely to be ambiguous because of the on/off modifier. However, the other three uses of *turn* could lead to ambiguity. More specific verbs such as "twist" or "rotate" could be used, and "become" could be used instead of the state change sense of *turn*.

3. CONCLUSIONS

This study should be considered a preliminary investigation of noun/verb and verb sense ambiguity in written WIs. We recommend additional future research, such as a larger-scale survey with more respondents, to identify additional meanings or other sources of ambiguity for these words. Some of the words classified as unambiguous in this study may have other meanings that would be revealed by a larger survey. In addition, the sample size for this study was too small to investigate factors such as the verb bias for different senses of a verb. Verb bias is another important contributor to sentence comprehension and merits further investigation in the context of WIs.

Although this survey had a small number of respondents, we were able to identify verbs from the DOE and Pantex writer's guides that have many different meanings for technicians who use WIs in their daily jobs. WIs that contain these words are more likely to be ambiguous or misleading because the reader's initial interpretation of the word may differ from the interpretation intended by the writer. Writers should use these words with caution. While it may be difficult to avoid using the potentially ambiguous words altogether, writers should be aware of the other meanings that the words have for people in the target audience. They can then use contextual information or explanations to ensure that the intended meaning of the word is clear and that there are no alternative interpretations of the instructions.

4. REFERENCES

1. U.S. Department of Energy, DOE Order 5480.19, *Conduct of Operations Requirements for DOE Facilities*.

2. *DOE Standard Writer's Guide for Technical Procedures (U)*, DOE-STD-1029-92, U.S. Department of Energy, Washington, D.C., December 1998.

3. *BWXT Writer's Manual for Technical Procedures (U)*, MNL-293084-004, BWXT Pantex, June 2004.

4. Brannon, N., Wenner, C., Ramos, V., & Stevens, S. *Human Error Mitigation Initiative (HEMI) (U)*, SAND2004-5416, Sandia National Laboratories, Albuquerque, NM, November 2004.

5. Christianson, K., Hollingworth, A., Halliwell, J., & Ferreira, F. (2001). Thematic roles assigned along the garden path linger. *Cognitive Psychology*, *42*, 368-407.

6. Garnsey, S. M., Pearlmutter, N. J., Meyers, E., & Lotocky, M. A. (1997). The contribution of verb-bias and plausibility to the comprehension of temporarily ambiguous sentences. *Journal of Memory and Language, 37*, 58–93.

7. Hare, M., McRae, K., & Elman, J. L. (2004). Admitting that admitting verb sense into corpus analyses makes sense. *Language and Cognitive Processes, 19*, 181-224.

8. Witmer, F., Observation report: Amarillo Area Office (AAO) monthly surveillance of BWXT Nuclear Explosive Operations (NEO) at the Pantex Plant, July 31-August 1, 2001.

APPENDIX A: WORDS USED IN STUDY

The words used in the present study were to 80 recommended action verbs in the *BWXT Writer's Manual for Technical Procedures* combined with 30 words from the action verb list in the *DOE Standard Writer's Guide for Technical Procedures*. Each verb is listed with its definition from one or both sources (with definitions from the DOE Writer's Guide shown in **bold** text).

Actuate: Put in action or motion.
Place into a specific state of functional performance.

Adjust: Change the value of a set point or parameter to a new desired value.
Make an incremental change or series of changes to arrive at a desired condition.

Align: Adjust to the proper condition or relationship.
Arrange equipment into a specific configuration to permit a specific operation.

Apply: Put on; adapt for a special use; put in action; be pertinent or relevant.

Assemble: Fit or join together parts or components.
Put together what is required to provide an operational or functional capability.

Avoid: Keep away from; keep from happening.

Backfill: Introduce a gas into a system after reducing system pressure to atmospheric or below.

Balance: Make specified parameters equal with respect to each other.
Adjust several parameters at the same time at certain points in a system to specified values.

