ELSEVIER Journal of Hazardous Materials 38 (1994) 257–275

Sneak analysis of batch processes

C. Whetton[a,*], W. Armstrong[b]

[a] *Department of Mechanical and Process Engineering, University of Sheffield, P.O. Box 600, Mappin Street, Sheffield S1 4DU, UK*
[b] *Howmar International Ltd., Albany Park Estate, Frimley Road, Camberley, Surrey GU15 2QQ, UK*

(Received 20 May 1993; accepted in revised form 24 March 1994)

Abstract

This paper presents a hazard identification method known as sneak analysis which may be used to identify certain classes of systematic failures. Because some aspects of the method pay particular attention to states of the plant (i.e. valves open or closed, pumps running, etc.) the method is of particular interest to batch operations where, in fact, such problems tend to be common. The proposed method is intended to be used as an adjunct to existing methods such as HAZOP and is not a complete means of hazard identification. As well as using path tracing procedures and state charts to represent aspects of the system, sneak analysis makes extensive use of a form of checklist known as a sneak clue lists and an example of their use is given in the text.

1. Introduction

A sneak[1] can be defined as a hazard arising from a design error or deficiency; i.e. it is a latent hazard, one arising from a design error or systematic failure. In this paper, the sneak concept is slightly extended to: a hazard arising from a design error or from the combination of a design error and a single-point failure. Sneak analysis (SA) is a method of identifying such latent hazards; *it is not a complete analysis method in its own right but supplements more traditional methods of hazard identification such as HAZOP.* Because SA is able to analyse systems with multiple states, it is particularly useful for analysing batch processes; furthermore, research [1] has identified certain

---

* Corresponding author. Present address: Risk & Policy Analysts Ltd., Warren House, Beccles Road, Loddon, Norfolk NR14-6JL, UK.

[1] The term 'sneak' seems to have originated with Hill and Bose [2], although there is evidence that it may date back to WW2. Inelegant though it is, we feel obliged to retain it since it is commonly used as an indexing keyword in the existing literature.

0304-3894/94/$07.00
SSDI 0304-3894(94)00038-I

categories of sneak which are especially prevalent in such processes. As described in Section 10, the method identifies a class of problems which are unlikely to be identified by HAZOP alone; consequently, it is felt that the method is effective and that its use justifies the extra effort involved.

Sneak analysis originated in the aerospace industries, where it was originally applied to relay control logic [2, 3] but fell out of favour, partly due to its becoming almost proprietary to one company and partly due to the advent of solid-state controls. Recently, interest in the method has revived, both in the aerospace community [4–7] and in the process industries [1, 8–11]. Current research on the identification of sneaks centres on two areas: the identification of paths down which an unintended flow of material, energy, or information may occur; and the use of clue lists to identify other categories of sneak. Such clue lists may readily be integrated with HAZOP [11].

The idea of sneak categories – the grouping of sneaks by common attributes – is important to the use of clue lists for the identification of sneaks. These categories are to some extent arbitrary and it has been found necessary to alter the original classifications of Hill and Bose [2] so as to better reflect the characteristics of process systems. The categories which have been found most useful for process applications are: Flow, Indication, Energy, Label, Procedure, Reaction.

Before treating these categories in detail, they are briefly defined as follows.

Sneak flows: A sneak flow is a flow of material, energy, or information which occurs along an unintended path, either as a result of a combination of intended actions or as a result of a single failure. In the well-known case of the Three Mile Island incident [12], the water which entered the instrument air supply is an example of sneak flow.

Sneak indications: A sneak indication is an erroneous indication which occurs either by a design error or by a single failure. Again, in the Three Mile Island incident [12], the panel light which indicated the state of the operating switch rather than the state of the pilot operated relief valves (PORV) is a case of sneak indication. An identical (from a sneak point of view) situation contributed to the loss of the Turkish Airlines DC-10 in 1975 [13], when a light which should have indicated whether the cargo-door *latch* was closed and locked actually indicated only the position of the door *handle*.

Sneak energy: Sneak energy is the unintended presence or absence of energy in a system, occurring either by a design error or by a single failure. In batch operations, layered reactants which form as a result of agitator failure is an example of sneak energy; another common example is pressure trapped within a system which is accidentally released during maintenance.

Sneak labels: A sneak label is an ambiguous or misleading label. Fig. 1 (adapted from Kletz [14]) shows seven pumps arranged side by side and offers a classic instance of sneak labelling; when asked to maintain pump 7, which one will the worker choose? Norman [15], also provides several very instructive examples, although without using the term 'sneak'.

Sneak procedures: A sneak procedure is an ambiguous or unintended procedure. Ambiguous procedures are legion; those that are recognised as such are sometimes replaced by unofficial and unrecorded procedures. Similarly, awkward or lengthy

Fig. 1. Sneak labels.

procedures may be bypassed or replaced by unofficial 'custom and practice'. All are examples of sneak procedures. A classic instance, which also reveals the difficulty which can occur in trying to distinguish between sneak labels and sneak procedures, is the Camelford incident [16], where material was delivered to the wrong tank because one key fitted the locks to both.

