# Recommended Method for Radioisotope Red-Cell Survival Studies

*International Committee for Standardization in Hematology**

## 放射性 同位元素를 利用한 赤血球壽命測定法(ICSH 추천)

血液疾患, 특히 溶血性貧血을 隨伴한 境遇에 赤血球의 生成, 破壞過程을 정확히 파악하는 것은 貧血의 發生機轉 및 病因, 治療, 豫後 決定에 매우 重要하다. 赤血壽命測定法은 最近 放射性同位元素를 利用한 方法이 소개된 이래 널리 施行되어 왔다. 그러나 그 方法 및 結果 解釋에 標準化가 되어 있지 않았던 중 1971년 ICSH(International Committee for Standardization in Hematology)에서 expert panel을 갖고 ICSH 추천 方法을 發表하였고, 本誌에서도 그 內容을 揭載한 바 있다.

1980년 ICSH는 전문기관 및 전문가의 協調를 얻어 다시 expert panal을 갖은 후 1971년에 추천한 赤血球壽命測定法의 一部를 修正하여 ICSH의 標準方法으로 發表하였다. 改正된 標準方法과 1971년 ICSH 추천 方法과의 差異는 다음과 같다. $^{51}Cr$ 標識方法中 參考方法(Reference method)인 ACD法에 修正을 가하여, ACD solution 構成成分이 差異가 있으며, 標識 $^{51}Cr$의 量을 體重當 1.5 $\mu$Ci에서 0.5 $\mu$Ci로 制限시켰다. 投與方法에 대한 언급 특히 투여하는 標識赤血球의 용적을 정확하게 측정 하기 위한 방법 4가지를 추가하였고, 檢體準備 過程中의 pipet error를 防止하기위해 一定한 형태의 pipet을 使用하며, 1 ml의 tuberculin syringe는 使用하지 않기로 하였다. 또한 結果分析時 血球容積의 恒定性을 위해 Sodium pertechnetate($^{99m}Tc$)를 利用해 赤血球容積을 反復해 測定하도록 하였으며 이때 使用하는 放射性同位元素는 $^{32}P$ 대신 $^{99m}Tc$로 하였다. 結果解釋時 IgG 抗體 또는 IgM 抗體에 따른 差異點에 대한 고려가 追加되었다.

ICSH와 國際血液學會에서 修正된 ICSH 標準方法에 의한 赤血壽命測定法을 널리 紹介하여 結果의 標準化를 기하고자 聯關雜誌에 揭載할 것을 要請하였기에 全文을 本誌에 紹介하고자 한다.

(編輯者註)

*The ICSH Expert Panel on Diagnostic Applications of Radioisotopes in Haematology recommended techniques for red cell survival studies which were published as a tentative ICSH Standard in 1971. Taking account of comments received from various organizations and in dividuals, the following revised document has been prepared by the Panel, and approved by the ICSH Board for publication as an ICSH Standard.*

It is not possible to propose a definitive method for this test(i.e. with no known source of inaccuracy or ambiguity), but a number of procedures have been considered as reference methods. Previously the Panel recommended three $^{51}Cr$(sodium chromate) selected methods:

*Method A*(ACD method): blood is mixed with acid citrate dextrose(ACD), centrifuged

* The members of the working group who prepared this document were: N.I. Berlin(U.S.A.), R.A. Dudley(I.A.E.A.), L. Garby(Sweden), H. Heimpel(F.D.R.), M. Lee(S. Korea), S.M. Lewis (U.K.), P. McIntyre(Panel Chairman) (U.S.A.), P.L. Mollison(U.K.), Y. Najean(France), J. Pettit(Panel Secretary) (New Zealand).

Correspondence: ICSH Secretariat(Dr S.M. Lewis), Royal Postgraduate Medical School, Du Cane Road, London W120HS.

to obtain a red cell concentrate, and after incubation of the suspension with $^{51}Cr$, the red cells are washed in saline before being injected.

*Method B* (citrate wash method): the red cells are washed in citrate phosphate dextrose (CPD) solution before being incubated with $^{51}Cr$, and then washed in saline before being injected.

*Method C* (ACD/ascorbic acid method): the red cells are not washed following incubation with $^{51}Cr$ but instead ascorbic acid is added and the suspension is injected directly.

The ACD method is the simplest and most convenient of the three methods, and is used extensively: it is now recommended as the reference method. As the citrate wash method is also reliable and gives results which are indistinguishable from those of the ACD method, it is recommended as a selected method.