Bleed: Remove a volume of liquid or gas from a system or container.
Remove fluid from a piece of equipment at a restricted flow rate.

Bond: Join securely.

Bypass: Divert or disable some automatic mode of a system or component.
To circumvent a safety circuit (unless a single device provides for bypassing, such as a bypass switch, identify specific actions to bypass).

Calculate: Compute mathematically.
To determine by computation (computation method should also be identified).

Calibrate: Check, adjust, and standardize the graduations of a measuring instrument.

Charge: **To load or fill (specific actions to charge should be included).**

Clamp: Fasten, grip, or support with a clamp or similar device.

Clean: **To rid of dirt, impurities, or extraneous matter.**

Clear: **To move people and/or objects away from.**

Close: Fully close or shut.
Manipulate a device to allow the flow of electricity or to prevent the flow of fluids, other materials, or light.

Collect: **Cause the assembly of something in a fixed location or container.**

Compress: Squeeze or press together; make smaller by squeezing.

Contaminate: Make impure by contact or mixture.

Continue: Resume an action; persist with a current action or step.
Maintain or resume the performance of an activity or condition.

Control: Regulate a parameter to a desired value.

Cool: Lower the temperature.
Lower the temperature of equipment or an environment.

Correct: **Alter to reestablish a desired activity or condition.**

Cover: **Protect or shelter equipment.**

Cut: Penetrate with a sharp edge; separate in parts with sharp instrument.

Cycle: Perform a repetitive sequence of events.
Cause repetition of an action or activity.

Depressurize: Reduce the pressure in a specified system or component.
To release gas or fluid pressure from.

Determine: Decide or establish conclusively the cause of some action or the status of some condition.
To find out; to ascertain.

Disassemble: Take apart.

Discharge: **To give outlet or vent to a fluid or other contents.**

Dispose: Get rid of.
Remove from a specific location.

Doff: Take off personal protective equipment (PPE), includes PPE clothing.

Don: Put on personal protective equipment (PPE), includes PPE clothing.
To put on an article of wear.

Ensure: Make sure or certain, use instead of the terms check or assure. Use of this verb allows the user to change conditions found.
Confirm that an activity or condition has occurred in conformance with specified requirements (by action if necessary).

Equalize: **To make equal or uniform**.

Establish: Create required conditions or state.
Bring about. Take necessary actions to cause a specified set of conditions to exist.

Evacuate: **Vacate.**

Exit: Leave or vacate.
To leave or withdraw.

Filter: **Pass fluid through a sized medium to stop the passage of unwanted material in the effluent.**

Follow: **Comply with an instruction.**

Ground: **Provide an electrical path to a system at zero potential.**

Guide: **To manage or direct movement of.**

Heat: Raise the temperature.

Hold: **Maintain a position for equipment, a place in a procedure, or an act of retention.**

Implement: **To carry out; to accomplish.**

Insert: Put into, between, or among.
Place or position into; move control rods into the reactor core.

Inspect: Examine, view closely, or scrutinize tooling, components or activities.

To examine; to perform a critical visual observation or check for specific conditions; to test the condition of.

Isolate: Separate systems or components.
To shut off or remove from service.

Label: Attach a label to; identify or designate with a label.
To mark or identify.

Latch: Couple mechanical parts by means of a trip mechanism.
To close or fasten.

Lift: Carry or direct from a lower to a higher position.
Elevate to a higher level or remove, as in removing electrical leads or restrictions.

Limit: **Restrict or impose bounds.**

Locate: **Determine or establish place or position.**

Log: **To enter into a record of operations or progress.**

Lower: Bring, let, or move down to a lesser level.
Cause to move down or decrease position or value.

Maintain: Preserve a stated condition.
To hold or keep in any particular state or condition, especially in a state of efficiency or validity.

Monitor: **Observe an activity, parameter value, or condition (usually on continuous basis) to meet an instruction requirement.**

Move: Change from one position to another, relocate, set or keep in motion.