Sneak reactions: A sneak reaction is an unintended reaction which occurs either by a design error, by small deviations from desired conditions or by a single failure. Corrosion inside sealed tanks, consuming oxygen and producing a reduction in air pressure, leading to a collapse of the tank under external atmospheric pressure is a common instance of sneak reaction [14], although this condition could also be characterised as sneak energy. The unintended catalysing of reactions by materials of construction is yet another example.

2. Sneaks in batch processes

Recent research [1] has shown sneaks to be very common in batch processes. In Armstrong's work [1], 41 incidents (out of several hundred surveyed) were identified as resulting from some form of sneak; the distribution of these sneaks is shown in Table 1. Since the Procedure category tends to be used as a 'catch-all' for events which do not fit well into the other categories, all that can be inferred from Tables 1 and 2 is that, in the incidents identified, sneak labels are less common than the other categories. In an earlier study [8], not limited to batch plant and using different rules for allocating sneaks to categories, 153 sneaks were identified in 85 incidents; their distribution is given in Table 2.

While too much emphasis should not be placed on a comparison between Tables 1 and 2 because they were made at different times and with significantly different rules for assigning sneaks to categories, it is interesting to note that the percentages for sneak procedures are roughly comparable and that sneak labels are the least common in both cases. The 41 incidents were also categorised by immediate cause, as in Table 3.

Table 3 reveals several surprises: intuition suggests that 'opening the wrong valve' might be a common cause of incidents on batch plant, yet incorrect plant state, in the incidents surveyed, occurs half as often as insufficient agitation. Mischarging is an activity which might reasonably be expected, but it is followed very closely by contamination – an event which is not necessarily expected. Table 4 lists incidents by plant state within the production cycle and suggests, as might be expected, that sneaks are more likely when setting up and charging a batch than when it is in the relatively static states of normal operation and holding.

Table 1
Batch sneaks by category

Sneak category	Quantity	%
Procedure	11	27
Reaction	8	20
Flow	7	17
Indication	6	15
Energy	6	15
Label	3	7
Total	41	101

Tabel 2
Process sneaks by category

Sneak category	Quantity	%
Flow	41	27
Procedure	38	25
Energy	35	23
Indication	22	14
Label	17	11
Total	153	100

Tabel 3
Batch sneaks by cause

Cause	Quantity	%
Insufficient agitation	9	22
Mischarging	7	17
Contamination	6	15
Incorrect plant state	4	10
Other	15	36
Total	41	100

Table 4
Batch sneaks by plant state

Plant state	Quantity	%
Charging	15	37
Normal operation	7	17
Holding	4	10
Other	15	36
Total	41	100

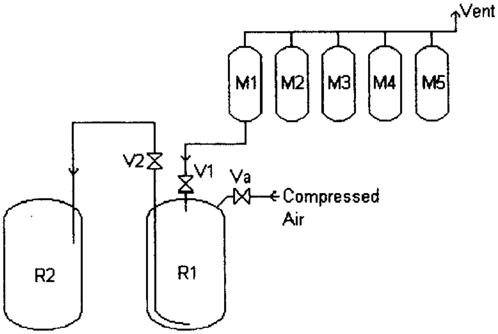

Fig. 2. Sneak flow.

3. Sneak flows

Sneak flows involve the unintended transport of material, energy, or information, as a result of a design deficiency. Since batch plants consist of vessels and other equipment connected by pipes and valves and are generally multi-purpose they must be set to the required configuration by opening and closing the relevant valves and running the appropriate pumps. These set-up operations are fruitful grounds for sneaks to occur. Fig. 2 shows an example of sneak flow [1]. In Fig. 2, a nitration reaction was performed in reactor R1 by charging nitrating acid from a measuring vessel M1, via V1. On completion of the reaction, compressed air was used to transfer material from R1 to R2. The operator forgot to close V1 and reacted material was transferred into the measuring vessel M1. Up to this point, the incident is a simple case of human error and it is arguable whether or not it would be categorised as a sneak at all. However, once vessel M1 had filled, a true sneak flow developed when material was transferred via the common vent line into vessels M2–M5. Subsequently, vessels M1–M5 were drained and flushed with nitrating acid. When M5 was being flushed, an exothermic reaction took place and an explosion occurred which destroyed the vessel and damaged the adjacent M4.

The unintended transfer of material – sneak flow – via utility lines is very common. Some instances, not all concerning batch plant, are given in Table 5.

