



<b>Health and Safety Executive</b>		<b>Operational Circular</b>	
<b>Field Operations Directorate</b>		<b>OC 690/13</b>	
<b>Review Date</b>	09/04/2005	<b>Open Government Status</b>	Fully Open
<b>Version No &amp; Date</b>	2: 09/04/2003	<b>Author Unit/Section</b>	Metals and Minerals Sector

To  
Agricultural, Factory and Quarries Inspectors  
SG Specialist Inspectors (Mechanical and Process Safety)

### **SAFE OPERATION OF BATCH BALL MILLS USED IN POTTERIES AND ALLIED INDUSTRIES**

This OC draws attention to the attached [information document \(ID\)](#) which deals with safety aspects of the design, operation and maintenance of batch ball mills used in pottery and allied industries. The ID should be made available to potteries with ball mills and may be copied to other interested parties outside HSE.

#### BACKGROUND

1 Sealed Batch ball mills (BBMs) are closed containers used for fine grinding of the raw materials used in the production of ceramic products. The mill is filled with the material, grinding media and water and operates continuously for periods typically between 2 and 40 hours. Whilst this type of mill is also used in other industries, particularly paint making, the advice in the ID has been produced only with the conditions in the ceramics and allied industries in mind.

2 This revision of the ID has come about because of further incidents of over pressurisation resulting in explosions. It takes into account advances in monitoring methods and the findings of research work commissioned by the British Ceramics Confederation, carried out by SIRIUS (Structural Integrity Research Institute University of Sheffield).

3 The ID has been produced in conjunction with users, manufacturers and other interested parties. It deals in particular with the:

- 1) safe working practices;
- 2) periodic inspection of BBMs as required by the Provision and Use of Work Equipment Regulations 1998 reg.6;
- 3) methods of monitoring the conditions within the BBM;
- 4) steps which can be taken to detect errors in charging before they present dangerous conditions.

#### ACTION BY INSPECTORS

4 When discussing BBMs, inspectors should alert users to this new guidance.

CANCELLATION OF INSTRUCTIONS

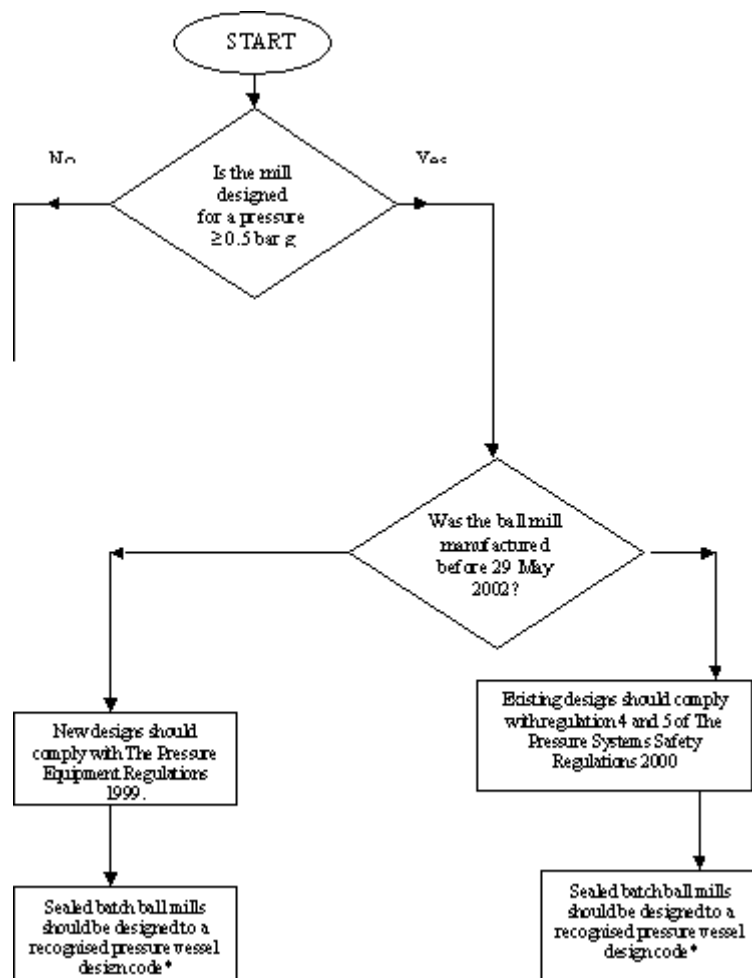
5 OC 690/13 (January 1995 version) – **cancel** and **destroy**.

Date first issued: 17 January 1995  
(FOD/220/1003/03)