Notify: Inform.
Contact, advise, or communicate to make someone aware of an impending or completed activity, parameter value, or condition.

Observe: Watch attentively.
To watch carefully.

Obtain: Gain possession of.
To get or attain.

Open: Release from a closed or fastened position.
Manipulate a device to prevent the flow of electricity or to allow the flow of fluids, other materials, or light.

Operate: **Cause equipment or system to perform designed functions.**

Pass: **To go by; move by.**

Per: When the word "per" is cited in a procedure, the user must physically obtain the cited procedure and adhere to the Level-of-Use on the procedure.

Perform: Complete a specific task.
Carry out specified actions or action steps.

Place: Put in a particular location, position, or order.
To put or set in a desired location or position.

Plot: **To represent graphically.**

Plug: **To connect or become connected, as in electrical plug; to stop or insert something.**

Press: Push; generally used in reference to operating buttons.
To act upon through thrusting force exerted in contact; to push.

Pull: Apply force to cause motion toward the source of the force; remove from a fixed position.
To exert force upon so as to cause or tend to cause motion toward the force.

Pump: **Move a fluid in a piping system by the use of suction, pressure, or both.**

Purge: Remove gas from a system or component.
To make free of unwanted substance such as an impurity or foreign material.

Push: Apply force away from the source of the force.
To press against.

Raise: Move or cause to move upward or to a higher position; increase the worth or value of a parameter.
Cause to move up, or increase position or value.

Record: Preserve in writing or other permanent form.

Reduce: Lessen in extent, amount, number, pressure, or degree.
Decrease a variable to meet a procedure requirement.

Reference: When the word "reference" is cited in a procedure, the user must adhere to the Level-of-Use on the referenced procedure.
Use specified information that is in another location or procedure.

Regulate: Control a parameter to obtain a desired value.

Release: **To set free from restraint or confinement.**

Remove: Take away; take off.
To take off, move away, or eliminate.

Repair: Restore to sound condition.
To restore to a sound state.

Repeat: Say or do again.
Do again.

Reset: Return a system to its default condition.
Reestablish a piece of equipment, part, or component to a previous condition, parameter value, instrument set point, or mechanical position.

Restore: Bring back to a previous condition.

Review: Inspect or survey.
Examine with deliberation for confirmation or compliance to an instruction.

Rotate: (Turn preferred if applicable) turn on an axis or around a central point; cause rotation; proceed in sequence.
Cause to turn on an axis.

Sample: **Take a representative portion for the purpose of examination.**

Screw: Turn or tighten (a screw); fasten, attach, or tighten by means of a screw; attach (a tapped or threaded fitting or cap) by twisting into place.

Secure: Fasten or make tight.
Fasten or make safe.

Select: Position a switch to a desired position; choose.
To take by preference of fitness from a number or group; to pick out; to choose.

Set: **Adjust equipment to a specified value.**

Slide: Move over a surface while maintaining smooth, continuous contact.

Squeeze: (Compress preferred if applicable) exert pressure: press on or together.

Stabilize: Establish constant conditions.
To become stable, firm, steady.

Start: Set into motion.
Originate the motion or function of an electrical or mechanical device.

Stop: Cause motion or activity to cease.
To halt movement or progress; to hold back; to halt.

Strip: Remove.

Stroke: **Operate a valve over its full travel. The travel time may be measured.**

Tear: Pull apart or into pieces; separate forcefully.

Tighten: Make tight or tighter.

Transfer: **To cause to pass from one to another.**

Trip: **To manually activate a semiautomatic feature; to cause to fail or stop.**

Turn: Cause to move around a central point or axis; change position of by rotating; reverse the position of; pivot.
Adjust with a force on an actuator that positions form a circular movement.

Twist: Turn; rotate.

Use: Put into action or service.
To avail oneself of; to employ; to utilize.