3.1. *Identification of sneak flows*

The identification of sneak flows requires a combination of path tracing and constructing a state table for the system, while the other sneak categories use a different method, based upon a checklist. It is thus convenient to detail the analysis of sneak flows here, while the general method is described later in the paper. The following method is partly based upon the work of Taylor [5]; while, as noted in the text, the analysis can be performed with a P and I diagram and a set of coloured pencils, it is felt that the tree diagram, while requiring greater effort, has the

Table 5
Some incidents of sneak flow in utilities

Incident	Location	References
Water entered instrument air	Three Mile Island	[12]
Vinyl chloride transferred to laboratory area via sewers	Dow Chemicals, Fort Saskatchewan, Alberta, Canada	[17]
Process fluid entered office water supply via pump priming line	Unspecified	[14]
Process material entered a steam line and later ignited	Unspecified	[21]
Solvent sucked into nitrogen purge line and then back into an electrical cubicle where it ignited	Unspecified	[21]

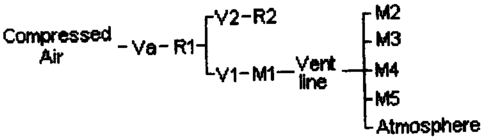

Fig. 3. A flow tree for Fig. 2.

advantage of producing a clearer, self-documenting analysis. Path tracing operates as follows:

1. Take the P and I diagram and choose in turn each material entering, leaving or created within the system. Remember to cover all flows, including steam, water, air, instrument air, drains, sewers, vents, ventilation systems, etc.

2. Assuming that all valves are open and all pumps are running, trace each flow through the system, marking where it could possibly go. This can be done with coloured pencils on the P and I diagram, but it is also advantageous to construct a tree diagram, starting at the origin of the material in question. A typical tree diagram is one such as that in Fig. 3, which shows possible flow of compressed air through the system.

(Note that the production of such flow trees could easily be automated, by the application of elementary graph theory, if a net-list were available from a P and I diagram CAD program.)

3. Having traced all possible flows, look for cases of incompatible substances coming together. Note that there will be considerable duplication amongst the diagrams, but this is necessary because each diagram should refer to the possible flow of one material. For example, Fig. 3 can be drawn from the point of view of material in the measuring vessel M1, as shown in Fig. 4.

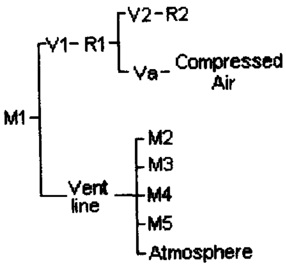

Fig. 4. Fig. 3 from the point of view of M1.

Table 6
State table for Fig. 2

Valve			State	Comments
V1	V2	Va		
o	c	c	Adding acid M1 and reacting	
c	o	o	Transferring from R1 to R2	

It is important to start the tree from each material, including materials created within the system at different times. As an example, in Fig. 4 it is clear that material from M1 can enter M2–M5 via the vent line; this is far less obvious in Fig. 3, which shows how compressed air can flow through the system.

4. Having established possible flows, determine whether they can or cannot occur in practice. Reference to Fig. 4 and the P and I diagram of Fig. 2 shows that there is nothing to prevent the transfer of material from M1 to M2–M5 and the atmosphere. Fig. 3 shows that transfer of compressed air to vessel M1 should be inhibited by valve V1. To determine whether that can happen, a system state table can be constructed, as in Table 6.

In Table 6, the states of the three valves are denoted by o for open and c for closed. Note that to go from the adding/reacting state to the transferring state, all three valves must change state simultaneously. This is not possible; even in an automated system there will be some overlap between the valve states and it is clear that, in this instance, there is nothing to prevent valves V1 and Va being open simultaneously. The table should be revised to separate the adding/reacting states and to show only one valve changing state at a time; this is shown in Table 7.

In Table 7, two new states have been added, each meeting the requirement that only one valve may change at a time. In practice, it would have to be verified that the pressure in R1 was satisfactory with all valves closed and relief valves and other controls would have to be taken into account; these have been omitted from the examples so as to make the method clearer.

Table 7
Modified state table for Fig. 2

Valve			State	Comments
V1	V2	Va		
o	c	c	Adding acid from M1	
c	c	c	Reacting	New state
c	o	c	Prepare to transfer	New state
c	o	o	Transferring from R1 to R2	

5. Once a satisfactory state table has been constructed, a check must be made for replicated states – states which occur more than once. While these may be necessary and safe (e.g. all valves closed, in the example above) it is possible to pass through undesired intermediate states which can result in sneak paths.

6. The final stage of the sneak flow analysis is to postulate single-valve deviations to each plant state, i.e. what if this valve is left open (closed) at this stage? This does not always identify a sneak as such but can identify the conditions which may activate a sneak.

In Table 7, the first state {occ} could change to: {ccc} which is acceptable because it is the next state; {ooc} *which may or may not be acceptable* – further information is needed; {oco} is unacceptable because it either introduces compressed air into M1 or transfers material from R1 to M1. In fact, this is the condition which initiated the sneak in the real incident.

Applying steps 1–6 above should identify the majority of potential sneak flows in the system; while the method can be a little tedious, it is very thorough. One obvious and major difficulty is that the state table may become very large – n valves have 2^n possible states, e.g. 1024 for $n = 10$. This can be overcome by considering sub-sets of valves but care must be taken when postulating single-valve deviations. For example, it must be certain that the valves excluded from the sub-set cannot change state during the operation being analysed. Consequently, automatically operated valves, such as relief valves, must be included in the sub-set as their non-operation cannot be guaranteed.

