PICKFORD, HOLLAND & CO., LTD.

Producers of refractory materials. 381 Fulwood Road, Sheffield S10 3GB. Telephone 0742 303921 (10 lines). Telex 54426
Registered Office. Registered in England No. 128414 VAT Reg. No. 172 3715 69

AJN/MT

8th July, 1980.

Air Products & Chemicals Inc.,
Escambia Plant,
P.O.Box 467,
Pensacola,
Florida 32592,
U.S.A.

Dear Sirs,

Re: Proposed use of PH/NUA21 Catalyst in your Methanol Plant Reformer

We confirm that Pickford Holland & Co.Ltd. will accept the return, of all normal radioactive waste (contaminated coveralls, radioactive dust, used catalyst etc.) which arise during the loading/unloading of our PH/NUA21 catalyst, to the United Kingdom for disposal at an approved dumping site within the United Kingdom. All costs to be borne by client.

The regulation packing requirements and current disposal costs are outlined in the attached publication.

Yours faithfully,
for PICKFORD HOLLAND & CO. LTD.

Alan J Norman

A.J.NORMAN
Technical Sales Manager, Catalyst Dept.

Encs.

Disposal of used NUA21 plus other radioactive waste.

1. Regulations

The regulations for shipping used NUA21 are as strict as those for shipping new catalyst and must be fully complied with. The requirements are as follows.

The catalyst must be loaded in good, rust free steel drums conforming to the International Atomic Energy Authority (IATA) Transport Regulations for Type 'A' packages.

In our experience the thickness of the steel including the lid should be not less than 0.048 inches (1.2mm). The catalyst should be packed inside a polythene liner inside the drum or in a number of smaller polythene bags. The radiation requirements are that the dose rate measurable on the outside of the steel drums (γ radiation) must not exceed 0.5mRem/hour and the removable surface contamination on the drums must be less than $10^{-3} \mu Ci/cm^2$.

To reduce transport costs the catalyst should be packed in drums of optimum size 23 inches dia (58.5 cms) by 33.1/2 inches high (85 cms). Four drums should be strapped on a wooden pallet, size 44 x 44 inches (112 x 112 cms), which will fit side by side in container vessels.

2. Method of disposal.

Pickford Holland have an arrangement with British Nuclear Fuels Ltd. for the disposal of spent NUA21 plus other radioactive waste arising from the charging and discharging of the catalyst in a Client's reformer tubes. The arrangements call for the following instructions to be carried out.

Upon arrival at a U.K. port, the containers holding the spent NUA21 plus waste material must be unloaded for onward transmission via road transport to Pickford Holland works at West Hunwick, Co.Durham. A BNFL Inspector will inspect the drums at Pickford Holland works.

continued..........

Disposal of used NUA21 plus other radioactive waste (cont'd).

After acceptance for dumping, the spent catalyst plus waste material will be taken by a special BNFL lorry from Pickford Holland works to the approved dumping site.

3. Cost of disposal.

(a) Provision of polythene bags, drums and pallets; Client's liability.

(b) Transport from Client's site to FOB port of Client's choice; Client's liability

(c) Shipping costs from port of Client's choice to U.K.port; Client's liability.

(d) Unloading from containers on to road lorries and transport to West Hunwick; £60.00 per tonne.

(e) Inspection at West Hunwick and transport to dumping site; £19.625 per tonne.

(f) Dumping charge; £12.25 per tonne.

Sub Total £41.375 per tonne.

(g) Pickford Holland handling charge; £150 or 10% of the subtotal, whichever is the greater.

Pickford Holland have no control over the prices shown in items (d), (e) and (f) which are therefore given without guarantee.

AP00026869

PRECAUTIONS TO BE TAKEN WHEN STORING, HANDLING AND USING NICKEL URANIUM STEAM REFORMING CATALYSTS

by

M.D. Hill and A.D. Wrixon

Pickford, Holland and Co.Ltd.
Contract No. 6/1017

National Radiological Protection Board
Harwell,
Didcot,
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June, 1975

Abstract

This report has been prepared by the National Radiological Protection Board for Pickford, Holland and Co. Ltd. The potential hazards associated with the use of nickel uranium steam reforming catalysts, which are slightly radioactive, have been assessed in the light of the recommendations of the International Commission on Radiological Protection. It is concluded that these catalysts can be used safely provided some simple industrial hygiene procedures are followed. The most important of these procedures are the wearing of gloves when handling the catalyst and the use of techniques to reduce dust levels when loading and unloading reformer tubes. Special medical supervision of workers should not be necessary.