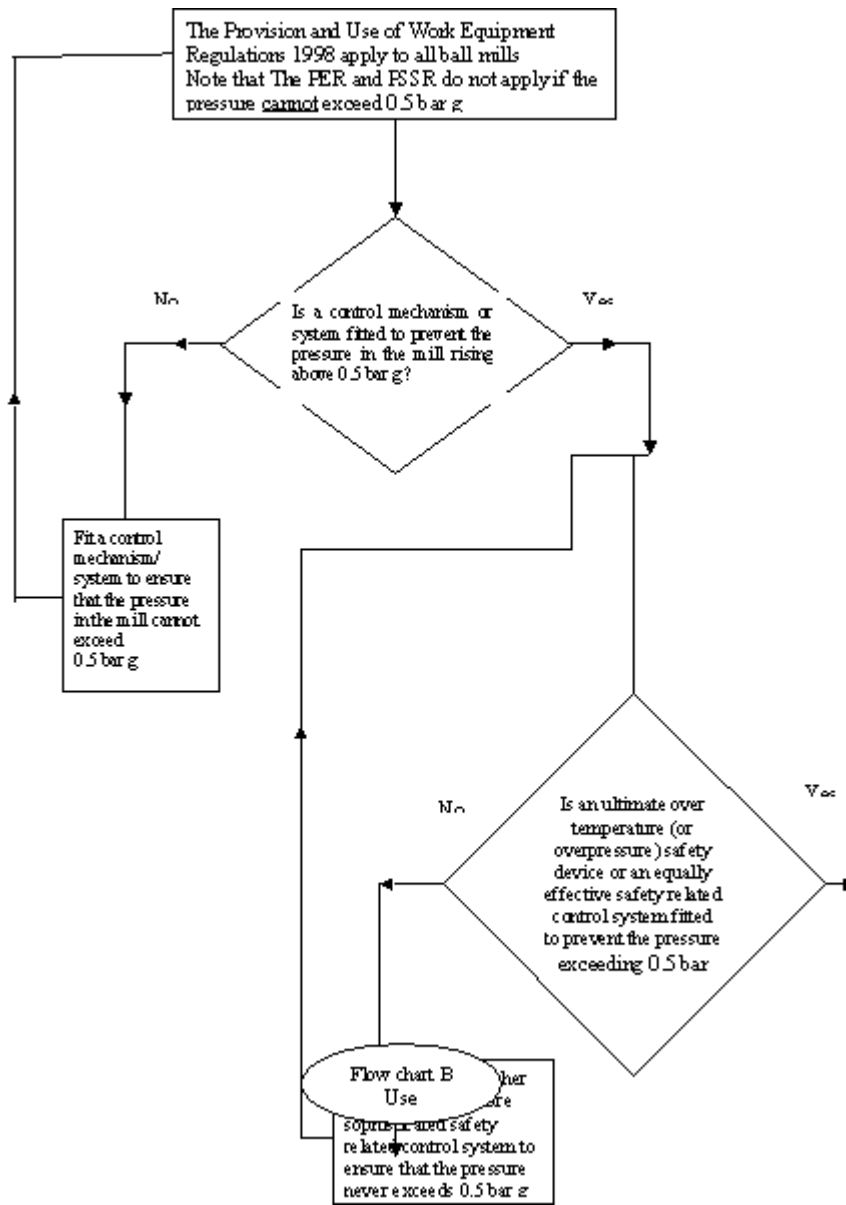


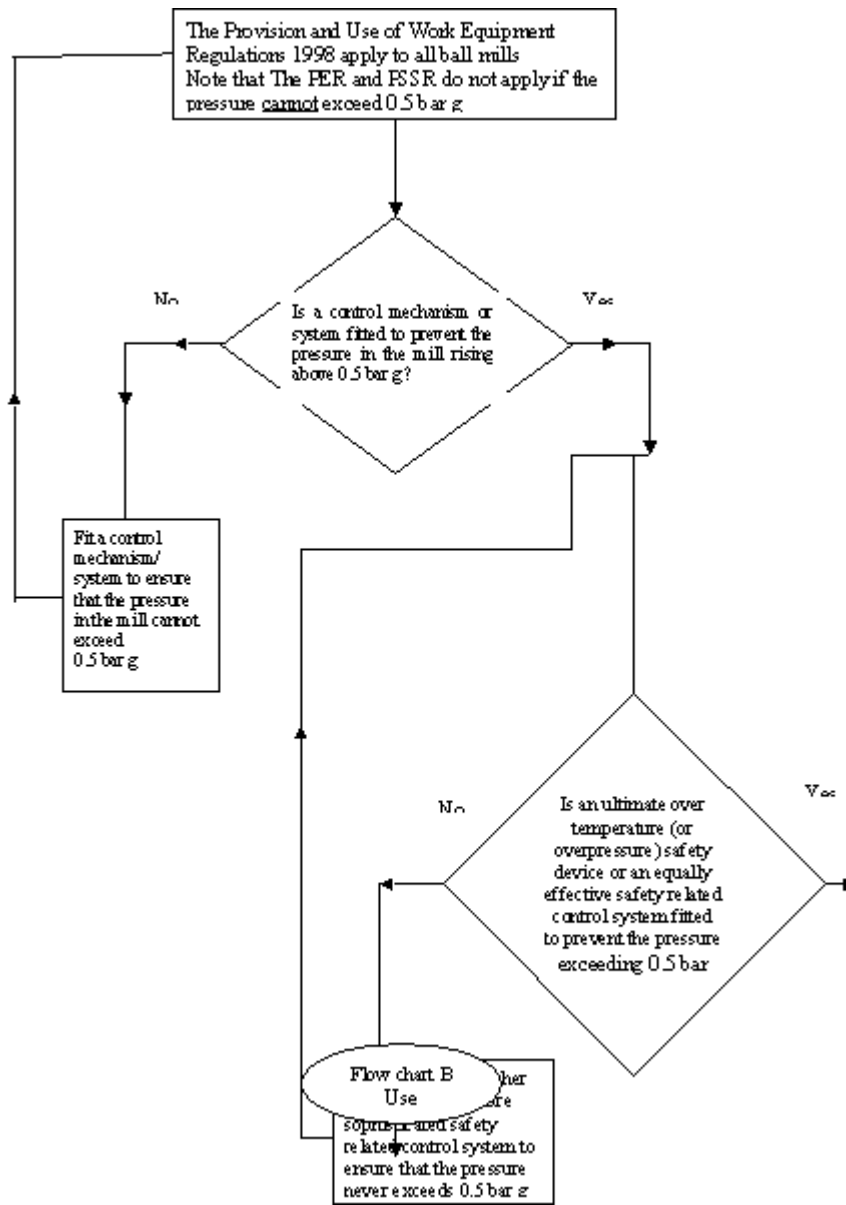
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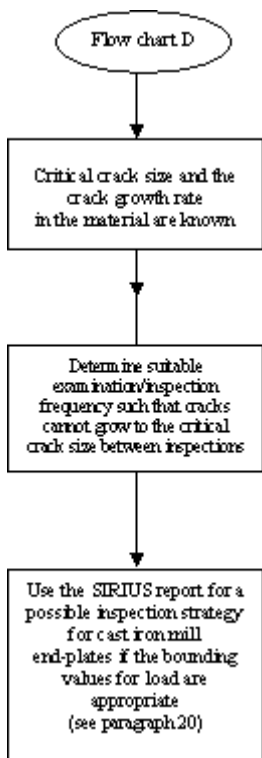
APPENDIX 1  
(paragraph 5)



(Footnote \*examples of design codes include BS 5500 (now superseded), ASME VIII, PD 5500, EN 13445. However, compliance with a code does not automatically mean compliance with the Pressure Equipment Regulations)







[ ]

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(paragraph 7)

## LEGAL REQUIREMENTS

**The Pressure Systems Safety Regulations 2000**

1 The Pressure Systems Safety Regulations 2000 (PSSR) will apply to a BBM if it contains, or is liable to contain a relevant fluid, which includes steam at any pressure, a gas including air at a pressure greater than 0.5 bar gauge or hot water at a temperature above 110°C.

2 PSSR require users to:

- 1) establish safe operating limits for each BBM;
- 2) produce a written scheme for examination of vessels by a competent person;
- 3) have BBMs examined in accordance with the written scheme;
- 4) cease operation if the competent person identifies imminent danger;
- 5) provide safe operating instructions; and
- 6) ensure proper maintenance.

3 The Regulations also provide a partial exemption from PSSR (Regs 5(4), 8-10 and 14) for small BBMs which are less than 250 bar litres (ie maximum allowable pressure x volume) provided they do not contain steam.

