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PRACTICAL GAS EMISSION CONTROL DURING LANDFILLING

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SUMMARY: Whilst the major emphasis on landfill gas control has previously related to post-completion of landfill cells or phases rather than that during active waste placement, increasing need for odour control has changed that pattern of *ad hoc* capping and gas collection systems. This project (Barry *et al*. 2003, 2004a and 2004b) has provided quantitative information from UK landfills on the scale of methane (CH_4) emissions from the commencement of waste deposition. The paper provides timescales for the establishment of methanogenesis and average surface flux rates from commencement of waste placement. The highest flux rates were recorded on waste side slopes and near the landfill edges; emissions from these zones are more conducive to control and it is likely that the most cost-effective emission control systems should be based on horizontal collection systems, reflecting the greater lateral permeability of wastes. Such controls are compatible with on-going disposal operations and can be readily integrated with permanent gas collection systems for energy recovery.

1. INTRODUCTION

Historically, the pre-closure stages of waste landfilling in cells have not usually been subject to any active gas controls, that is except where odour controls have been required to reduce impacts on sensitive neighbouring areas. This situation is changing, due to both the implementation of the Landfill Directive (Council of the European Union 1999) and government policy with respect to global atmosphere and climate impact effects. On one hand, the Landfill Directive requires collection and treatment of landfill gas and future changes in waste composition may result in significant changes in the generation and constituent components of landfill gas. On the other hand, as part of the UK Climate Impacts Programme, the UK government is committed to reducing the overall emissions of greenhouse gases in accordance with internationally agreed targets. Similarly, the Environment Agency is developing a strategy for emissions-based regulation of landfill gas (Environment Agency 2002) in order to minimise global impacts of CH_4 and local impacts on health, environment and amenity.

In order to improve the current understanding of timescales for methanogenesis to commence in landfills and the scale of surface emissions from waste surfaces during the landfilling stages, this project (Barry *et al*. 2004a) was initiated. Therefore, it was considered that, apart from losses in energy potential, a greater understanding of the gas flux regimes would help identify the possible needs for emission controls and, in turn, the practical methods of achieving such control before conventional final gas collection systems are installed. This paper highlights the findings relating to the practical methods by which the main surface emission zones could be controlled without greatly compromising the on-going waste placement operations. Firstly, however, the principal findings of the research project are outlined.

2. METHANE FLUX RATES DURING WASTE PLACEMENT

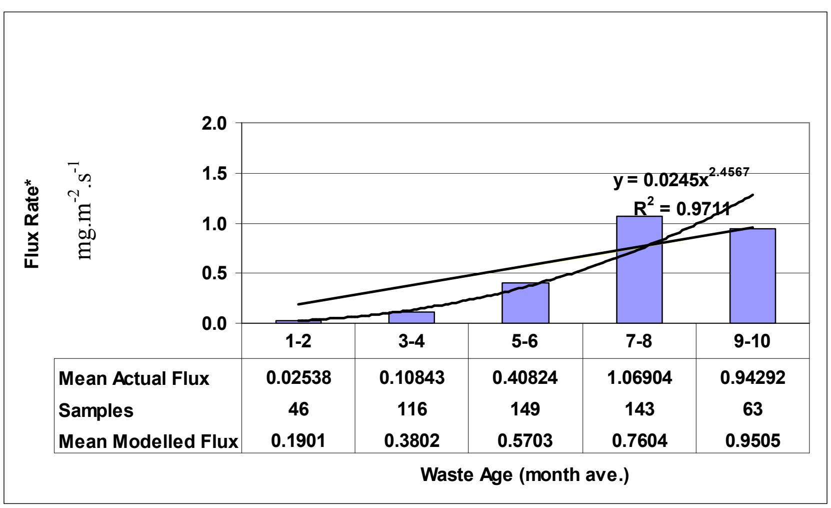
Surface flux data was collected at 21 UK operational municipal solid waste (MSW) landfill sites (on 32 occasions) where gas control systems had not yet been installed. Data analysis showed the following main findings.