Nickel uranium steam reforming catalysts contain depleted uranium which is slightly radioactive. However, the hazards associated with this material are negligible if simple precautions are taken to ensure good industrial hygiene. The catalysts consist of uranium oxide, nickel oxide and a small amount of barium, supported on alumina. The main problem arising from their use is due to the dust produced during handling, and most of the precautions are therefore directed at reducing dust levels and hence intakes of dust.

2. RADIOLOGICAL PROTECTION DATA

2.1 Properties of Depleted Uranium

Naturally occurring uranium consists of three isotopes: uranium-238 (99.3%), uranium-235 (0.7%) and uranium-234 (0.006%). Depleted uranium has a lower activity than natural uranium since part of the uranium-235 (and some of the uranium-234) has been artificially removed, typically depleted uranium contains 0.3% uranium-235.

All three isotopes of uranium emit α-radiation and produce daughter isotopes which are also radioactive, emitting α, β and γ-radiation. These three types of radiation will therefore be emitted by depleted uranium catalysts.

Alpha-radiation has a very short range and is stopped by, for example a few centimetres of air or the dead layer of the skin. External to the body it therefore presents no hazard but internally it is the radiation of principal concern. Since the catalyst is in insoluble form the organs of the body chiefly affected by eating or breathing in the catalyst will be the gastro-intestinal tract and the lung respectively. Beta-radiation has a somewhat longer range and if the catalyst is handled directly this can cause external irradiation of the skin and hands. However, any normal form of containment of the catalyst will eliminate this since, for example, 1.4 mm of steel is sufficient to completely stop the radiation.

Gamma-radiation is much more penetrating than α or β-radiation but the intensity decreases rapidly with distance. In view of its penetrating nature it can cause irradiation of the whole body and is the only radiation of interest when the catalyst is contained in storage drums or reformer tubes.

2.2 Basic Standards

The basic standards of radiological protection are those of the International Commission on Radiological Protection, ICRP, who have laid down maximum permissible levels of radiation exposure(1). These levels have been accepted internationally and those which are relevant to this assessment are given in Table 1.

ICRP Maximum Permissible Doses for Occupationally Exposed Persons

Organ	Maximum Permissible Doses rem y^{-1}
Whole Body	5
Skin	30
Hands	75
Lung	15
GI tract	15

In addition ICRP recommend that workers who might receive more than $\frac{3}{10}$ of the maximum permissible annual dose should be subject to special health supervision and personal monitoring.

For short term or intermittent exposures ICRP consider that up to one-half of the annual dose limit may be received in any period of a quarter of a year.

2.3 Derived Standards

The basic standards of ICRP have been used as a basis for derived standards more suitable for the working environment. Since uranium catalyst can cause both internal irradiation (principally from its α-emission) and external irradiation (from its β and γ-emission) the derived standards for these will be considered separately.

2.3.1 Internal irradiation

This would arise following inadvertent ingestion or inhalation of the catalyst.

The maximum permissible concentrations of natural uranium (insoluble form) in water and air for continuous occupational exposure (40 h per week, 50 weeks per year) and the maximum quarterly and daily intakes obtained from ICRP data are given in Table 2[2].

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Table 2

Maximum Permissible Concentrations, Quarterly and Daily Intakes for Natural Uranium (insoluble form)

Maximum Permissible Concentration		Maximum Permissible Quarterly Intake		Maximum Permissible Daily Intake	
In Air	In Water	Inhalation	Ingestion	Inhalation	Ingestion
180 $\mu g\ m^{-3}$	1.5×10^{9} $\mu g\ m^{-3}$	225 mg	206 g	1.8 mg	1.7 g
270 dpm m^{-3}	2.3×10^{9} dpm m^{-3}	-	-	-	-
1.2×10^{-10} $\mu Ci\ cm^{-3}$	1.0×10^{-3} $\mu Ci\ cm^{-3}$	1.5×10^{-1} μCi	138 μCi	1.2×10^{-3} μCi	1.1 μCi

Notes

1. 1 Ci = 3.7×10^{10} disintegrations per second. A special definition of the 'curie' of natural uranium used in ICRP publications has not been employed in the Table.

2. dpm = disintegrations per minute.

3. The maximum permissible concentration in air of 180 $\mu g\ m^{-3}$ is very close to that recommended by the American Conference of Governmental Hygienists who consider that 200 $\mu g\ m^{-3}$ of natural uranium is the maximum concentration allowable for occupational exposure(3).