4 In practice, most BBMs are not intended to be run at pressures above 0.5 bar g and hence are not treated as pressure vessels. They are therefore not subject to any periodic thorough examination or test by independent bodies. Most BBMs are discharged by running out the contents under gravity. However, if they are pressurised to more than 0.5 bar g either as an intended part of the milling process or to assist the discharge of product then they will be subject to PSSR and will require a competent person's examination, etc. In the absence of the precautions outlined in this document it is possible for pressures greater than 0.5 bar g to be reached routinely during milling, users will have to take steps to ensure that this cannot occur and provide suitable evidence that this is the case before they can avoid the requirements of PSSR.

**Management of health and safety at work regulations 1999**

5 Regulation 3 requires employers and self-employed persons to make and maintain a suitable and sufficient assessment of the risks to the health and safety of employees, other workers and "the public", for the purpose of identifying the measures to be taken to comply with the requirements imposed under Relevant Statutory Provisions. The significant findings of the assessment must be recorded by employers with five or more employees. Risk assessment should be a common-sense consideration of the risks in the

work activity to identify remedial action necessary. Significant findings which have to be recorded should be considered as those which require action to comply with RSPs and the level of detail recorded should be broadly proportional to the risk. Quantified risk assessment will rarely be required. The focus should be on those risks that are liable to arise out of the work activity.

### **Provision and Use of Work Equipment Regulations 1998 (eg training, maintenance, inspection).**

6 Equipment must be suitable for the intended use. Regulation 4(1) covers the integrity of the work equipment in terms of both design and safeguarding.

7 Equipment must be properly serviced and maintained. Regulation 5(1) deals with the frequency of servicing intervals and the appropriateness of maintenance management techniques.

8 Equipment must be inspected when equipment or parts of equipment could deteriorate and lead to danger and this will not be adequately controlled through operator checks and normal servicing regimes (Regulation 6).

9 There are three circumstances when a user should carry out an inspection. These are where:

- 1) the safety of the equipment is **critically** dependent on its being correctly installed or reinstalled and failure to do this would lead to a significant risk;
- 2) safety of the equipment is critically dependent on its condition in use and there is likely to be deterioration which would give rise to a dangerous situation; and
- 3) 'exceptional circumstances' which are likely to have jeopardised the safety of the work equipment. The depth and level of the inspection should be adequate to identify deterioration leading to risk and the action necessary to avoid a dangerous situation.. Employers will need to decide whether their own employees are competent to carry this out or whether further training is required or whether third party inspection will be necessary.

10 Employers will need to provide information, instructions and training not only to those who actually use work equipment, but also to employees supervising or managing its use (Regulations 8 & 9).



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APPENDIX 3  
(paragraph 7)

SUMMARY OF THE FINDINGS OF THE SIRIUS RESEARCH

**Conclusions**

1 Un-cracked Boulton-type mill end plates have a large margin of safety if worked at pressures that are less than 0.5 bar.

2 Any cracks that develop in the end plates have to reach very large sizes before becoming unstable, when mills are worked at pressures below the 0.5 bar limit.

NOTE: Both these conclusions only stand if the mill is operated below 0.5 bar.

3 A mill running at 23 rpm with two adjacent cracked ribs (less than 90<sup>0</sup> included angle) should have nearly three years of safe continuous working life remaining. Once the crack is through seven ribs the continuous working life is less than a day.

4 Operating procedures to ensure pressures do not exceed 0.5 bar are essential.

5 The findings of the report allow a realistic specification of safety procedures for the operation of potentially cracked mills. They identify those flaws which are:

- 1) not immediately significant;
- 2) significant but are sufficiently safe to allow the mill to continue running whilst repairs are effected;
- 3) dangerous and require the mill to be immediately withdrawn from service and repaired or scrapped.

6 The safe working of the mills depends upon inspection being carried out for potential flaws at agreed and regular intervals.



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(paragraph 12)

## INCIDENTS KNOWN TO HAVE INVOLVED BATCH BBMS

No	Date	Summary
1	1967	Failure to non drive side shaft on recently refurbished mill.
2	1971	Ejection of contents due to hydrogen ignition as operator unloaded mill wet grinding manages ore. Hydrogen production due to action of steel balls against wet steel lining.
3	1973	5' diameter rubber-lined BBM exploded whilst milling manganese dioxide. Over-milling due to operator error.
4	1975	Major failure/explosion from over pressurisation. Hydrogen explosion due to aluminium ear tags in bone.
5	1980	"Explosion" of 3' 6" diameter rubber-walled BBM. Over pressurisation due to failure of timer to turn mill off. Similar incident had occurred several years before.
6	1981	Major failure/explosion of 7' diameter mill. Over pressurisation caused by overheating due to lack of water/inadequate venting.
7	1981	Failure of stub shaft/support from fatigue due to age, poor maintenance and wear.
8	1983	5' diameter BBM exploded whilst milling damp silicon. Temperature up to 100°C which caused hydrogen evolution and ignition.
9	1985	Operator's hands trapped by "bung" against loading floor. Mill not vented.
10	1985	Operator's ankles scalded when hot glaze ejected as 'bung' removed.
11	1986	Milling molysdendium disulphate with ammonium bicarbonate. Failure of cooling water supply to casing caused overheating and explosion due to over pressurisation.
12	1986	As 10 below, but drive end of 6' diameter mill.
13	1986	Failure of stub shaft at non-drive end of 7' diameter mill. General fatigue due to age. (Machine 26 years old).
14	1987	Explosion whilst in 6' diameter mill milling barium titanate. Over pressurisation (40 psi) due to addition of "dry ice" which caused carbon dioxide formation.
15	1988	Major failure/explosion from over pressurisation at bone grinding. Believed to be due to lack of adequate water. Bursting pressure estimated 60 psi+.
16	1989	Traumatic failure of concrete support plinth as mill stationary during discharge.
17	1991	Major failure/explosion. Over pressurisation due to heating effect caused by lack of adequate water.
18	1991	Operator splashed with mill contents as removing "bung" 20 hours after short run. Pressurisation with carbon dioxide due microbe action on sawdust contamination.
19	1994	Operator hit in face and eyes with glaze when removing "bung" from 5' diameter mill. Mill running 25½ rather than 1½ hours.
20	2000	Cast iron end plate blew off 7ft diameter mill after 23 hours milling (near to end of cycle). Resulted in significant damage to the end wall of the building in which the mill was housed.
21	2000	Large part of cast iron end plate blew off 7ft diameter mill, near to end of cycle (~12 hours). From the texture of the product in the mill, the company deduced that virtually no water had been added to the mill.



## **SAFETY ASPECTS OF THE DESIGN, OPERATION AND MAINTENANCE OF BATCH BBMS USED IN THE POTTERY AND ALLIED INDUSTRIES**

### INTRODUCTION

1 This Information Document (ID) contains internal guidance which has been made available to the public. This guidance is considered good practice but is not compulsory. You may find it useful in deciding what you need to do to comply with the law. However, the guidance may not be directly applicable in all circumstances and any queries should be directed to the appropriate enforcing authority.