(a) **Overall flux rates**: the average rates of flux increased progressively until the waste was, on average, ~ 10 months old (i.e. 20 months after commencement of waste placement), to ~ 1 $mg.m^{-2}.s^{-1}$ (See Figure 1), or 10 times the proposed emission level for temporarily capped sites (Environment Agency 2003). Surface emissions were measurable long before full methanogenic conditions prevailed within the waste mass, a phenomenon considered to reflect the greater advection effects of carbon dioxide (CO_2) in the early stages of biodegradation.

(b) **Waste side slopes**: the emission rates from these site areas were, on average, ~ four times the corresponding top surface emission rates (these areas relate to the edges of cells and not to an individual waste lift face).

(c) **Landfill edges**: these areas (next to the landfill containment system) can have the highest rates of surface emission.

(d) **Top surfaces**: these emission rates increased relatively slowly with increasing waste age, suggesting that the influence of the deeper, more substantial gas regime is not so significant.



	1-2	3-4	5-6	7-8	9-10
Mean Actual Flux	0.02538	0.10843	0.40824	1.06904	0.94292
Samples	46	116	149	143	63
Mean Modelled Flux	0.1901	0.3802	0.5703	0.7604	0.9505

Figure 1. Methane surface flux rates from 21 operational UK landfill sites

There is an obvious similarity between the two major emission rate areas (slopes and landfill edges) because they both appear to reflect the effects of the high lateral gas permeability of the waste mass. Thus, the essential difference is that when the gas reaches the side of the landfill, it rises through a relatively narrow relatively high permeability zone (probably amplified by a leachate drainage blanket or a membrane protection layer). The project did not define the edge zone width over which the high emission rates occur but it is deduced that it is only a few metres wide.

It was also found that methanogenic processes had commenced effectively ~ two months after initial waste placement and was well-established in ~ six months; the CO_2 concentrations reached 60+% within 2-3 months after waste placement. Overall, the increases in CO_2 and CH_4 concentrations and the decrease in oxygen (O_2) levels followed the classic profiles of Farquhar and Rovers (1973). This was the first time that a timescale has been placed on the concentration profiles of the three bulk gases during the initial phases of biodegradation.

The greater flux rates through side slopes matches the site study findings in the USA (Lofy, 1996) that showed the effective gas permeability of MSW is considerably greater laterally than vertically, i.e. lateral suction influences were found to be 7 to 8 times greater than the vertical. This differential is probably due to a combination of the layering of the wastes and the additional effects of daily cover soils, both of which can help create a general lateral bias as well as being the cause of perched leachate tables within the waste.

3. IMPLICATIONS FOR GAS CONTROL SYSTEMS

It is recognised that, whatever the regulatory policy on the scale of necessary gas control for landfills during the filling stages of waste cells (for minimising global atmosphere impacts), odour control could remain a key driver in many situations. Whatever the situation, the same general gas control design principles are likely to apply to both scenarios. Thus, there is a presumption in this paper that gas controls could be needed to a greater degree than currently employed, for the period before the installation of conventional post-capping (albeit temporary capping) gas collection systems.

While the emission rates from the general top surfaces of uncapped wastes were shown to be much lower than those from side slopes and near landfill edges, the overall contributions from each type of landfill surface area or feature is a function of the 3-dimensional shapes of cells at any time and the landfill as a whole. Other controlling factors, not included in this study, are likely to be temperature and moisture content. While many landfills have highly complex surface shapes that prevail for varying time periods the research project attempted to assess the implications on overall emission volumes of several permutations of geometric cell shapes and waste filling rates. The evaluation of a hypothetical site showed that because smaller cells can have a disproportionately large slope surface area in comparison with the top surface, the slopes can provide not only higher emission rates but also result in higher emission volumes (indeed, the first cell could have three open side slope faces). In contrast, large cells (that obviously take longer to fill) would have a lower top surface over a larger area but for a much longer time.

Overall total emission volumes showed that cells that are filled within ~ 20-24 months should result in significant reductions in CH_4 emission volumes when compared with cells that take longer to complete. Reducing the timescale further should enhance that benefit, provided that the opportunity is taken to construct the relevant capping and permanent gas collection system as soon as the cell filling has been completed. Thus, from both practical and cost-effectiveness points of view, the main gas control actions should probably relate to waste side slopes and to landfill edge areas. The main practical benefits of such controls for waste placement are that they would not generally interfere with day-to-day operations, a factor that has greatly influenced the choice of control systems historically. This is not to say that there would not be considerable benefits from any top surface controls, merely that those would probably have much higher capital and operational cost implications, as discussed below.