The ACD/ascorbic acid method obviates the need for washing the red cells prior to injection; but requires the preparation and counting of additional standards and more complex computations and this is overall a much more complicated procedure; it is, however, used widely in the U.S.A. Although there have been no direct comparisons with the ACD method, it appears to give similar results and to be reliable in clinical practice; accordingly, it is also recommended as a selected method.

The techniques for these selected methods are described in detail in the original document (ICSH, 1971). Only the technique for the reference method will be given in this document.

In the orginal document methods for labelling red cells with DFP (as $DF^{32}P$ and $^{3}H$-DFP) were also described. No amendments are proposed to these techniques, although other isotopic forms of DFP (e.g. $^{14}C$-DFP) are equally acceptable.

## 1. Technique for Red-Cell Survival Study by ICSH Reference Method

### 1.1. Labelling

Throughout the document, unless otherwise specified, it is assumed that the patient's own red cells are being labelled. Donor red cells may be needed to study compatibility (see Section 4) and are also needed very occsionally to discover whether a haemolytic state is due to an intrinsic defect of the patient's red cells or to some pathological process resulting in the accelerated destruction of intrinsically normal red cells. Except in these circumstance survival studies should be conducted using the patient's own red cells, to avoid the risk of alloimmunization and of transferring infectious disease. During labelling, all operations should be carried out by sterile techniques and all soultions used must be sterile and pyrogen-free.

1.1.1. Obtain blood in a plastic or glass syringe by venepuncture. Add 10 vol of blood to 1.5 vol of 'NIH A' ACD solution (trisodium citrate dihydrate, 22g; citric acid, 8g; dextrose, 25g; water to 1l). The solution should be sterilized by autoclaving at 126°C for 30 min; it has a pH of 5·4.

1.1.2. Centrifuge the suspension at 1000—1500 g for 5—10 min. Remove and discard supernatant plasma, taking care not to remove any red cells. If leucocyte count is greater than $25\times10^{9}$/l, also remove and discard buffy coat.

1.1.3. Add $^{51}Cr$-sodium chromate solution slowly, and with continuous gentle mixing, to

the packed red cells. The amount of $^{51}Cr$ added should be as low as possible consistent with the equipment used to measure the radioactivity of the samples, and in any case limited to 0.5 $\mu$Ci/kg body weight. The specific activity of the $^{51}Cr$ should be such that less than 2 $\mu$g of chromiun is added per ml of packed red cells. The added $^{51}Cr$ sodium chromate should be in a volme of at least 0.2 ml, being diluted in 9g/l sodium chloride solution (isotonic saline). Allow mixture to stand at room temperature for 15 min or incubate in a water bath at 37°C for this period.

1.1.4. Wash labelled cells twice in 4—5 vol of isotonic saline. After the second wash there is generally less than 1% of the remaining radioactivity in the supernatant liquid. Resuspend red cells in a sufficient volume of isotonic saline to allow intravenous injection of 20 ml or a lesser amount if appropriate to a particular circumstance(e.g. in children). When red-cell osmotic fragility is greatly increased(e.g. in some cases of hereditary spherocytosis), wash the red cells in 12 g/l sodium chloride solution.

1.1.5. If the total red-cell volume or external blood loss is also to be determined*, set aside an aliquot of the labelled red-cell suspension for preparation of appropriate standards.

### 1.2. Administration

1.2.. Inject the major portion of the labelled red-cell suspension. If the red-cell volume is to be determined, the actual amount must be known. Methods to determine this amount precisely are described below(1.2.2).

1.2.2. To determine the amount of labelled RBC suspension administred, one of the following methods should be used:

(a) Fill a precalibrated syringe to the mark with the labelled RBC suspension, then discard the needle used for filling the syringe and inject the contents into a vein through another needle, preferably having inserted the needle previously into the vein. Flush it two or three times by withdrawing blood from the vein and then reinjecting it.

(b) Fill a syringe and needle with the labelled RBC suspension and weigh them. Inject the content of the syringe without flushing it and weigh the syringe and needle again.

(c) Weigh an empty syringe, fill it with the labelled RBC suspension and reweigh it. Inject and flush in the contents as in (a).

With any of these methods it is necessary to set aside a sufficient volume of the labelled RBC suspension for the preparation of a diluted standard solution, if blood volume is to be measured. The ratio of the amount injected to the amount used for preparation of the standard is determined.