2 This document has been revised and reissued because of recent incidents of over pressurisation resulting in explosions. It takes into account advances in monitoring methods and the findings of research work commissioned by the British Ceramic Confederation and carried out by SIRIUS (Structural Integrity Research Institute University of Sheffield). The Information Document provides guidance:

- 1) for employers and employees on the safe operation of sealed batch ball mills (BBMs) in the pottery and allied industries;
- 2) on the steps which may be needed to assess the risks from this equipment;
- 3) concerning the periodic routine inspection procedures;
- 4) on methods of monitoring the conditions within a BBM;
- 5) on modifications which may be necessary; and
- 6) on matters which should be taken into account when purchasing replacement mills.

3 It has been prepared after consultation with interested parties (British Ceramic Confederation, users and SIRIUS) and with the oversight of the Ceramics Industry Advisory Committee and summarises the recommendations of a working group with members drawn from these bodies.

4 This guidance is aimed primarily at users of BBMs grinding wet charges in mills with cast iron end plates. Over pressurisation due to the processing of potentially explosive materials or where solvents are used (neither of which takes place in the ceramics and allied industries) are outside the scope of this guidance. Dry grinding which often makes use of steel balls is also outside the scope.

5 The flow diagram (Appendix 1) provides an illustration of most permutations of materials of manufacture and operating conditions and the requirements which flow from them.

6 BBMs are closed and sealed vessels with no permanent outlet to atmosphere during use. Normal grinding processes will usually result in a rise in temperature and hence in pressure. The whole approach to operating most BBMs is to avoid excessive rise in pressures and specifically a rise of 0.5 bar g or more. If pressures exceed this level, the equipment should be considered to be pressure equipment and should comply with the relevant requirements of PER and PSSR. This guidance is intended to help users to conclusively demonstrate that pressures greater than 0.5 bar g are not generated during normal operation.

7 A Summary of the legal requirements applying to Batch BBMs is contained at Appendix 2. A summary of the findings of the SIRIUS research is contained in Appendix 3.

## BACKGROUND

8 Batch ball mills (BBMs) are widely used in the pottery and allied industries. BBMs range in size from approximately 0.3-3 metres in diameter. Older mills have cast-iron ends and a mild steel casing. They are lined with silex, porcelain or rubber and are used to mill materials such as minerals, frits, glazes and colours. The milling is usually done in an aqueous medium. The grinding medium in these mills may be flint or pebbles. Modern BBMs are usually fabricated entirely of steel.

9 Compressed air may be introduced deliberately into the BBM to discharge the contents or as part of the milling process.

10 Pressure will be produced inside all BBMs due to the rise in temperature which occurs during the processing. It can vary considerably depending on a range of factors including:

- 1) the type of material being milled;
- 2) the mill lining material;
- 3) the grinding media;
- 4) the running time;
- 5) the water content;
- 6) the amount of mill charge.

11 Different combinations of these factors can affect the working temperature and therefore inevitably the pressure in the BBM. Explosions due to over pressurisation of mills from this cause have occurred and can have catastrophic consequences

(destruction of the equipment and extensive damage to buildings) which pose significant risks to anyone in the vicinity. The larger the mill, the more serious the likely outcome. The risk of personal injury is self-evident.

12 Appendix 4 contains summaries of known recent incidents. The incidents fall into four general categories:

- 1) failure of mountings;
- 2) failure of stub-shafts and/or cast iron end casings due to fatigue;
- 3) explosion due to over pressurisation; and
- 4) ejection of the contents under pressure as an operator removes the discharge bung or hatch.

Of these, (3) is likely to be the most serious.

13 Factors which can affect the likely risk involved in this process include:

<b>Factor</b>	<b>Comments</b>
<i>i. the age of plant</i>	the pedigree of the BBM may be unknown, along with previous service, level of maintenance, possibility of previous over pressurisation, modifications etc.
<i>ii. length of grinding period</i>	the longer the grinding period, the more energy involved and the higher the temperature
<i>iii. errors in charging</i>	one of the most frequently reported causes of over pressurisation is a failure to charge sufficient water
<i>iv. errors in venting</i>	if venting during the working cycle is part of the milling procedure, failure to do so will inevitably result in higher pressures
<i>v. production of steam</i>	there is a step change in risk if the temperature rises to such an extent that steam is produced
<i>vii. extent of pre-existing cracks</i>	these will inevitably result in weakening of the structure

#### DESIGN SAFEGUARDS

14 User should have a clear understanding of the proposed operating conditions and selection of the plant should take into account the safe operating limits for a new installation. For new installations, the best course of action would be to use BBMs constructed from steel which is stronger and less likely to suffer brittle fracture. Where BBMs with cast iron end plates are introduced, this fact must be taken into account when considering the limits to the conditions of operation.

15 All new mills should be fitted with means of monitoring the conditions within the mill and protection systems to ensure that the safe operating limits are not exceeded. These could include:

- 1) direct pressure measurement;
- 2) temperature measurement, with calibration to pressure;
- 3) over temperature and/or overpressure trips;
- 4) interlocked water metering devices (to guard against insufficient water being charged into the BBM).

16 It is important to note that one system of protection sometimes used - interlocked current overload monitoring - which was thought to detect a condition where insufficient water has been introduced, has been shown to be ineffective for this purpose.

17 New BBMs should be mounted on steel-framed supports, or a reinforced concrete structure. Manufacturers and suppliers should consider the means of support as part of the overall installation and supply civil engineering drawings for the construction of the supporting piers, together with information on dynamic and static loading. Users should seek the advice of a competent architect or civil engineer to decide a suitable form of mounting.