In reality, there is a readily recognisable limit to the degree of overall emission control that can be achieved during the period of waste placement, and so any controls are best focussed on the main areas and features, until such time as the long-term gas collection systems are constructed and operated. Furthermore the most significant source areas of gas (and odour) are uncapped leachate wells and areas of leachate breakout. This paper does not address those particular aspects.

4. CURRENTLY AVAILABLE TEMPORARY CONTROL SYSTEMS

The main control methods generally used in uncompleted/operational parts of landfills are as follows.

- Horizontal pipe/pathway systems (formed with perforated pipes or high permeability materials) within the waste body.
- Shallow pin wells set into the superficial waste layers (in combination with a temporary capping layer).
- Vertically built-up pipes/pathways.

There are relatively few published details of these systems, at least with respect to their general effectiveness at particular sites. Also, best practice guidelines are lacking and the current systems have, understandably, evolved largely through trial and error by individual operators using knowledge gained from the conventional gas collection and control systems. Whatever the design system choices a critical factor in all gas abstraction systems is that the consequence of over-extraction can be excessive ingress of air, often resulting in high oxidation rates and an increased risk of spontaneous combustion. While these risks are well recognised in the industry, there are increasing incidents of landfill fires, phenomena that are considered, at least in part, to be due to poor abstraction system management and acceptance of inappropriate wastes.

4.1 Horizontal control systems

UK experience with horizontal systems is based mainly on short-term needs, such as solving a specific environmental problem and in this situation the systems are usually considered to be fully or partially sacrificial. They are usually laid in geometric patterns (such as herringbone or parallel lines) and are usually constructed in a trench that is excavated into a waste layer with a typical vertical frequency of 5m-8m (or ~ every 2-3 waste lifts). The collection part of the control system usually involves either perforated pipework or high permeability materials, such as building rubble or gravels. The network is usually laid at 20-25m lateral intervals. The final 10-15m sections of the pipe/pathway systems approaching an open waste face usually comprise solid pipes (in a relatively low permeability surround) so as to reduce the risk of air ingress to the wastes resulting from negative pressures too close to the waste edge. In some systems the perforated pipes are designed so that the perforations are spaced at decreasing centres as one moves away from the open face. This helps ensure that the applied suction is not concentrated excessively near the open face and so reduces further the risks of air ingress.

Pipes are normally laid in rock-filled trenches in order to support and protect the pipe; this backfill material can also act as an effective gas pathway. Further, the backfill medium can be particularly important in reducing the risks of the pipe water-logging due to perched leachate conditions, a factor that is fundamental to the effectiveness of the abstraction system. That effectiveness can also be affected by silting up, which can be caused by fine particles being sucked into the system. The degree to which this aspect can become an issue will depend on the life expectancy of the system.

4.2 Pin wells

Pin well systems involve a network of shallow, small diameter tubes (63mm) that are driven vertically into the waste, usually to a depth of $<$6m. They can be used on both top surfaces and on reasonably-graded side-slopes (i.e. where drilling rigs can safely operate). A typical installation layout has wells at 15–20m intervals, with gas collection pipe sizes being dependent on the number of wells installed on a single suction line. Sizes typically range from 63mm (for up to three wells) to 125mm (for 20 wells). Operationally, they tend to have a limited life span (typically less than two years) although this is highly site- and location-specific.

4.3 Vertically built-up systems

Vertical wells within operational cells are usually considered to be sacrificial and so are normally replaced ultimately by retro-drilled vertical wells when the cell capping and restoration works have been completed. Well installations are usually based on a regular grid pattern, typically at 50-60m centres, with a corresponding radius of influence assumed for each well. The wells are, by definition, constructed in tandem with the rising level of wastes. The core of such wells usually involves an HDPE 125mm diameter pipe, with extensions being fusion-welded.

In order to protect the pipework, stone is laid around the pipe by using a steel tube (see Figure 2). This pipe not only acts as the funnel for placing the stone surround, it also acts as a temporary seal at the top of the assembly to reduce air ingress and gas emissions. Further, the steel tube helps protect the protruding plastic pipework from mechanical damage by site plant. Thus, with each successive waste lift the steel tube is raised by a crane and then the extra vertical pipe is added, followed by the stone, and so on. Suction can then be applied to the steel tube lid to extract gas (rigorous health and safety precautions need to be applied during such operations due to the probable scale of asphyxiant and flammable gas emerging).