Vent: Equalize pressure with atmospheric pressure.
Release a gas or liquid confined under pressure.

Verify: Prove to be true, exact, or accurate by observation and comparison. Use of this verb does not allow the user to change the conditions found.
Confirm, substantiate, and assure that a specific activity has occurred or that a stated condition exists.

APPENDIX B: OVERALL STUDY RESULTS

The frequency with which each word appeared in the survey responses and the breakdown of its uses are shown in the table below. Each time a word appeared in the survey responses is referred to as a "token" of that word. Each sense or meaning of a word is counted as one use of that word. For example, the word actuate appeared 6 times in the survey responses and was used in three different ways. In this case, its uses were three different closely-related verb senses. The (*) denotes words that appeared only in the *BWXT Writer's Manual for Technical Procedures* and the (†) denotes words that appeared only in the *DOE Standard Writer's Guide for Technical Procedures*. All unmarked words appeared in both sources.

WORD	TOTAL NUMBER OF TOKENS	TOTAL NUMBER OF USES	VERB USES		NOUN USES		OTHER USES	
			Number of Tokens	Number of Uses	Number of Tokens	Number of Uses	Number of Tokens	Number of Uses
actuate	**6**	**3**	6	3	0	0	0	0
adjust	**6**	**1**	6	1	0	0	0	0
align	**7**	**4**	6	3	1	1	0	0
apply*	**8**	**4**	8	4	0	0	0	0
assemble	**7**	**2**	6	1	1	1	0	0
avoid*	**7**	**1**	7	1	0	0	0	0
backfill*	**6**	**2**	6	2	0	0	0	0
balance	**6**	**3**	2	2	4	1	0	0
bleed	**7**	**3**	6	2	1	1	0	0
bond*	**8**	**2**	4	1	4	1	0	0
bypass	**6**	**4**	3	2	3	2	0	0
calculate	**6**	**1**	6	1	0	0	0	0
calibrate*	**9**	**2**	6	1	3	1	0	0
charge†	**5**	**5**	3	3	2	2	0	0
clamp*	**7**	**2**	5	1	2	1	0	0
clean†	**11**	**3**	6	1	1	1	4	1
clear†	**6**	**3**	3	1	0	0	3	2
close	**9**	**4**	6	1	0	0	3	3
collect†	**7**	**2**	6	1	1	1	0	0
compress*	**6**	**2**	6	2	0	0	0	0
contaminate*	**6**	**2**	5	1	1	1	0	0
continue	**7**	**1**	7	1	0	0	0	0
control*	**7**	**5**	3	2	4	3	0	0
cool	**6**	**3**	4	1	0	0	2	2
correct†	**23**	**5**	2	1	1	1	20	3
cover†	**8**	**5**	4	2	4	2	0	0
cut*	**10**	**5**	8	3	2	2	0	0
cycle	**6**	**5**	1	1	5	4	0	0
depressurize	**6**	**2**	6	2	0	0	0	0
determine	**6**	**1**	6	1	0	0	0	0
disassemble*	**6**	**1**	6	1	0	0	0	0
discharge†	**6**	**3**	6	3	0	0	0	0
dispose	**6**	**1**	6	1	0	0	0	0
doff*	**3**	**1**	3	1	0	0	0	0