18 In addition a means of safely venting the BBM should be provided.

#### OPERATING SAFEGUARDS

19 The following measures may help to ensure that unexpected pressure rise does not occur, or if it does, limit the consequences. They may not be relevant to all installations. Users should assess the application of these measures to their own equipment:

- 1) venting BBMs during the course of a milling cycle will provide an opportunity to:
  - a) check that the process is progressing satisfactorily;
  - b) clearly relieve the pressure; and
  - c) confirm that sufficient water was charged into the BBM at the start of the process.
- 2) users should ensure that procedures laid down are rigidly followed, paying particular attention to ensuring that venting is not forgotten due to inadequate supervision or training of personnel, problems with shift changeover, staff absences, etc. Where users do not routinely vent at mid cycle, particular attention is required to ensure correct charging takes place;

- 3) means should be provided for stopping mills after a predetermined time or a set number of revolutions. Such devices are a useful back-up to correct operating procedures and their use is strongly recommended;
- 4) careful attention should be given to the correct loading of mills, both with large and small grinding media, to ensure that the mill is run under ideal and balanced conditions;
- 5) users should keep records of desired run-off temperatures and grinding times. Any increase in temperature above the norm for a particular process provides an early warning of potential problems and should be investigated;
- 6) where processes are to be varied, or new materials milled, the preliminary operating criteria should be determined from experience of similar materials. Close supervision of initial batches should take place in order to establish correct and safe operating procedures;
- 7) the water level in the mill should be positively monitored either by manual means (ie dipping of the BBM) or automatically (ie via water meters providing a reading of the water actually pumped into the vessel);
- 8) some companies have fitted current overload detection systems in the belief that a lack of water would normally result in a higher than expected motor current. It has been shown that this method is unreliable;
- 9) existing mountings of older BBMs should be inspected periodically as it is possible that any cracks or faults occurring in the mountings could result in a mill falling during operation;
- 10) operators should be properly trained. The training should include the identification of unacceptable excursions from routine operating, safe venting procedures, the importance of over temperature or overpressure trips, etc;
- 11) BBMs should not be sited near to other potentially hazardous installations, eg storage of liquid oxygen, LPG or highly flammable liquids. So far as is reasonably practicable, such installations should be sited so that in the event of a BBM failure they would not be affected.
- 12) to conform to normal practice, equipment similar to BBMs should be fitted with two lines of defence - a control mechanism to avoid excessive pressurisation and a safety device which would operate in the event of a failure of the control mechanism. In the past, the operating conditions within the mills, coupled with the absence of suitable technology made this impossible. However, developments have recently taken place which make these objectives attainable. The operating conditions within test ball mills have been monitored on a real time basis, making use of either:
  - a) direct measurements of pressure; or
  - b) direct measurements of temperature (which is directly related to the pressure). This technique makes use of a thermocouple probe set in the lining 3 mm short of the internal surface, together with a battery powered transmitter on the outside of the cast iron end plate and receiver unit arranged to give a temperature display.

Other developments have concentrated on the issue of providing a safety device which would operate in the event of the temperature and hence pressure exceeding the desired conditions. A fusible plug, fitted into the charging cover (suitably protected to prevent uncontrolled ejection) is being actively pursued.

## MAINTENANCE AND EXAMINATION

20 Following an explosion in a 7ft diameter Boulton type mill with 12 ribs SIRIUS (see Appendix 2) carried out an analysis of the failure and discovered that the materials of construction in the end plates were very low in strength. This means that the conclusions from the analysis can be applied more widely, since it was clear that other mill end plates could not realistically have poorer metallurgical properties. The analysis also indicated that BBMs with readily visible cracks in their end plates may still be safely run provided:

- 1) routine inspection and measuring of the cracks takes place;
- 2) the mill is run at pressures below 0.5 bar gauge; and
- 3) ongoing measurement of internal conditions confirms 2) above.

Before embarking on the inspection regime set out below, a thorough initial inspection is necessary together with repeated inspections every week for the first month to set out a clear baseline. Guidelines on the frequency of inspection after this initial stage are given below along with suggested actions.

### For mills with 8 or 12 ribs

<b><i>Number of cracked ribs</i></b>	<b><i>Frequency of inspection</i></b>	<b><i>ACTION</i></b>
No discernible cracking	Every 6 months	Continue routine inspection if no change detected
1	Every 3 months	Reduce frequency after 3 identical measurements
2	Every month	Reduce frequency after 3 identical measurements
3 and above	N/A	Remove from service and repair or replace

There is a range of different designs of mills (eg different number of webs, different diameters, etc). Based on the available information, the above regime is felt to provide a realistic basis on which to build an inspection regime, provided competent engineers oversee the arrangements and make adjustments as necessary.

### For small mills with 6 ribs and a diameter of 2 feet

<b>Number of cracked ribs</b>	<b>Frequency of inspection</b>	<b>ACTION</b>
No discernible cracking	Every 6 months	Continue routine inspection if no change detected
1	Every 1 month	Reduce frequency after 3 identical measurements
2 and above	N/A	Remove from service and repair or replace

21 The preliminary inspection techniques do not require special equipment, but employees required to carry out this task must clearly be competent. Guidelines on these matters are included below:

- 1) the end plates must be prepared for examination (eg wire brush);
- 2) a good standard of lighting will be required;
- 3) only persons competent to do so should carry out this work;
- 4) the results should be logged; and
- 5) a defect reporting system should be introduced and used. This system should include guidelines on what to look for and what steps to take if cracks are found. Clearly, a crucial part of these guidelines will be the action to take if changes in the crack size are identified (consultation with competent engineer, etc).

Further more detailed guidance can be obtained from professional bodies such as The British Institute of Non-Destructive Testing, is 1 Spencer Parade, Northampton NN1 5AA, e-mail [info@bindt.org](mailto:info@bindt.org). They publish an authoritative guide *The NDT Yearbook* which is used extensively not only by those working in NDT and Condition Monitoring, but by users and potential users of equipment and services. This regular reference work contains sections on materials testing methods and capabilities.

### REPAIRS TO BATCH BALL MILLS

22 The repair of cracked cast-iron end plates must only be undertaken by a competent engineer with an understanding of the repair of cast iron. If these repairs are to be considered, for each particular case a very careful assessment of the nature and extent of the damage and the suitability of the repair method must be made. In addition, the tests which will be required immediately after repair and any further tests and examinations which are necessary should also be specified.

23 Some of the matters which will need to be taken into account include:

- 1) costs of repair against the remaining useful life of the BBM;

- 2) the existence of appropriate repair techniques;
- 3) whether the examination procedures will need modification after the repair;
- 4) an estimation of the remaining safe life.

## OTHER MATTERS

### **Relining of mills**

24 Some of the methods used for loosening old linings prior to removal could result in damage to the structure of the BBM. In particular:

- 1) striking the outside of the BBM on the cast-iron ends is likely to crack them;
- 2) hitting the lining on the inside of the BBM where it covers the end plate; or
- 3) using a pneumatic drill in the same circumstances could also result in damage to the end plate castings.

Methods that could result in damage to the end plate castings should not be used.

25 Relining operations could also produce more immediate hazards to the workers involved, in particular from dusty residues of toxic materials in BBMs, portable electrical equipment, etc. Appropriate precautions should be taken. Seek further advice on suitable precautions if necessary. Before relining takes place, a thorough internal inspection of the cast iron end plates should take place.