The other major problem is that of being sure to include everything. Everything means everything: steam, air, instrument air, vacuum, water, drains, sewers, etc., and in these cases it is sometimes difficult to know when to terminate the path. Clearly, on the basis of the Fort Saskatchewan incident [17], sewers should be followed through the whole plant, as should any material which may enter the drinking water supply, but should this procedure terminate at the plant boundary? At the water treatment plant? At the point of discharge? These questions are matters of judgement for the analyst and any decision must be made in the light of the toxicity of the material involved and the likelihood of a sneak flow being initiated. Finally, on the subject of sneak flows, two important areas must be mentioned: temporary connections and heating, ventilating and air conditioning (HVAC).

Batch plants make frequent use of temporary connections by flexible hoses; these must be accounted for as if they were valves in the state table and the possibility of misconnection must also be considered.

HVAC systems are not generally considered to be part of process plant; however, they can provide a means to transport material from one part of the plant to another and should be considered in any sneak flow analysis. The authors know of at least one instance (in a plant producing semiconductor wafers) where significant quantities of a chemical were transferred almost 30 m through a common air conditioning system which provided a sneak flow between two clean-rooms, despite the fact that the air-flow direction and velocity were supposed to prevent this from happening.

4. Sneak indications

Sneak indications have been responsible for several famous incidents, some of which (not confined to batch plants) are listed in Table 8. Note that the first three incidents, and that of the Turkish Airlines DC-10 [13], are almost identical; the problem of indicators showing the state of the initiating device, rather than the state of the control device, appears to be universal. Fig. 5 shows a well-known example of sneak indication [1] where glycerol was charged into a reactor and circulated through a heat exchanger and catalyser. At the start of the batch, the heat exchanger was used to raise the batch temperature to 115 °C and when this point was reached ethylene oxide was charged at a predetermined rate. Once ethylene oxide is added, the reaction is exothermic and the heat exchanger is used to cool the batch.

Because the reaction was known to be exothermic, the following interlocks were incorporated to inhibit the ethylene oxide pump if: (i) the circulating pump is not running; (ii) glycerol temperature is below 115 °C (by TZA) since the reaction will not start; (iii) glycerol temperature is above 125 °C (by TZA) since the reaction will be too rapid.

At the time of the incident, the flow indicator and alarm – F – were known not to be working. The operator in charge of the batch noted that when the ethylene oxide feed began, pressure in the vessel rose, and deduced – correctly – that the reaction was not taking place. Assuming that TZA was out of calibration or otherwise incorrectly set, he increased its setting to 200 °C. The pressure continued to rise, so the operator searched for another reason; he realised that he had forgotten to open the reactor outlet valve, V1. He opened it. Approximately 3 t of glycerol and ethylene oxide mixture surged through the heat exchanger and over the catalyser, where a runaway reaction developed and the batch exploded. Two operators were injured.

The sneak indication can be better understood from Fig. 6, which shows the approximate placement of the temperature interlock, TZA. Because the reactor outlet valve was closed, there was no flow through the circulating pump. Running dry, the pump overheated and heat was conducted to TZA, sufficient to release the interlock and allow the ethylene oxide pump to be started. Stated bluntly, the instrument was not measuring what it was supposed to be measuring.

Table 8
Some examples of sneak indications

Incident	Location	Reference
Light indicated switch state rather than the state of the relief valves	Three Mile Island	[12]
A panel light showed the state of a switch rather than that of an oxygen shut-off valve	Unspecified	[21]
A pump 'stop' button turned off the indicator but not the pump which ran dry, overheated and caused an explosion	Unspecified	[21]
Temperature indicator not in contact with fluid led to exotherm and explosion	Sweden	[19]
Temperature indicator not in contact with material led to exotherm and explosion	Hickson and Welch	[20]
In electrical practice, a red light indicates ON or running; in process instrumentation, a red light indicates tripped or OFF!	Everywhere!	

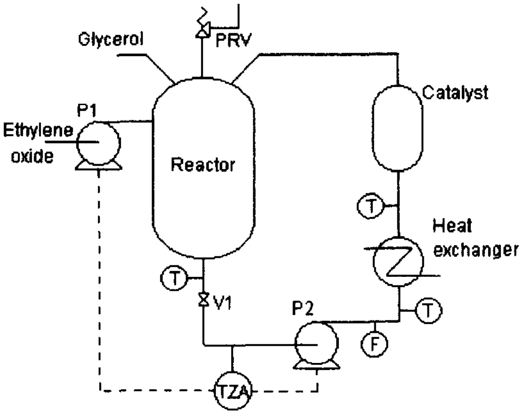

Fig. 5. A sneak indication.

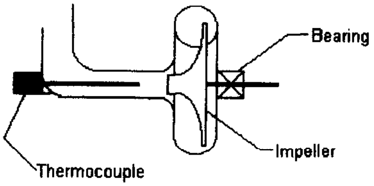

Fig. 6. Schematic location of TZA.

(Detailed procedures for identifying sneak indications, and other sneak categories, are given in a later section of this paper since all categories except sneak flow use a common method.)