(d) *Fixed geometry method.* This method depends on the prior determination of a calibration factor relating (a), the counting rate obtained with an amount of radioactivity in the injection syringe supported in a mechanical holder at a fixed distance(e.g. 40 cm) above the crystal of the well-scintillation counter, to (b) the counting rate obtained with the same amount of radioactivity, in a volume equal to that of subsequent blood samples, and placed in the well of the crystal. The counting rate obtained with blood samples in the counter can thus be related directly to the corresponding counting rate due to the injected radioactivity, and the need to prepare a diluted standard solution is avoided.

Take approximately 5 ml of the labelled RBC suspension. Place the syringe in the holder above the scintillation counter and mea-

* For the ISCH Recommended Mehods for Measurement of Red Cell Volume using $^{51}Cr$ See ICSH (1980)

sure the counting rate. Inject the suspension. Replace the syringe in the holder and measure the residual counting rate.

### 1.3. Sampling

At 10 min, take a 4—5 ml blood specimen from a vein other than that used for injection. When it is suspected that mixing will not be complete in 10 min(e.g. in patients with splenomegaly), a specmen should also be taken at 60 min. Solid heparin(0.1 mg/ml of blood) or ethylenediaminetetra-acetate(EDTA) (disodium or dipotassium salt, $1.5\pm0.25$ mg/ml of blood) should be used as anticoagulant. Take a further blood specimen at 24 h, three further specimens between day 2 and day 7 and thereafter at least two further specimens per week for the duration of the study. Measure the haemoglobin(g/l or g/dl) by the hemiglobincyanide(cyanmethaemoglobin) method or the PCV on a part of each specimen.

### 1.4. Sample Preparation and Radioactivity Measurement

For the preparation of samples for the measurement of radioactivity, add to each specimen a small amount of saponin powder and mix well preferably on a mechanical rotary mixer for 5 min. Deliver 1—2 ml of the lysed blood into a counting tube. In cases of polycythaemia or when the blood is unusually viscous, the whole blood should be well mixed and delivered into the counting tube before being lysed with saponin. Agitate gently, taking care not to allow the sample to touch the cap of the counting tube. The volume delivered must be known precisely and if necessary made up to the same volume in each consecutive tube. To achieve precision and to minimize errors in pipetting, pipettes of uniform type should be used for a given series of samples. When practcial it is preferable to prepare replicate samples of each specimen.

1.4.1. Measure the radioactivity of each sample in a well-type scintillation counter or other suitable gamma-ray measurement system. The coefficient of variation attributable to counting statistics should not exceed 2%. If there is a significant difference in counts (>2%) between the 10 min and 60 min samples, the latter should be used for subsequent calculation of red cell survival.

## 2. Presentation and Analysis of Red-Cell Survival Data

2.1. The object of red-cell survival studies is to obtain estimates of the rates of red-cell production and destruction. If the patient is in a steady state(see 2.2) the rate of destruction(and, by definition, the rate of production) may be obtined as the product of the volume (or number) of circulating red cells and the fractional rate of disappearance of labelled cells at zero time. The reciprocal of this latter value is, by definition, equal to the mean red-cell life span. Mean red-cell life span is here defined as the mean survival time of all circulating red cells irrespective of whether they are destroyed randomly or by sensescence mechanisms. Derivation of red-cell production and destruction is simple only when the patient is in a steady state and when the red-cell label is not eluted from the circulating red cells.

It is common to use $^{51}Cr$ survival data to determine the $T_{50}Cr$; that is, the time taken for the concentration of $^{51}Cr$ in the circulating blood to fall to 50% of its initial value after correction of the data for physical decay. An objection to the use of this index is that without additional information on the type of destruction(random or senescent) mean red-

cell life span cannot be calulated from it. It is preferable to derive estimates of mean red-cell life span from the data as described below.

2.2. A patient is in a steady state when the rates of production and destruction of red cells have been constant for a time that is not less than the life span of the longest living cells in the particular patient. 'Destruction' in this context includes the loss of red cells from the circulation by haemorrhage, both internal and external. In practice, a patient can be considered to be in a steady state if during the previous 2 months and throughout the period of the study the reticulocyte count and the haemoglobin concentration(or PCV) do not change significantly and the patient is not being transfused. Information on the haematological indices during the period preceding the study may, however, be incomplete, in which case a steady state may have to be assumed. Measurements of radioactivity in blood samples derived from patients in a steady state should be expressed as counting rate/g Hb, or counting rate/ml red cells or counting rate/ml of whole blood. In a non-steady state it is not possible to measure mean red-cell life span with accuracy, partly because the age distribution of red cells in a population may be distorted and partly because the red-cell volume is changing. Nevertheless, on the assumption that the total blood volume remains constant, an approximate estimate can be obtained if the measurements are expressed as counting rate/ml of whole blood. In order to check the constancy of blood volume, repeated red cell volume measurements can be made during the survival study by the sodium pertechnetate($^{99}Tc^{m}$) method, with correction for the contributing $^{51}Cr$ radioactivity, as described in the ICSH *Recommended Methods for Measurement of Red-Cell and Plama Volume*(ICSH, 1980)