26 Certain precautions need to be taken where work has to be undertaken in a confined space in which dangerous fumes are liable to be present to such an extent as to involve risk of persons being overcome. In these circumstances the access hole used for entering the confined space should be not less than 460 mm long and 410 mm wide, or if circular, not less than 460 mm in diameter. Where appropriate, employers should ensure that the work is carried out in accordance with the Confined Spaces Regulations 1997. (OC288/7)

### **Use of pressure relief devices**

27 Pressure rise occurs because BBMs are closed and sealed with no form of pressure relief fitted. It has not been feasible to fit any form of conventional pressure relief valve set to operate at a 'safe' pressure level, because of the likelihood that the valve would either be blocked by the contents, or damaged by the arduous conditions inside the BBM. Means of manually relieving pressure are provided and are operated at intervals during grinding to vent the BBM after it has been stopped. Pressure build-up could be eliminated if a means could be found of relieving pressure continuously, eg at the top point of each revolution. The development of such devices is however to be encouraged.

## Second-hand ball mills

28 In cases where an existing ball mill is sold on and where the operating parameters or fundamental use of the mill is changed then consideration should be given to the application of The Pressure Equipment Regulations 1999 which are concerned with the design, manufacture and supply of new pressure equipment. The PER will only apply to pre-owned equipment where the equipment has undergone extensive modification and/or repair, such that the BBM can now be considered to be new equipment. (HSE Guide to the Inspection of Manufacture and Supply - Chapter 4.9). This will need to be determined on a case by case basis. (See also Commission Working Group 'Pressure' Guideline 1/3 reproduced below).

**Question:** Are replacements, repairs or modifications of pressure equipment in use covered by the directive ?

**Answer:** 1) Entire change: the complete replacement of an item of pressure equipment by a new one is covered by the PED.

2) Repairs are not covered by the PED but are covered by national regulations (if any).

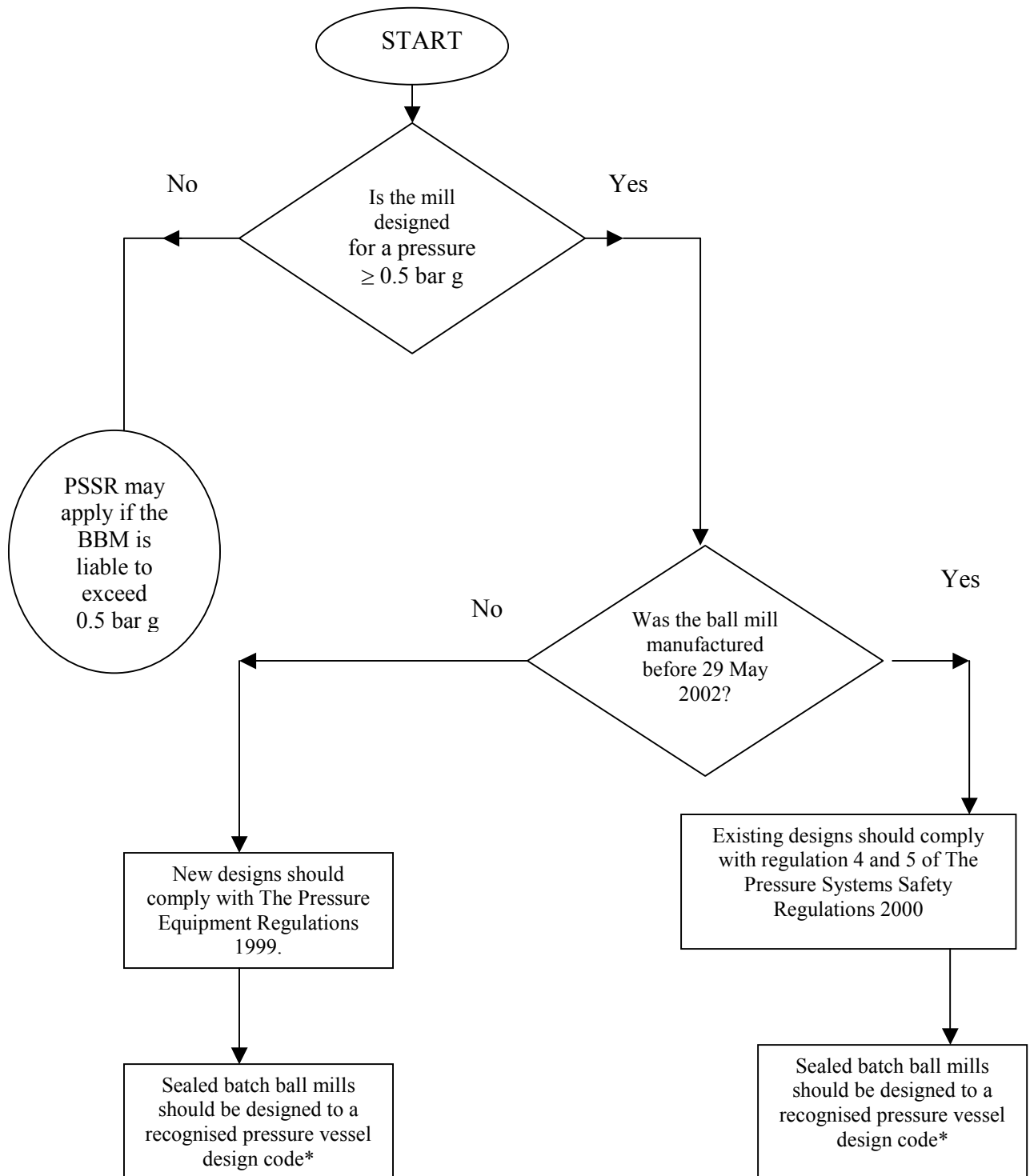
3) Pressure equipment which has been subject to important modifications that change its original characteristics, purpose and/or type after it has been put into service has to be considered as a new product covered by the directive. This has to be assessed on a case by case basis.

**Reason:** The directive applies only to the first placing on the market and putting into service.

## Evolution of Hydrogen

29 This problem is mainly confined to the grinding of bone, when aluminium ear tags have been included in the bone. The small number of users involved in this trade now generally purchase from countries not thought to use ear tags, with the back-up of a visual examination of the material together with a metal detector fitted to the loading belt. Wet grinding of any material with steel balls and lining will result in hydrogen evolution and must not take place.