5. Sneak energy

Sneak energy incidents on batch plant tend to be associated with unreacted materials, often as a result of agitator failure or the formation of layers during charging. Fig. 7 shows a simplified flowsheet [1] for a plant on which a spectacular instance of sneak energy occurred. In Fig. 7, glycol is charged to the reactor, followed by molten phenol, after which a 12% solution of methoxide in methanol is metered in. The heat of neutralisation raises the temperature of the mixture above its atmospheric boiling point and a refluxing operation is started, with condensed methanol being returned to the reactor.

When the incident occurred, all the ingredients had been charged but the temperature failed to rise. The plant manager was called and he saw through the sight glass that the agitator was not running. He started the agitator. In the words of one witness, the batch responded ‘with a rumble that turned immediately to a roar’. Reactants filled every part of the system, gaskets sprung, phenolic vapours leaked, and the reactor and building began to vibrate. The building was evacuated. Shortly afterwards, the reaction subsided without further incident.

Process instructions called for the agitator to be stopped while discharging and started before the next batch; unfortunately, there was no interlock to prevent the adding of reactants while the agitator was not running. The reactants were added via a dip-pipe and, due to their different densities and lack of agitation, layering resulted, leading to the existence of sneak energy which manifested itself when the agitator was started. Such incidents appear to be numerous.

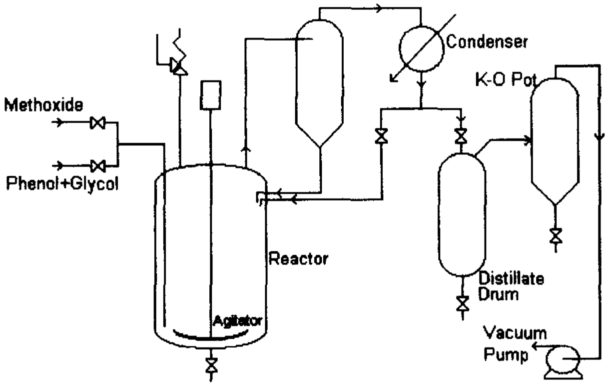

Fig. 7. Sneak energy.

Table 9
Some examples of sneak labels

Incident	Location	Reference
Man poisoned by CO because a vent damper was unlabelled and the handle position ambiguous	Unspecified	[21]
Tank cars supplied with a hinged label with 'oxygen' on one side and 'nitrogen' on the other The label fell over and oxygen was discharged into the nitrogen supply	Unspecified	[21]
A workman overpressurised and burst a pipe because the test gauge was calibrated in atmospheres, not psi	Unspecified	[21]

6. Sneak labels

Sneak labels result from ambiguous labelling of instruments and other equipment. In one example [1], a procedure called for the operator to set a temperature of 60 °C and the dial of the instrument was calibrated as 0–100 so the operator set the pointer at 60. Unfortunately, the dial calibration was 0–100% of a maximum scale of 200 °C. The elevated temperature led to a runaway reaction and the operator was injured.

Some other instances of sneak labelling are: (i) a lack of correspondence between the P and I diagrams and the plant; (ii) containers without labelling, or with labels on the lids only (the lids tend to be misplaced once the container is opened); (iii) association of container contents with container shape or location. (what happens if someone uses the 'wrong' container as temporary storage or puts a container in the wrong location?); (iv) inconsistent sequences. (see the example of the seven pumps, earlier in this paper).

Further examples are given in Kletz [20]. Table 9 shows some further examples of sneak labels.

7. Sneak procedures

Sneak procedures often occur through the absence of a procedure, in which case the operators invent something, or in the transfer of information from one party to another, such as at shift changes. One such example [1, 20] is shown in Fig. 8. This figure, which is grossly simplified, shows a plant which was being cleaned and revalidated after some modifications had been made. Reactor R3 was charged with toluene using the pump, manifold and flexible hose. After refluxing, half the batch was transferred each to R1 and R2 where a reflux again took place. Next, R3 was charged with isopropanol and the process was repeated. Finally, the vessels were washed with water.

At the end of the operation, the foreman noticed a film of dust inside R1; he noted this in the shift log-book, with a message to the shift manager to: 'Agitate R1 with

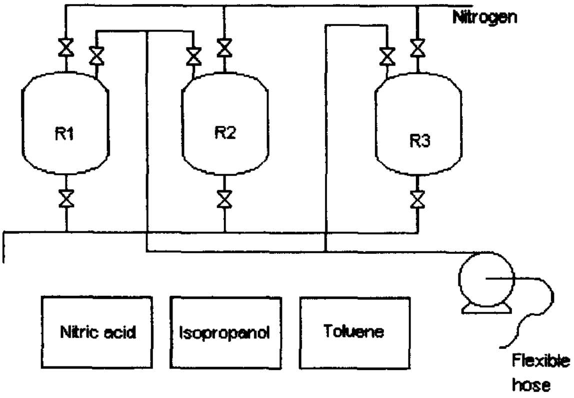

Fig. 8. Sneak procedure.