2.3. $^{51}Cr$ is eluted at a rate which significantly affects estmates of mean red-cell life span. The average rate of chromium elution is of the order of 1% per day, which is of the same magnitude as the normal rate of red-cell destruction. Accordingly, variations in the rate of elution in different individuals may seriously affect the accuracy of mean red-cell life span when survival is normal or only slightly reduced. Elution is fairly constant in normal subjects with the ACD method (or with the citrate wash method) and an appropriate correction factor can be applied (see 2.4.1.; Table I). Elution is thought to vary in some disease states when red cell life span is considerably reduced. However,in such cases chromium elution and variations in the rate of chromium elution become relatively unimportant.

2.4. The following sections summarize the way in which mean red-cell life span should be estimated from $^{51}Cr$ measurements in a steady state. Correction for physical decay is assumed.

2.4.1. Correct all $^{51}Cr$ measurements for elution(see Table I).

2.4.2. Plot the data from $^{51}Cr$(corrected for elution) as counting rate/g Hb, counting rate/ml red cells or counting rate/ml whole blood against time on linear graph paper.

2.4.3. Examine the plot to see if a straight line can be fitted to the data points. If so, use a least squares fitting procedure to obtain the line, and determine the goodness of fit. If it appears that the data are fitted by a straight line it is likely that red cell destruction is largely the result of senescence, and the mean red cell life span can be derived as the reciprocal of the slope of the line or as

**Table I. Correction factors which convert the Cr survival into 'true' red-cell survival (ACD or citrate-wash methods). Elution may, however, vary in some diseases (see 2.3.)**

| Day | Correction factor | Day | Correction factor | Day | Correction factor |
|---|---|---|---|---|---|
| 0 | | | | | |
| 1 | 1.03 | 11 | 1.16 | 21 | 1.29 |
| 2 | 1.05 | 12 | 1.17 | 22 | 1.31 |
| 3 | 1.06 | 13 | 1.18 | 23 | 1.32 |
| 4 | 1.07 | 14 | 1.19 | 24 | 1.34 |
| 5 | 1.08 | 15 | 1.20 | 25 | 1.36 |
| 6 | 1.10 | 16 | 1.22 | 26 | 1.38 |
| 7 | 1.11 | 17 | 1.23 | 27 | 1.40 |
| 8 | 1.12 | 18 | 1.25 | 28 | 1.42 |
| 9 | 1.13 | 19 | 1.26 | 29 | 1.45 |
| 10 | 1.14 | 20 | 1.27 | 30 | 1.47 |

the intercept obtained by extrapolating the line to zero activity. If a straight line does not fit the data well, examine the plot on semi-logarithmic paper to see if a straight line can then be fitted to the data thus plotted. If so, again use a least squares fitting procedure to obtain the line and determine the goodness of fit. If a good fit obtains a random destruction mechanism is likely and the mean red cell life span can be derived as the time corresponding to 37% survival, or by multiplying the half-time of the fitted line by 1.44. If it is not obvious by simple inspection which plot gives the best fit, apply a statistical fitting criterion. If neither of these procedures results in all the data being satisfactorily fitted by a straight line, obtain the initial slope of the curve on the linear plot by drawing a straight line through the first few points only.

2.4.4. If computing facilities are available the following method can be used instead of that described in 2.4.3.

Fit one of the functions (1), (2) or (3), as appropriate, to the data:

$$N_t/N_o=(e^{-kt}-e^{-kT})/1-e^{-kT} \quad (1)$$

$$N_t/N_o=\left(1-\frac{t}{T}\right)e^{-kt} \quad (2)$$

$$N_t/N_o=\alpha e^{-\beta t}+(1-\alpha)e^{-\gamma t} \quad (3)$$

where $N_t$=radioactivity at time '$t$' corrected for elution (see 2.4.1.) and expressed in one of the ways described in 2.2.; $N_o$=radioactivity at time '0', similarly expressed; $k$=destruction rate factor deduced from the data; $T$=upper limit of life span of the red cells (Function 1) or the assumed potential life span of each cell (Function 2); $\alpha$, $\beta$ and $\gamma$ are arbitrary fitting constants. The mean red cell life span ($\bar{T}$) is given by:

$\bar{T}=(1-e^{kT})/k$ for (1)

$=1/\left(k+\frac{1}{T}\right)$ for (2)

$=1/[\alpha\beta+\gamma(1-\alpha]$ for (3)

Function (1), which is of the form $[Ae^{-kt}-B]$, ($A$ and $B$ being constants), may be fitted with a standard exponential curve fitting program that is usually available with a computer system.