4. $\mu g = 1 \times 10^{-6}$ g. mg = 1×10^{-3} g.

No data have been published by ICRP for depleted uranium, but since its radioactivity is less than that of natural uranium, somewhat higher maximum permissible concentrations in mass terms ($\mu g\ cm^{-3}$ or $\mu g\ m^{-3}$) may be allowed. However, the values in Table 2 for natural uranium will be used here.

Although the values in Table 2 are only for drinking water, the maximum permissible quarterly and daily intakes for water can be applied generally to all processes of ingestion e.g. eating, transfer from contaminated hands to mouth.

To keep intakes from these processes within safe limits a maximum skin contamination level of 10^{-5} $\mu Ci\ cm^{-2}$ is allowed for uranium in the U.K.*

2.3.2 External irradiation

Based on a normal working habit of 40 hours/week and 50 weeks/year, the values in Table 1 can be used to calculate derived standards for continuous occupational exposure. For whole body exposure from γ-radiation the limit will be 2.5 mrem h^{-1} and $\frac{3}{10}$ of the limit, 0.75 mrem h^{-1}. This means in practice that only employees working for appreciable periods of time in areas where the dose rate is greater than 0.75 mrem h^{-1} will require the special health supervision mentioned in section 2.

In a similar way for exposure of the hands from β-radiation the limit will be 40 mrem h^{-1} and $\frac{3}{10}$ of the limit, 12 mrem h^{-1}. These values will apply to continuous handling of uranium. To keep the β-radiation dose rate to 40 mrem h^{-1} surface contamination in controlled access areas is limited to 10^{-3} $\mu Ci\ cm^{-2}$ in the U.K. for uranium. This is reduced to 10^{-4} $\mu Ci\ cm^{-2}$ for general access areas.*

3. ASSESSMENT OF POTENTIAL HAZARDS FROM DEPLETED URANIUM CATALYST

It will be assumed that 10% by weight of the catalyst consists of depleted uranium.

3.1 Storage

Here there is no possibility of intake of the catalyst into the body and only the external radiation need be considered. As already shown the α and β-radiation will be absorbed by the drums in which the catalyst is contained and only the external γ-radiation need therefore be considered.

The theoretical γ-dose rate at the surface of depleted uranium is about 4 mrem h^{-1}(4), while measurements on a catalyst containing 7% uranium showed a dose rate of 1 mrem h^{-1} at the surface of the uncovered catalyst and 0.2 mrem h^{-1} at the surface of a steel drum containing 225 kg catalyst. The dose rate falls off rapidly with increasing distance and at 1 m is indistinguishable from natural background radiation. It is therefore inconceivable even with catalysts containing 15% depleted uranium that the $\frac{3}{10}$ derived standard of 0.75 mrem h^{-1} will ever be exceeded.

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*Limits for skin and surface contamination vary from one country to another(5). U.K. limits have been quoted but catalyst users should consult the regulations of their country on this point.

3.2 Operation of Reformer Tubes

Here, as in the case of storage there is no possibility of internal irradiation. The external radiation hazard is also negligible since the walls of the reformer tubes are thick enough (typically 1.2-1.5 cm) to reduce the dose rate at the surface of the tubes to a level indistinguishable from background radiation.

3.3 Handling

Handling of the catalyst during the loading and unloading of reformer tubes may give rise to dust which will subsequently be breathed in or ingested. External irradiation, particularly of the hands and skin needs to be considered.

3.3.1 Internal irradiation

Assuming that only catalyst metals give rise to dust the figures given in Table 2 for the quantities in μg and $\mu g\ m^{-3}$ should be multiplied by three for a catalyst containing 20% total metals and 7% uranium. This will represent the worst case.

(a) Inhalation of dust

The maximum permissible concentration of catalyst in air is therefore about 0.54 mg m^{-3} for continuous occupational exposure. A visibly dusty atmosphere would contain about 2 mg m^{-3}. Although during handling operations this value may be exceeded for short periods of time, in view of the intermittent nature of the operations, it is unlikely that the maximum permissible daily intake will be exceeded and certainly for the long-term average conditions doses will be well below the $\frac{3}{10}$ limit.

(b) Ingestion of dust

As already stated ingestion of dust could arise via transfer of catalyst on hands to mouth or to foodstuffs and it was from a consideration of this that the derived standard of 10^{-5} $\mu Ci\ cm^{-2}$ was obtained for skin contamination. Of course, if no precautions at all were taken during handling of the catalyst, contamination levels of hands could exceed this level but use of very elementary precautions such as wearing of gloves and washing of hands before eating will virtually eliminate any possible intake from this source.