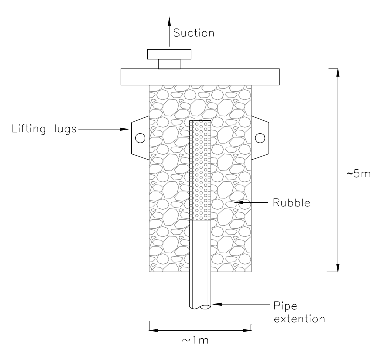


Figure 2. Typical gas control built-up vertical wells in operational landfill cells

Variations on this design include the installation of three pipes in one well, all of different lengths, in order to control better the level from which gas is abstracted. In some instances the pipe is used only in the top 10m because, below this level, the building rubble/stone can provide an adequate gas pathway. There are a number of operational issues that limit the effectiveness of the built-up vertical well systems, the most obvious of which concerns the depth below waste surface to which the un-perforated pipes should extend. For example, unless there is a sufficient length of pipe near the top of the well, gas extraction cannot be very effective and if only a small portion of the pipe is perforated, its operation will also be limited. A novel concept being considered by one company for circumventing this potential conflict involves the use of degradable plastic film which can be wrapped around the top section of the perforated pipe to provide a temporary seal. As the plastic degrades, the pipe progressively becomes perforated as the waste height increases.

Protrusions above the working area of the landfill can be readily damaged by typical surface operations, and so most landfill operators prefer to avoid this situation as far as possible. Many attempts have been made to train site personnel on this aspect of damage limitation but, generally, with relatively little success. Thus, an on-going concern in the waste management industry appears to relate to the difficulty in keeping well-assemblies sufficiently vertical, a risk that is amplified by the effects of the inevitable movement and settlement of the wastes. In practice, vertical wells tend to become markedly off-centre and this is reflected in damaged pipework and a consequent decrease in extraction efficiency.

4.4 System management

Control systems usually require routine balancing and, as far as practical, they are operated in a similar fashion to the systems used for completed landfill phases. Typically, however, because gas extracted from shallow waste zones is usually of poor quality, it is often conveyed to a flare stack (usually mobile), whereas the good gas from deeper waste zones is conveyed to the main ring main and, thence, the gas engine. Low suction pressure (~ 0.5mBar) is common to all systems, a factor necessary to minimise the risks of air ingress. Such ingress can have two effects; firstly excessive air ingress increases the risk of landfill combustion and secondly it reduces the quality of gas extracted. Therefore, particular attention is usually given to O_2 and carbon monoxide (CO) monitoring as well as temperature, to ensure that the applied suction is not excessive. Monitoring young gas in particular for silicate compounds is also considered very important because these compounds can cause extensive damage to engines.

5. FUTURE DESIGN NEEDS AND OPTIONS

The creation of a particular design for controlling surface emissions on an operational site would actually commence with the selection of cell sizes and filling rates that help minimise the period during which high-emitting surfaces were uncontrolled. This optimisation might not be compatible with the overall site geometry and logical cell filling sequences. For example, a site where cells are normally created around the landfill perimeter zone first, with the central area being filled last, could result in extensive open faces. The period of temporary capping for such sites could also be very protracted.

5.1 Top surface emission controls

In the absence of some form of temporary capping layer, any attempts to control surface emissions can be only partially successful, whatever the actual effects on waste placement operations. Further, any vertical abstraction system without such capping could greatly increase a combustion risk through over-pumping. Thus the prospect of having extensive vertical wells is very remote. Since the cell areas to be addressed could be very extensive, and because new surface emission controls would continue to be needed as waste placement progressed upwards, the only practical control method would be using a build-as-you-go horizontal network of pipes or preferential pathways that can be connected to a gas collection system. A horizontal network would capitalize on the higher lateral permeability of the wastes and, having been installed at any particular level, the network at each level would be activated when, say, a further two to three lifts of waste had been added (i.e. about 5-8m). This covering would reduce the risks of drawing air into the system because of the lower vertical permeability and the lack of direct pathway to the surface (as occurs with conventional vertical systems).