Table 10
Some examples of sneak procedures

Incident	Location	Reference
Tons and pounds were mixed in the same instruction and decimal points were not aligned, resulting in a charge of 104 lbs instead of 0.014 lbs.	Unspecified	[21]
Unreliable pressure switches were bypassed, negating interlocks and permitting the reactor drain valve to be opened while under pressure.	Unspecified	[21]
Many instances of inadequate and confusing instructions in Permits To Work	Everywhere	

150 l HNO_3 solution for 4 h at 80 °C'. The foreman assumed that 'the usual method', which had been practised for many years, would be used; this was to fill the vessel with about 3.5 m^3 of water and then pump in 150 l of 53% nitric acid. Unfortunately, the shift manager was not aware of the 'usual method' and charged 150 l of concentrated nitric acid via the pump and flexible hose. After about 120 l of acid had been charged, gas began to evolve rapidly in R1, the relief valve lifted and the shift manager ran. The vessel ruptured but the shift manager received no injuries.

As a common example of a sneak procedure, this shows the danger of assuming that everyone knows 'the usual method'. It also shows an instance of sneak reaction. The pump, which had last been used to transfer isopropanol to R3, had not been completely drained and about 5 l of isopropanol was pumped into R1 along with the nitric acid. This formed unstable isopropyl nitrate, which then decomposed explosively. Some other examples of sneak procedures are given in Table 10.

Before leaving the question of sneak procedures, mention must be made of an instance in fiction (although clearly based on fact). The story Sulphur, in the late

Primo Levi's collection The Periodic Table [22], can be read as a tale of sneak indication, procedure and reaction! Although clearly set in the early 1950s, only the fact that the hero, Lanza, smokes while he tends the batch differentiates it from modern practice.

8. Sneak reactions

Sneak reactions arise from unanticipated changes to process conditions, unintended material, or catalysis by unintended material. The following [1] is one example.

Gaseous chlorine was being added to a solution of aromatic monomer in carbon tetrachloride at 50 °C. When about 10% of chlorine had been added, a violent reaction occurred, lifting the top of the vessel, buckling the piping, and spraying solution over two operators. It was subsequently established that ferric chloride had entered the reactor from the stainless steel chlorine line and that ferric chloride catalyses a violent reaction between chlorine and aromatic monomers.

It is very difficult to give much guidance on sneak reactions. They are often the consequence of sneak flow or, as in the case above, of another sneak reaction. At present, the best procedure seems to be:

1. Identify all materials in the system and determine whether or not they can react with any of the process materials or catalyse reactions between process materials. If so, verify that measures exist to prevent the particular combination occurring.
2. Verify that no unwanted reactions will occur if process conditions deviate from the nominal.

Clearly, the identification of sneak reactions can be a heroic task and it is to be hoped that more experienced chemists than the authors may care to tackle this problem.

9. The identification of sneaks

The previous discussion has said nothing about identifying sneaks, beyond giving a procedure for sneak flow and some comments on the difficulty of identifying sneak reactions. The favoured method is by the use of a checklist, historically [2] known as a sneak clue list. In the course of this research, a sneak reporting form has been developed [1], and is shown in Fig. 9 which is a completed copy of the form for the glycerol reactor incident cited above.

The heading 'Sneak clues' is used to record features which should have been taken into account in the design and which, if implemented, would have prevented the occurrence of the sneak. Data under this entry are then correlated with the clue lists and new entries generated, should these be necessary. Fig. 10 shows the format adopted for clue list entries.

The clue list is organised as a simple database in which retrieval is determined by the four indices of Category, Hardware, Parameter and Deviation. Clues can be

Ref	009	**Source**	Loss Prev Bulletin 028 p92	**Date**	92.05.03
Incident date	?	**Sneak category**	Indication, procedure		
Substances involved	Ethylene oxide, Glycerol				
Properties					
Plant state at time of incident	Start of ethylene oxide feed				
Initiating event(s)	Increase in temperature				
Causes	Due to reactor outlet valve being closed, no flow over temp.				
sensor gave false indication. Op'r adjusted set point, then realised error and opened valve. Runaway reaction resulted.					
Consequences	Reactor burst. Two men injured.				
Sneak clues	Sensor not in contact with fluid but reading conducted temp.				
Inadequate interlocks. No formal recovery procedure, case not anticipated.					

Fig. 9. Sneak reporting form.

INDICES			
Sneak category	**Hardware item**	**Parameter**	**Deviation**
Indication	Temp. sensor	Temperature	No
			Too little
			Too much
			Incorrect
		Flow	No
		Level	No
			Too low
Clue	Are temperature sensors arranged so that they are always in contact with the process fluid? What happens if they are not?		
Refs.	11,23,86		

Fig. 10. Clue list format.

recalled by sneak category: i.e. one of the following: Flow, Indication, Procedure, Energy, Reaction, or Label. This serves the user as an aide memoire when checking for sneaks in a given category.

Some clues can be indexed to one or more pieces of Hardware, e.g. a clue referring to sneak flow in priming lines or in the priming operation would be referenced to centrifugal pumps.