3.3.2 External irradiation

The principal concern here is with the possibility of β -irradiation of the hands and skin. Some γ -irradiation will also occur but this is much smaller. For a catalyst containing 10% depleted uranium the theoretical surface β -dose rate is about 20 mrem h^{-1}(4), while measurements on a catalyst containing 7% uranium gave a value of 8.7 mrem h^{-1}. Handling of the catalyst will normally be infrequent but even assuming a β -surface dose rate of 20 mrem h^{-1}, a worker could spend 1000 hours each year handling bulk quantities of the catalyst with his bare hands without exceeding $\frac{3}{10}$ of the maximum permissible annual dose. Wearing PVC gloves (thickness 1.1 mm) would reduce the dose received by about 60%(4) and would also prevent contamination of the hands. The presence of nickel in the catalysts also makes protection of the skin and

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It is probable that during the handling procedure some dust will be spread into surrounding areas. Measurements have shown that on visibly dusty surfaces the derived limit of 10^{-4} μCi cm^{-2} for inactive areas may occasionally be exceeded. However, again it must be emphasised that this limit is for the continuous situation and provided elementary cleaning is undertaken following the handling there will not be any problem.

4. PROCEDURES AND PRECAUTIONS

The main hazard associated with these catalysts arises from the dust produced during operations such as the loading and unloading of reformer tubes. Some simple precautions will reduce the risks of inhalation and of contamination of skin and working surfaces to a minimum. The presence or absence of visible dust is a good indication of the standard of industrial hygiene.

4.1 Personnel Protection

Persons engaged in handling the catalyst should be given instructions on safety procedures and informed of the possible hazards. The following precautions apply to any potentially dusty operations, in particular the loading and unloading of reformer tubes.

(a) Clothing

Persons handling the catalyst should wear gloves (stout rubber or PVC), one-piece overalls, boots and helmets. Some form of respiratory protection is desirable although not strictly necessary: either goggles and a dust respirator, or an air-line hood is suitable. Overalls and other protective equipment should be removed on leaving the working area. The cleaning of clothing and equipment is dealt with under 4.5.

(b) Eating, drinking etc.

Eating, drinking, smoking and the handling of consumable items should be prohibited in working areas, as they are in any places where materials of similar toxicity are handled.

(c) Washing

Workers should wash their hands before meal breaks and at the end of the day. More extensive washing may be considered necessary, depending on the levels of dust encountered. It is essential to remove all traces of dust from the skin. Separate washing facilities should be reserved for workers during catalyst handling operations. They can be released for general use after decontamination and monitoring.

(d) Cuts, abrasions etc.

Any cuts, abrasions or wounds which have been exposed to contamination should be treated by a medical practitioner. Existing cuts or breaks in the skin should be covered before starting work to prevent entry of dust or catalyst.

(e) Handling time

The time spent handling the catalyst should be kept to a minimum and gloves should always be worn.

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(f) Medical Supervision

Special medical supervision of workers and the wearing of film badges or other personal dosimeters is normally unnecessary. In the U.K. workers with the catalyst need not be formally classified as radiation workers providing they are employed in accordance with a scheme of work approved by H.M. Chief Inspector of Factories.

4.2 Storage

The catalyst should be kept in a separate store or in a specially designated area of the main store. The storage area should be marked with the radioactivity symbol and access to it should be limited. The catalyst drums should be sealed when not in use. Any spillage should be dealt with in a smiliar manner to that described below for loading and unloading reformer tubes. An account should be kept of the issues and receipts of catalyst.

4.3 Precautions during Operation of the Reformer Tubes

No precautions are necessary during the operation of the reformer tubes. The walls of the tubes provide adequate shielding against external radiation.

4.4 Loading and Unloading of Catalyst from Reformer

(a) The working area should be regarded as a controlled or active area and access to it should be limited.

(b) The working area should be covered with polythene sheets to facilitate collection of dust and spilled catalyst. These can be cleaned with an industrial vacuum cleaner and hosed down after use.

(c) The catalyst should be loaded and discharged from the reformer tubes by a method which minimises the creation of dust. For example, loading can be done by the sock or canister method and unloading by means of an industrial vacuum cleaner.

(d) Protection of the working area from draughts reduces the inhalation risk and prevents the spread of catalyst.