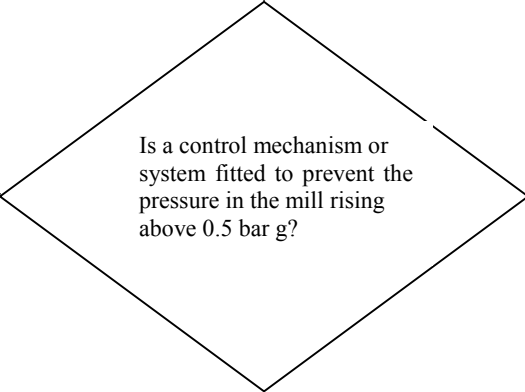
APPENDIX 1  
(paragraph 5)



*(Footnote \*examples of design codes include BS 5500 (now superseded), ASME VIII, PD 5500, EN 13445. However, compliance with a code does not automatically mean compliance with the Pressure Equipment Regulations)*

Flow chart B  
Use

The Provision and Use of Work Equipment Regulations 1998 apply to all ball mills  
Note that The PER and PSSR do not apply if the pressure cannot exceed 0.5 bar g



No

Yes

Fit a control mechanism/system to ensure that the pressure in the mill cannot exceed 0.5 bar g

No

Yes

Flow chart C

Is an ultimate over temperature (or overpressure) safety device or an equally effective safety related control system fitted to prevent the pressure exceeding 0.5 bar

Fit a fusible plug, other safety device or more sophisticated safety related control system to ensure that the pressure never exceeds 0.5 bar g

Flow chart C

A second line of defence against overpressure is fitted

Is the critical crack size for the end plates known?

Estimate or measure loads on likely cracked region

Are the loads higher than the values assumed in the SIRIUS report?

Use SIRIUS report for bounding loads

Establish the fracture and yield properties of the material **OR** use SIRIUS report for lower bound fracture properties of cast iron

Calculate critical crack

Is the crack growth rate in the material known?

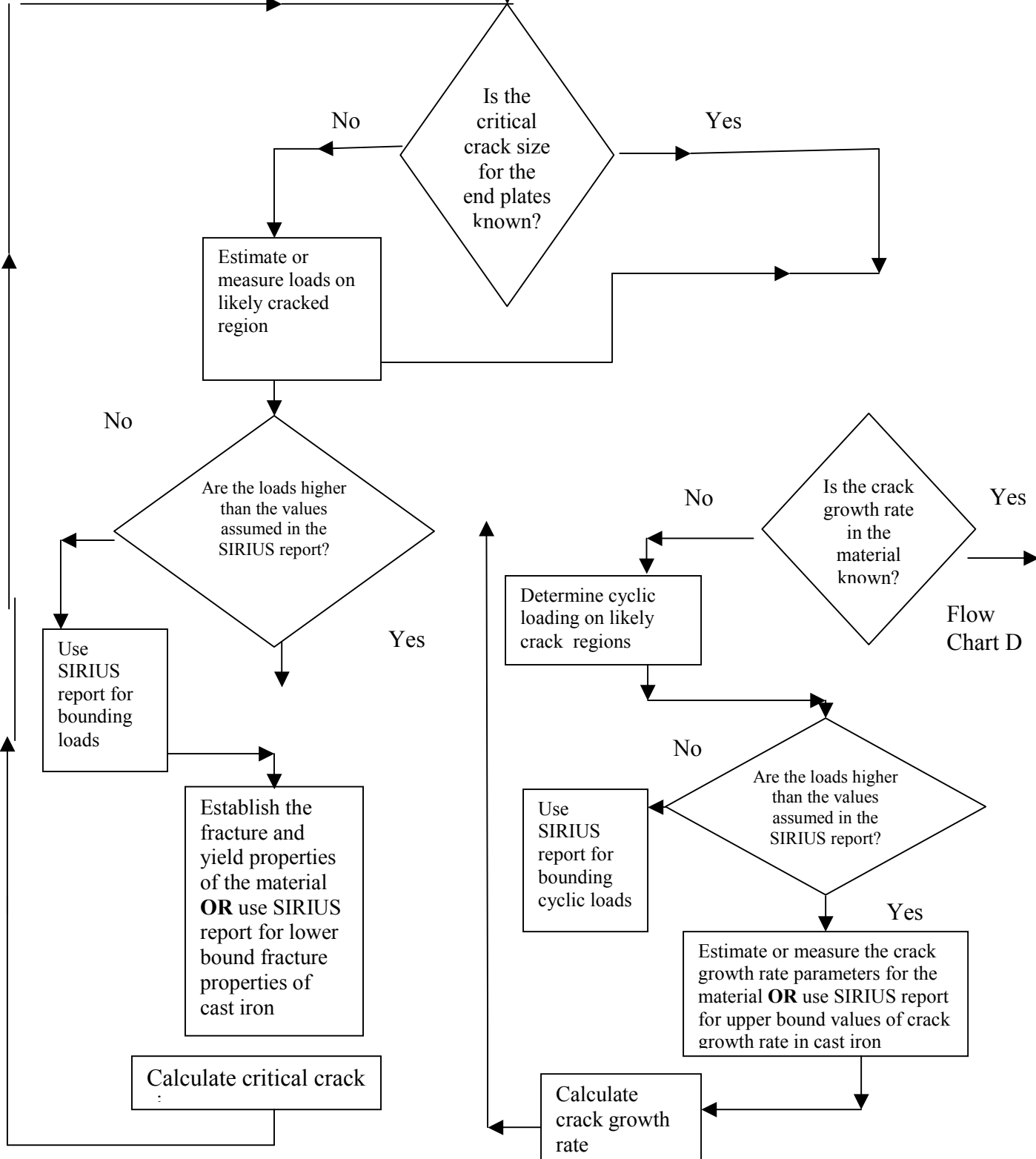
Determine cyclic loading on likely crack regions

Are the loads higher than the values assumed in the SIRIUS report?

Use SIRIUS report for bounding cyclic loads

Estimate or measure the crack growth rate parameters for the material **OR** use SIRIUS report for upper bound values of crack growth rate in cast iron

Calculate crack growth rate



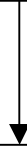
Flow chart D



Critical crack size and the crack growth rate in the material are known



Determine suitable examination/inspection frequency such that cracks cannot grow to the critical crack size between inspections



Use the SIRIUS report for a possible inspection strategy for cast iron mill end-plates if the bounding values for load are appropriate (see paragraph 20)

APPENDIX 2  
(para 7)

LEGAL REQUIREMENTS

**The Pressure Systems Safety Regulations 2000**

1 The Pressure Systems Safety Regulations 2000 (PSSR) will apply to a BBM if it contains, or is liable to contain a relevant fluid, which includes steam at any pressure, a gas including air at a pressure greater than 0.5 bar gauge or hot water at a temperature above 110°C.

2 PSSR require users to:

- 1) establish safe operating limits for each BBM;
- 2) produce a written scheme for examination of vessels by a competent person;
- 3) have BBMs examined in accordance with the written scheme;
- 4) cease operation if the competent person identifies imminent danger;
- 5) provide safe operating instructions; and
- 6) ensure proper maintenance.

3 The Regulations also provide a partial exemption from PSSR (Regs 5(4), 8-10 and 14) for small BBMs which are less than 250 bar litres (ie maximum allowable pressure x volume) provided they do not contain steam.