A key design issue is the frequency at which the pipes/pathways would be needed, bearing in mind that there would be a series of networks, constructed as waste filling progresses. A further consideration, for top surface emission control, is that the deeper collection networks would become progressively redundant as waste height increased; to reiterate, the research (Barry *et al.* 2004a) showed that increased top surface emissions did not correlate with waste depth. High permeability trenches can be very effective for gas collection/interception efficiency but they can also consume costly landfill void space (apart from materials and operational costs).

For most landfill cells, it is unlikely that the costs of such a network would be justified solely by the top surface emission reductions achieved. The system would inevitably help reduce side slope emissions, provided that the collection network at each level continued to be pumped. However it is considered that there is a much better way of achieving this benefit, though not tested experimentally, as discussed below.

5.2 Side slopes

Retro-fitting any collection system for side slopes would be even more difficult than for top surfaces because of the physical aspect of the slopes themselves; the only practical solution to this generic high-rate emission zone is to construct the control system infrastructure as waste filling progresses. In essence the control system can be quite similar to some main aspects of a top surface pipe/pathway network but with some important differences. For side slopes the targeted control zone could be some 20m-30m in from the side slope, i.e. it could take the form of a gas interception system rather than collection *per se*. Thus, the emphasis would be on collecting only that gas that entered a zone from which it might otherwise result in a surface emission; in that way the system could be operated pro-actively based on monitoring results.

There is no published information on which to define the possible optimum spacing of interception pipework; neither are there data to help define the lengths of either the initial unperforated section of pipe or the perforated pipes penetrating further into the wastes. However, based on current industry experience, it is considered that the controls should be installed at some 5-8m vertical spacing (i.e. ~ 2-3 waste lifts) with ~ 25m lateral centres. In selecting the respective lengths of perforated/unperforated pipework, it seems logical that this should also be a function of the basic spacing between the pathway lines. For example, if the lateral pipe/pathway spacing is 20m-25m and the solid pipe section extends at least some 10m-15m, then a further penetration length of some 15m-20m perforated pipe should be sufficient to achieve a major degree of gas interception at each level. As discussed earlier, the effect of deeper lateral penetration of the collection pipe network into the wastes would be to reduce the potential for vertical migration and so reduce top surface flux rates, subject to gas collection infrastructure capability.

To reiterate, these systems should be installed as landfilling proceeds and then only activated when, say, two layers of waste had been placed above them. While this amounts to only 5m-6m depth of cover, the lower vertical permeability of the wastes should be sufficient to reduce the risks of excessive air ingress (all subject to effective site management, of course). Further in this regard, the stability of the waste side slopes needs to be given due attention so that (apart from any physical damage caused by soil/waste slippage) large fissures do not arise, thereby providing preferential air ingress pathways.

5.3 Landfill edge zones

As outlined earlier, the interface zone between wastes and the landfill boundary barrier system is inevitably of relatively high permeability, and any edge-based gas control system should attempt to intercept the gas along the full perimeter of the filled edge zone. This is probably best achieved by a perforated pipe, or similar, placed at alternate waste lifts (i.e. the same vertical interval as for the side slope controls).

These perimeter systems could be connected to ground level by solid up-riser pipes using an appropriate degree of suction. In this regard it is logical that the perimeter pipework is considered as being a series of discrete horizontal elements that can be controlled by valves in a manner similar to conventional vertical wells. Again, although empirical data are lacking on the design of such systems, based on general industry gas abstraction experience, it is reasonable that perforated pipe lengths of up to ~ 100m (i.e. 50m each side of an up-riser collector pipe) are likely to be effective, subject to detailed design and suction pressures.

These perimeter systems could, as waste heights increase, be abandoned if the controls in the upper waste levels were found to be capable of adequately intercepting the overall gas volumes. However, because the gas from the lower levels of waste will always be expected to be a greater volume than that from the upper layers (and would be of higher quality), continuing the deeper gas abstraction would seem prudent, even if only as a supplement to the flaring of upper collection zone gas. On the other hand, energy for utilisation could be wasted by unnecessary flaring, an aspect that amplifies the need to carefully assess how the emission control and overall gas collection systems can be integrated.

5.4 Integrated management

Figure 3 shows a system for a typical operational cell that could achieve the main emission control objectives in a practical manner, namely on the side slopes and in the landfill edge areas.