(e) The working area should be decontaminated and monitored before general access is allowed. The maximum permissible contamination level depends on the country concerned. If no such level exists the U.K. figure of 10^{-4} μCi cm^{-2} is recommended.

(f) The industrial vacuum cleaner used for unloading reformer tubes and for collecting dust and spilled catalyst should exhaust to fresh air to avoid raising dust and its exhauster outlet should be filtered.

(g) Any dust or spillage collected should be removed from the working area and disposed of as outlined below.

4.5 Waste

The waste arising from the use of nickel uranium catalysts is technically radioactive waste and must be disposed of according to the legislation of the country concerned. Spent catalyst, dust and spilled catalyst are all classed as solid radioactive waste and should be stored in sealed drums pending disposal. Protective clothing and equipment should be vacuumed to remove loose dust and monitored for contamination. If the levels are sufficiently low clothing can be laundered in the normal way, if not it should be specially cleaned or disposed of as solid waste. Disposable clothing and equipment must be treated as radioactive waste.

Liquid wastes from cleaning operations are also technically radioactive waste but the activity levels will probably be low enough for them to be disposed of to drain. This includes washings from cleaning protective equipment e.g. boots and helmets.

At least for a period after reloading a reformer tube, condensate produced during the steam reforming process will contain some uranium. U.K. measurements have shown that the concentration of uranium in the condensate is likely to be small (of the order of 0.01 $\mu g\ cm^{-3}$) and since dilution with other non-radioactive waste liquors will probably occur, there should be no restriction on disposing of the condensate to drain.

5. CONCLUSIONS

1. Nickel uranium steam reforming catalysts can be used safely providing some simple industrial hygiene procedures are followed.

2. The most important of these procedures are the wearing of gloves when handling the catalyst and the use of techniques intended to reduce dust levels when loading and unloading reformer tubes.

3. No special medical supervision of workers should be necessary.

4. Internationally accepted recommendations on maximum permissible radiation doses have been quoted but potential catalyst users are advised to consult the legislation of their country on points of detail.

6. REFERENCES

1. ICRP Publication 9, Pergamon Press, Oxford 1966.

2. ICRP Publication 6, Pergamon Press, Oxford 1962.

3. ACGIH (Threshold Limits Committee) 1971, Documentation of Threshold Limits Values (ACGIH, P.O. Box 1937, Cincinnati, Ohio 45201, USA).

4. A review of the Toxicology and Potential Hazards of Natural, Depleted and Enriched Uranium. E.J. Bennellick UKAEA Report AHSB (RP) R58 (1966).

5. Monitoring of Radioactive Contamination on Surfaces, IAEA Technical Reports Series No. 120 IAEA, Vienna, 1970.

Storage, handling and loading of PH/NUA 21 catalysts

NUA21 is slightly radioactive as a result of its uranium oxide content. A frequently accepted definition of a radioactive substance is one that has a specific activity greater than 0·002 microCuries per gram. Pickford Holland use only depleted uranium oxide which means that NUA21 is less radioactive than it would be if uranium oxide from natural uranium ore was used. The specific activities of and radiation from NUA21 are as follows:-

Specific activities

Alpha 0·035 microCuries per gram of catalyst
Beta 0·0476 microCuries per gram of catalyst
Gamma 0·00084 microCuries – MeV per gram of catalyst.

Radiation measurements in millirads/hour

Radiation measurements in millirads/hour

	Beta plus Gamma	Gamma
At catalyst surface	9·7	1·0
0·3 metres from surface	0·5	0·1

The above data show that there is no radiation danger in handling NUA21 catalyst. Precautions are required to avoid operators ingesting or inhaling the catalyst or dust arising from it (e.g. during the sieving operation prior to loading the catalyst in the reformer tubes). Uranium is of a similar toxicity to nickel. Therefore the same sort of precautions with NUA21 as with conventional nickel catalysts are required.

It will also be necessary to satisfy local regulations regarding the use of radioactive materials. Our technical staff will be pleased to assist customers in meeting the regulations.

A separate Assessment Report entitled 'Precautions to be taken when storing, handling and using Nickel-Urania Steam Reforming Catalysts' prepared for Pickford Holland by the National Radiological Protection Board in the UK is available. Catalyst loading and start-up instructions are also available.