don	**6**	**1**	6	1	0	0	0	0
ensure	**9**	**1**	9	1	0	0	0	0
equalize†	**6**	**3**	6	3	0	0	0	0
establish	**7**	**1**	7	1	0	0	0	0
evacuate†	**6**	**1**	6	1	0	0	0	0
exit	**8**	**2**	7	1	1	1	0	0
filter†	**7**	**3**	1	1	6	2	0	0
follow	**13**	**5**	10	4	0	0	3	1
ground†	**10**	**4**	4	2	4	1	2	1
guide†	**6**	**4**	4	2	2	2	0	0
heat*	**8**	**3**	3	1	5	2	0	0
hold†	**9**	**6**	7	5	2	1	0	0
implement†	**6**	**1**	6	1	0	0	0	0
insert	**7**	**1**	7	1	0	0	0	0
inspect	**7**	**2**	6	1	1	1	0	0
isolate	**6**	**4**	6	4	0	0	0	0
label	**7**	**2**	6	1	1	1	0	0
latch	**8**	**5**	4	3	4	2	0	0
lift	**8**	**3**	7	2	1	1	0	0
limit†	**6**	**3**	5	2	1	1	0	0
locate†	**6**	**1**	6	1	0	0	0	0
log†	**7**	**5**	4	3	3	2	0	0
lower	**7**	**3**	6	2	1	1	0	0
maintain	**7**	**2**	7	2	0	0	0	0
monitor†	**7**	**5**	4	4	3	1	0	0
move*	**6**	**2**	6	2	0	0	0	0
notify	**6**	**1**	6	1	0	0	0	0
observe	**6**	**4**	6	4	0	0	0	0
obtain	**7**	**1**	7	1	0	0	0	0
open	**19**	**4**	17	2	0	0	2	2
operate†	**13**	**4**	5	1	7	2	1	1
pass†	**9**	**5**	6	3	3	2	0	0
per*	**7**	**1**	7	1	0	0	0	0
perform	**8**	**1**	8	1	0	0	0	0
place	**8**	**3**	6	2	2	1	0	0
plot†	**6**	**4**	4	2	2	2	0	0
plug†	**7**	**4**	3	1	3	2	1	1
press	**10**	**4**	9	3	1	1	0	0
pull	**9**	**5**	8	4	0	0	1	1
pump†	**8**	**4**	5	3	3	1	0	0
purge	**6**	**1**	6	1	0	0	0	0
push	**7**	**3**	6	2	1	1	0	0
raise	**6**	**2**	5	1	1	1	0	0
record*	**6**	**3**	4	1	2	2	0	0
reduce	**6**	**1**	6	1	0	0	0	0
reference*	**6**	**4**	3	1	1	1	2	2
regulate*	**6**	**1**	6	1	0	0	0	0
release†	**6**	**4**	5	3	1	1	0	0
remove	**12**	**2**	12	2	0	0	0	0
repair	**6**	**1**	6	1	0	0	0	0

repeat	**6**	**2**	6	2	0	0	0	0
reset	**7**	**4**	5	3	2	1	0	0
restore*	**6**	**2**	6	2	0	0	0	0
review	**6**	**1**	6	1	0	0	0	0
rotate	**6**	**1**	6	1	0	0	0	0
sample†	**7**	**1**	0	0	7	1	0	0
screw*	**11**	**4**	3	2	7	1	1	1
secure	**7**	**5**	5	3	0	0	2	2
select	**6**	**3**	5	2	0	0	1	1
set†	**16**	**10**	10	6	6	4	0	0
slide*	**7**	**2**	5	1	2	1	0	0
squeeze*	**6**	**2**	5	1	0	0	1	1
stabilize	**6**	**4**	6	4	0	0	0	0
start	**13**	**3**	9	1	4	2	0	0
stop	**9**	**2**	8	1	1	1	0	0
strip*	**6**	**5**	5	4	1	1	0	0
stroke†	**6**	**4**	1	1	3	2	2	1
tear*	**7**	**2**	7	2	0	0	0	0
tighten*	**9**	**2**	9	2	0	0	0	0
transfer†	**6**	**3**	6	3	0	0	0	0
trip†	**7**	**2**	4	1	3	1	0	0
turn	**12**	**5**	11	4	1	1	0	0
twist*	**6**	**3**	5	2	1	1	0	0
use	**36**	**3**	28	1	7	1	1	1
vent	**7**	**2**	3	1	4	1	0	0
verify	**7**	**1**	7	1	0	0	0	0

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