On the assumption that the system might be justified on the basis of minimising surface emissions, it is logical to consider its integration with the conventional long-term collection and energy utilisation system. As a concept this would appear quite straight-forward but in practice it is rarely ever likely to be simple. Accordingly, the process would need considerable fine-tuning before it was effective. Nonetheless, on the basis that the lateral permeability of the wastes is higher than the vertical, at least some advantage could be gained for connecting the final vertical system with the horizontal. This would not require any precision engineering but could be achieved by simply optimising the proximity of vertical wells to high permeability horizontal zones. This should increase pumping efficiency, not least because the high permeability zones can help relieve any perched leachate conditions that can compromise normal gas pumping objectives. Whatever the ultimate designs, an over-arching consideration in all gas collection and control systems is their safe and effective management. Accordingly, these aspects should be given high priority in the research into and implementation of any emission control systems.

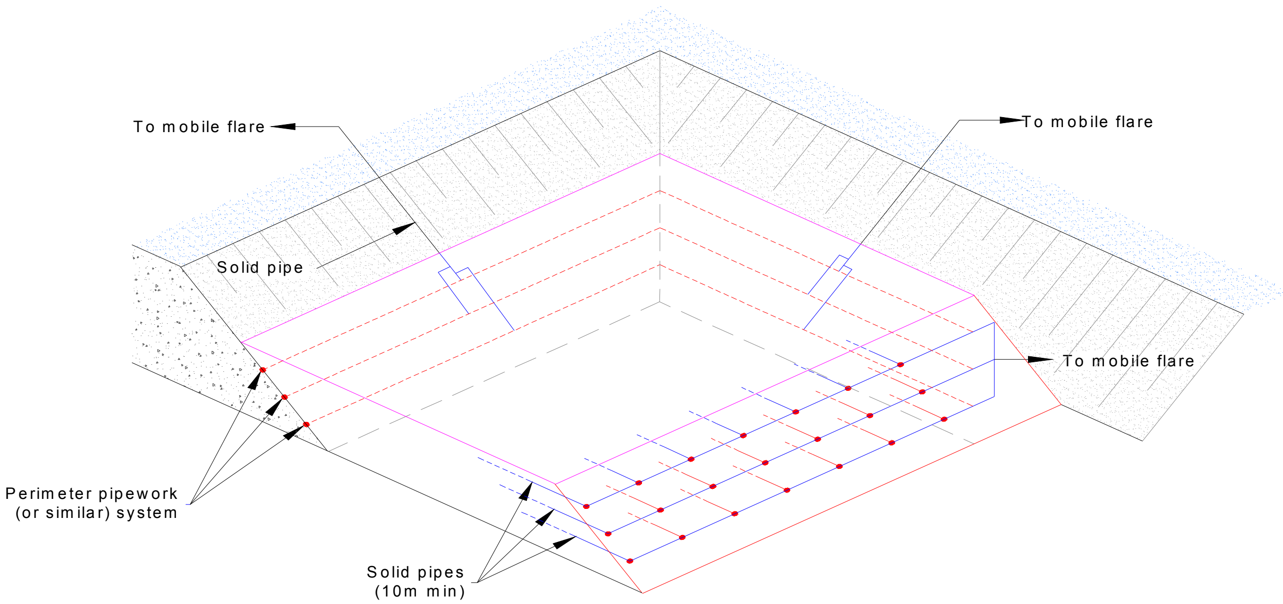


Figure 3. Schematic of basic CH_4 emission controls from key emission areas

6. CONCLUSIONS

There is a need for a greater sharing of industry experience in the effectiveness of horizontal control systems and especially where these systems have been absorbed into the final gas collection and utilization system. The traditional water-balance influence on waste cell dimensions may need to be reviewed for deeper sites in particular because the period prior to temporary capping on such sites might be excessive in terms of emission rates. On the other hand, using smaller cells so as to reach the top level more quickly would increase the effective slope areas disproportionately. In such situations a simple model would help identify the best compromise. The Landfill Directive (Council of the European Union 1999) is likely to have an effect on the principles outlined above by reducing the biodegradable waste content but its significance and timescale remains uncertain. In the interim, there is a need to maximise gas collection efficiencies for all control systems.

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