The advantages of PH/NUA 21

1. Manufactured by Pickford, Holland & Co. Ltd., a company with almost a century of manufacturing experience in the field of high technology refractories.
2. Backed by the engineering, chemical engineering and gas manufacturing expertise of British Gas Corporation.
3. Manufactured only from carefully selected raw materials of the highest quality.
4. Manufactured to British Gas specifications to ensure consistent physical, mechanical and chemical properties.
5. NUA21 has a high initial activity, the approach to methane equilibrium usually being less than 10°C (18°F).
6. NUA21 maintains its high activity throughout its long working life.
7. NUA21 will reform a variety of hydrocarbon feed stocks from methane to hexane or, in certain cases, light naphthas without carbon deposition.
8. Feedstock composition may be altered on the run with no deviation from equilibrium product gas composition.
9. NUA21 will reform hydrocarbon feedstocks over a wide range of steam carbon ratios.
10. In the event of accidental carbon or sulphur deposition, NUA21 may be regenerated with no disintegration of the catalyst. The regenerated NUA21 will be capable of producing equilibrium gas at full design output.
11. NUA21 contains no sulphur.
12. NUA21 contains no volatile silica or alkalis and therefore will not produce problems downstream from the reformer.
13. The customer does not pay a process royalty.

Pn/NUA 21 catalyst typical properties

Chemical composition

	Ni	%	11
	U	%	7
	Ba++	%	1.6
Alpha	Al_2O_3	%	substantially balance

Physical and mechanical properties

		no vibration	full vibration	
Density	lbs/cu. ft.	84	90	
	kg/litre	1·34	1·44	
Crushing strength (side)		kg	100	
Permanent linear change 24 hrs at 1300°C		%	< 0·1	
Abrasion loss		%	< 2·5	British Gas Test (done on the support)

Typical Sizes (Raschig ring form)

height,	mm (inches)	15 (5/8)	15 (5/8)
dia,	mm (inches)	15 (5/8)	10 (3/8)
central hole dia,	mm (inches)	6 (1/4)	6 (1/4)

Other sizes can be manufactured to customers' specifications.

How does the catalyst work?

Typical properties of NUA21 are shown on page 11. An essential feature of NUA21 steam reforming catalyst is the presence of the nickel uranate compound NiU_3O_{10}. On reduction of this compound with hydrogen or in some instances with feedstock, nickel crystallites and the uranium oxide U_3O_8 are formed. The nickel crystallites measured along the 111 plane typically have a size of 230 to 270 Å; this may be compared with 330 to 370 Å also measured along the 111 plane of nickel crystallites produced from the reduction of nickel oxide (the compound present in conventional nickel catalysts before reduction) under similar conditions. The nickel crystallites produced from nickel uranate thus have a higher surface area than those produced from nickel oxide, hence the nickel urania catalyst has a higher activity than the conventional nickel catalyst.

The uranium oxide U_3O_8 separates the nickel crystallites from each other and thus prevents them from sintering. In this way the high activity of the catalyst is maintained. Because the high surface area of the nickel crystallites is independent of the surface area of the support material, a low surface area support of very high strength may be used. The support used in the production of NUA21 is pure alpha alumina with a surface area controlled between 1.5 and 2.0 sq.metres/gram. The pore volume and pore size distribution are also carefully controlled. The result is a finished catalyst with a side crushing strength of 2 to 4 times that of conventional nickel catalysts. The very high strength enables the catalyst to withstand plant upsets that would cause conventional nickel catalysts to disintegrate.

Uranium oxide, U_3O_8, being a non-stoichiometric oxide, favours the dissociation of steam; laboratory studies have indicated that in service the surface of NUA21 is fully saturated with adsorbed water. Thus carbon deposition, whether from catalytic and thermal cracking of the hydrocarbon feedstock or from the Bouduard reaction

$$2CO \rightleftharpoons CO_2 + C,$$

is much less likely to occur with NUA21 than with conventional nickel catalysts.

Uranium oxide U_3O_8 therefore performs 4 major functions.

1. Its presence ensures that the nickel crystallites are smaller and therefore are of greater activity.

2. It prevents the nickel crystallites from sintering thus maintaining the high activity of the catalyst.

3. It permits the use of a very strong pure support material which enables the catalyst to withstand severe plant upsets.

4. It strongly inhibits carbon deposition thus enabling feedstocks up to hexane or, in certain cases, higher hydrocarbons to be reformed.

In addition NUA21 contains 1.6% barium in the form of barium carbonate. This compound also inhibits carbon deposition, the suggested reactions being:-

$BaCO_3 + C = BaO + 2\,CO$

$BaO + CO_2 = BaCO_3$

Barium carbonate and barium oxide are both solids of low vapour pressure and do not therefore migrate downstream from the reformer. As a result NUA21 does not give rise to corrosion problems.

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