The indices of Parameter and Deviation work together after the fashion of HAZOP; e.g. a clue referring to sneak indication of temperature sensors (see the examples) would be referenced to the temperature parameter, with deviations of 'NO', 'TOO LITTLE', 'TOO MUCH' and 'INCORRECT'. It would also, on the basis of the incidents examined, be referenced to FLOW and LEVEL since conditions of no flow or too low level can result in sneak temperature indications.

The clue field allows unstructured entry of clues, in the form given in the main text. The references field contains references back to the original sneak reports which were used to generate the clue. While far more complex clue list formats could be devised, that shown here has the advantages that it is very simple and it is integrated with the existing HAZOP method. Two sneak analysis procedures applicable to process plants can now be outlined: the first is the sneak-augmented HAZOP and the second is a full-featured sneak analysis.

9.1. Sneak-augmented HAZOP

This proceeds exactly as for a conventional HAZOP, but in addition the clue list is interrogated for each HAZOP keyword (parameter/deviation) and hardware item, and a search for possible sneaks is made on the basis of the clues presented. A sneak flow analysis is also performed, as described above. That done, the analyst must satisfy him/herself that adequate precautions have been taken to prevent any such sneak flows occurring.

9.2. Full-featured sneak analysis

The following procedure represents an 'ideal' sneak analysis; it is doubtful if this would ever be required on any but the most critical of processes (e.g. nuclear chemistry or space-borne life-support systems) but it is presented for completeness so that the user can adapt portions of it to his or her own needs.

1. Bring all drawings up to the as-built configuration.

2. Partition the plant into manageable sections, as would be done for a HAZOP and for each section.

3. Conduct a sneak flow analysis.

a. Starting with each flow which crosses the section boundary and assuming that all valves are open, mark all possible destinations that the flow could reach. Be sure to include drains, sewers, steam, water and other utilities and to carry the analysis as far as the plant boundary, where necessary.

b. Note any such flows which could result in incompatible substances coming into contact or travelling to inappropriate locations and verify that adequate precautions exist to prevent them from occurring.

c. Travelling along each potential sneak flow identified in a, interrogate the clue list for each hardware item encountered and search for sneaks on the basis of the clues.

d. For each state of the plant, examine the effect of each valve deviating from its intended state while all the others are correct.

4. Screen for sneak indications.

a. For each instrument, examine for sneaks in accordance with the clue list for Indication.

b. Repeat the exercise for the control room, remembering that the concept of 'instrument' extends down to the humblest indicator light.

5. Screen for sneak labels.

a. Check the plant drawings against the as-built plant for consistency of labelling.

b. For every label, examine for sneaks in accordance with the clue list for Label.

c. Check for consistency of labels against indicators. Be especially alert for controls and indicators which act in opposite directions (see clue list).

6. Screen for sneak procedures.

a. Examine all procedures with respect to the clues for Procedure.

b. Ensure that this is done for maintenance, start-up, shut-down, transport, etc. (remember Camelford).

7. Screen for sneak energy.

a. Search for possible sneak energy with the aid of the clues for Energy.

b. Pay particular attention to the problems of agitator failures and layering of reactants.

c. Review all maintenance procedures for the possible occurrence of sneak energy conditions, being particularly aware of the hazard of trapped energy.

8. Screen for sneak reactions

a. Obtain complete descriptions of all process chemistry involved.

b. Establish process limits (temperature, pressure, etc.) for the occurrence of unwanted reactions.

c. Consider the effect of incompatible fluids coming into contact, as revealed by the sneak flow analysis of step 3, above.

d. List all materials of construction and verify that they are compatible with process fluids.

e. Verify that construction materials cannot catalyse unwanted reactions, remembering that sneak flows can transport such materials as well as process fluids.

10. Conclusions

This paper shows the existence of sneaks as a class of latent conditions and describes some instances of their occurrence in batch plant. The historical evidence suggests that sneaks are particularly common in batch plant and this may be attributed to the multi-purpose nature of such plant: plant may have to be reconfigured, leading to possible sneak flows and the need for many procedures increases the likelihood of their containing sneaks. It has also been shown that agitation failure is a common cause of sneak energy, although the problems of agitation are already well-known in the industry. Procedures for identifying sneaks have been presented.

It is not suggested that sneak analysis (SA) be viewed as a method of hazard identification in its own right, except in certain special cases. In every case, SA must be used to supplement an existing method of analysis, usually HAZOP, and to this end the clue list has been developed by one of the authors (Whetton) into a program designed especially to work with HAZOP. A commercial version of this program – SClu – is under development. Of particular advantage to hazard identification on batch plant is the sneak flow analysis which pays more formal attention to the states of the plant than do other methods, and use of this method alone should identify many potentially hazardous problems.

Until recently, SA of process plant has been handicapped by its unfamiliarity, the lack of a good method and the lack of a good clue list; it is to be hoped that this paper has gone some way towards remedying these deficiencies.