4 In practice, most BBMs are not intended to be run at pressures above 0.5 bar g and hence are not treated as pressure vessels. They are therefore not subject to any periodic thorough examination or test by independent bodies. Most BBMs are discharged by running out the contents under gravity. However, if they are pressurised to more than 0.5 bar g either as an intended part of the milling process or to assist the discharge of product then they will be subject to PSSR and will require a competent person's examination, etc. In the absence of the precautions outlined in this document it is possible for pressures greater than 0.5 bar g to be reached routinely during milling, users will have to take steps to ensure that this cannot occur and provide suitable evidence that this is the case before they can avoid the requirements of PSSR.

**Management of health and safety at work regulations 1999**

5 Regulation 3 requires employers and self-employed persons to make and maintain a suitable and sufficient assessment of the risks to the health and safety of employees, other workers and "the public", for the purpose of identifying the measures to be taken to comply with the requirements imposed under Relevant

Statutory Provisions. The significant findings of the assessment must be recorded by employers with five or more employees. Risk assessment should be a common-sense consideration of the risks in the work activity to identify remedial action necessary. Significant findings which have to be recorded should be considered as those which require action to comply with RSPs and the level of detail recorded should be broadly proportional to the risk. Quantified risk assessment will rarely be required. The focus should be on those risks that are liable to arise out of the work activity.

### **Provision and Use of Work Equipment Regulations 1998 (eg training, maintenance, inspection).**

6 Equipment must be suitable for the intended use. Regulation 4(1) covers the integrity of the work equipment in terms of both design and safeguarding.

7 Equipment must be properly serviced and maintained. Regulation 5(1) deals with the frequency of servicing intervals and the appropriateness of maintenance management techniques.

8 Equipment must be inspected when equipment or parts of equipment could deteriorate and lead to danger and this will not be adequately controlled through operator checks and normal servicing regimes (Regulation 6).

9 There are three circumstances when a user should carry out an inspection. These are where:

- 1) the safety of the equipment is **critically** dependent on its being correctly installed or reinstalled and failure to do this would lead to a significant risk;
- 2) safety of the equipment is critically dependent on its condition in use and there is likely to be deterioration which would give rise to a dangerous situation; and
- 3) 'exceptional circumstances' which are likely to have jeopardised the safety of the work equipment. The depth and level of the inspection should be adequate to identify deterioration leading to risk and the action necessary to avoid a dangerous situation. Employers will need to decide whether their own employees are competent to carry this out or whether further training is required or whether third party inspection will be necessary.

10 Employers will need to provide information, instructions and training not only to those who actually use work equipment, but also to employees supervising or managing its use (Regulations 8 & 9).

APPENDIX 3  
(paragraph 7)

SUMMARY OF THE FINDINGS OF THE SIRIUS RESEARCH

**Conclusions**

1 Un-cracked Boulton-type mill end plates have a large margin of safety if worked at pressures that are less than 0.5 bar.

2 Any cracks that develop in the end plates have to reach very large sizes before becoming unstable, when mills are worked at pressures below the 0.5 bar limit.

3 A mill running at 23 rpm with two adjacent cracked ribs (less than 90<sup>0</sup> included angle) should have nearly three years of safe continuous working life remaining. Once the crack is through seven ribs the continuous working life is less than a day.

NOTE: Both these conclusions only stand if the mill is operated below 0.5 bar.

4 Operating procedures to ensure pressures do not exceed 0.5 bar are essential.

5 The findings of the report allow a realistic specification of safety procedures for the operation of potentially cracked mills. They identify those flaws which are:

- 1) not immediately significant;
- 2) significant but are sufficiently safe to allow the mill to continue running whilst repairs are effected;
- 3) dangerous and require the mill to be immediately withdrawn from service and repaired or scrapped.

6 The safe working of the mills depends upon inspection being carried out for potential flaws at agreed and regular intervals.

APPENDIX 4  
(paragraph 12)

INCIDENTS KNOWN TO HAVE INVOLVED BATCH BBMS

No	Date	Summary
1	1967	Failure to non drive side shaft on recently refurbished mill.
2	1971	Ejection of contents due to hydrogen ignition as operator unloaded mill wet grinding manages ore. Hydrogen production due to action of steel balls against wet steel lining.
3	1973	5' diameter rubber-lined BBM exploded whilst milling manganese dioxide. Over-milling due to operator error.
4	1975	Major failure/explosion from over pressurisation. Hydrogen explosion due to aluminium ear tags in bone.
5	1980	"Explosion" of 3' 6" diameter rubber-walled BBM. Over pressurisation due to failure of timer to turn mill off. Similar incident had occurred several years before.
6	1981	Major failure/explosion of 7' diameter mill. Over pressurisation caused by overheating due to lack of water/inadequate venting.
7	1981	Failure of stub shaft/support from fatigue due to age, poor maintenance and wear.
8	1983	5' diameter BBM exploded whilst milling damp silicon. Temperature up to 100°C which caused hydrogen evolution and ignition.
9	1985	Operator's hands trapped by "bung" against loading floor. Mill not vented.
10	1985	Operator's ankles scalded when hot glaze ejected as 'bung' removed.
11	1986	Milling molybdenum disulphate with ammonium bicarbonate. Failure of cooling water supply to casing caused overheating and explosion due to over pressurisation.
12	1986	As 10 below, but drive end of 6' diameter mill.
13	1986	Failure of stub shaft at non-drive end of 7' diameter mill. General fatigue due to age. (Machine 26 years old).
14	1987	Explosion whilst in 6' diameter mill milling barium titanate. Over pressurisation (40 psi) due to addition of "dry ice" which caused carbon dioxide formation.
15	1988	Major failure/explosion from over pressurisation at bone grinding. Believed to be due to lack of adequate water. Bursting pressure estimated 60 psi+.
16	1989	Traumatic failure of concrete support plinth as mill stationary during discharge.
17	1991	Major failure/explosion. Over pressurisation due to heating effect caused by lack of adequate water.
18	1991	Operator splashed with mill contents as removing "bung" 20 hours after short run. Pressurisation with carbon dioxide due microbe action on sawdust contamination.
19	1994	Operator hit in face and eyes with glaze when removing "bung" from 5' diameter mill. Mill running 25½ rather than 1½ hours.
20	2000	Cast iron end plate blew off 7ft diameter mill after 23 hours milling (near to end of cycle). Resulted in significant damage to the end wall of the building in which the mill was housed.
21	2000	Large part of cast iron end plate blew off 7ft diameter mill, near to end of cycle (~12 hours). From the texture of the product in the mill, the company deduced that virtually no water had been added to the mill.