10.1. Experiences

A manual version of the clue list, referred to above, has been used to perform a sneak-augmented HAZOP on two plants:

(i) *A large, multi-purpose batch plant with six reactors and ten storage tanks.* Three sneaks were found that would probably not have been identified by HAZOP alone. Two were sneak flows in utility lines, of which one allowed a steam system at 12 barg to be connected to another at 6 barg via the common vent line to two reactors and the second allowed steam at 12 barg to flow directly to an ethylene glycol storage tank, probably displacing its contents over the adjacent roadway. The third was a sneak indication (of which there were six identical instances) in which a protective temperature sensor was positioned so that there was no guarantee of its measuring the liquid temperature intended.

(ii) *A natural gas liquefaction plant.* Four sneaks were found. One was so obvious that it needed almost no analysis and involved the configuration of valves to select one of three reactors for states of operating, regenerating and standby. One involved a sneak indication of flow and would have been found by HAZOP in the normal course of events. The other two sneaks were quite subtle and had not been found on a previous HAZOP of that section of the plant. Of these, one was a sneak flow which occurred during the changeover between reactors (mentioned above) and was found to account for a mysterious instability which had plagued the plant over the last 20 years. The fourth sneak involved two relief lines, one at 3.5 barg (manually operated) and the other at over 80 barg (and operating automatically via a relief valve), connected to a common vent system. The dimensions of the vent were such that the pressure drop in the vent could be considerable and explained why, during the last plant shut-down, natural gas had blasted its way into the l-p cooling water system. The engineers involved in this exercise expressed enthusiasm for the method, despite having to use a printed copy of the clue list, rather than the program.

In addition to the two exercises detailed above, a major fine-chemicals company has requested a copy of the clue list and is intending to use it with a HAZOP in the next few months. It is hoped to produce a separate joint paper on this analysis. A similar exercise is also anticipated for a biochemical system. Unfortunately the competitive nature of the fine-chemicals business seems to be preventing us from describing these analyses in detail.

References

[1] W. Armstrong, Sneak analysis applied to batch plants, Unpublished dissertation for the Degree of M.Sc. in Process Safety and Loss Prevention,University of Sheffield, 1992.

[2] E.J. Hill and L.J. Bose, Sneak circuit analysis of military systems. in Proc. 2nd Int. Systems Safety Conf., 1975, pp. 351–372.

[3] J.P. Rankin, Sneak circuits – A class of random, unrepeatable glitch, Plant/Oper. Prog., 3(3) (1984) 175–178.

[4] P. Hokstad, R. Årø and J.R. Taylor, Integration of SA and RAMS techniques, Report No. 757302, SINTEF, Trondheim, Norway, 1991, 70 pp.

[5] J.R. Taylor, The sneak path analysis procedure, in Proc. of the Sneak Analysis Workshop, ESA-WPP033, European Space Agency, ESTEC, Noordwijk, Netherlands, 17–18 June 1992, 10 pp.

[6] B. Dore, Overview of ESA activities on sneak analysis. in Proc. of the Sneak Analysis Workshop. ESA-WPP033, European Space Agency, ESTEC, Noordwijk, Netherlands, 17–18 June 1992.

[7] B. Dore, ESA research and development strategy on sneak analysis, in Proc. ESA Symp. on Space Product Assurance for Europe in the 1990s, ESa/ESTEC, Noordwijk, Netherlands, 15–19 April 1991.
[8] C.P. Whetton, Sneak analysis applied to process systems, VTT Research Notes No. 1376, Espoo, Finland, 1992.
[9] C.P. Whetton, Thermohydraulic sneaks, in Proc. of the Sneak Analysis Workshop, ESA-WPP033, European Space Agency, ESTEC, Noordwijk, Netherlands, 17–18 June 1992.
[10] A.H. Hahn et al., Applying sneak analysis to the identification of human errors of commission. Reliability Eng. System Safety, 33 (1991) 289–300.
[11] C. P. Whetton, Sneak analysis of process systems, Trans. IChemE, 71 (1993) 169–179.
[12] Anonymous, Report on the President's Commission on the Accident at Three Mile Island, Pergamon, New York, 1979.
[13] P. Eddy, E. Potter and B. Page, Destination Disaster, Hart-Davis, London, 1976.
[14] T. A. Kletz, What Went Wrong?, Gulf Publishing Co., Houston, 1985.
[15] D.A. Norman, The Psychology of Everyday Things, Basic Books, New York, 1988.
[16] R. Milne, One wrong delivery, and a whole town is poisoned, New Scientist, 21 (1989) 60.
[17] J. Easterbrook and D.V. Gagliardi, Sewers can pass on problems, Plant/Oper. Progr., 3 (1) (1984) 29–31.
[18] Anoymous, Pressinformation: F25 Olyckan, Press release (in Swedish) dated 92.03.06, Nobel Chemicals, Karlskoga, Sweden, 1992.
[19] Anoymous, Exothermic runaway caused Hickson deaths, Chem. Eng., 10 December (1992) 7–8.
[20] T. Kletz, An Engineer's View of Human Error, Institution of Chemical Engineers, Rugby, 1985.
[21] D. Embrey, Human reliability, Module 6 of Sheffield University M.Sc. Course in Process Safety and Loss Prevention, 1991.
[22] P. Levi, The Periodic Table, Sphere Books, London, 1986.