Function (2) is an alternative version of (1); it may involve a non-standard fitting procedure.

Function (3) is a more flexible, though empirical and arbitrary, formula which can be used for fitting a mathematical function to the data so as to obtain the initial slope if the data show two components when plotted on semilogarithmic paper.

2.5. In cases where there is an external blood loss and where this blood loss has been demonstrated to have been constant for a long time, the true mean red-cell life span($\bar{T}$) is given by the equation below, where $T_a$ is calculated in accordance with 2.4.3. and 2.4.4.

$$\bar{T} = T_a \cdot \frac{V}{(V - T_a L)}$$

where $T_a$=apparent mean red-cell life span (days); $V$=total red-cell volume(ml); $L$=average rate loss of red cells(ml/d).

## 3. Normal Values

Normal value for mean red-cell span is usually taken as 120 d, SD 15d. $T_{50}$ Cr is about 28 d.

## 4. Use of Isotope-labelled Red Cells as a Test of Compatibility

4.1. Possible circumstances in which the test may be indicated are as follows: (a) when serological tests suggest that all normal donors are incompatible; (b) when 'cold' alloantibodies are present, active *in vitro* at 30°C or higher, and non-reacting donor cannot be found; (c) when the recipient has had an unexplained haemolytic transfusion reaction and requires a further transfusion.

4.2. *Donor.* The potential donor is generally selected by the blood bank on the basis of serological studies. A blood sample may be withdrawn from the donor bag, using sterile technique. The anticoagulant solution in the bag should be NIH A ACD or CPD to ensure that it is suitable for the subsequent labelling procedure.

4.3. *Conduct of test.* Take a blood sample from a potential donor, label approximately 0.5ml of red cells with 20 $\mu$Ci $^{51}$Cr and make up a suspesion of the washed cells to about 13 ml. Inject 10 ml and prepare a standard from the remainder. Note the time of injection of the cells precisely by starting a stop watch at the mid-point of injection. Take blood samples at 3, 10 and 60 min from a vein other than that used for the injection. At 10 and 60 min take sufficient blood to provide plasma as well as whole blood for radioactivity measurement.

It may sometimes be necessary to estimate the recipient's red-cell volme; this can be done either by injecting a sample of the recipient's own red cells labelled with a small amount of $^{51}$Cr(10$\mu$Ci) before injecting the donor red cells(in this case labelled with 50$\mu$Ci) or by injecting the recipient's own red cells l abelled with $^{99}$Tc$^{m}$. Alternatively, the recipient 's red-cell volumc may be deduced from his weight, height and PCV(see ICSH, 1980).

4.4. *Interpretation.* When compatible donor red cells have been injected, the counting rate of the 60 min sample is, on the average, about 99% of the 3 min sample. In the individual case, owing to errors of measurement, values between 94% and 104% may be accepted as normal.

In cases of urgency or when there is great difficulty in finding completely compatible red cells, donor red cells may be transfused with minimal hazard when, following a test with 0.5 ml of the donor's red cells, the amount of radioactivity in the plasma, both at 10 and 60 min, does not correspond to more than 3%

of the radioactivity injected and when the red-cell survival at 60 min is not less than 70%. If survival is at least 70% the deduction is that the concentration of the offending antibody is very low, so that the destruction of a large volume of incompatible red cells with be either negligible or will take place only slowly. When survival is significantly lower at 10 min than at 3 min but shows little or no furher fall at 60 min, indicating a two-component curve, the implication is that the antibody is IgM. On the other hand, when survival at 10 min is only slightly less than at 3 min but is substantially less at 60 min, indicating an exponential curve, the most likely interpretation is that the antibody is IgG. The distinction is of some importance since with cold IgM alloantibodies immune responses are common whereas with IgG antibodies they are the rule. Although in both cases the survival of a whole unit of red cells may be virtually normal during the 24 h or so following transfusion a delayed haemolytic reaction must be expected when the antibody is IgG.

## 5. Radiation Dose to the Patient in Red-Cell Survival Studies

5.1. Data relating to the radiation dose to a 70 kg patient in the procedures described above are shown in Table II. It should be emphasized that the calculations on which these data are based involve many assumptions. Firstly, the blood circulation cannot readily be represented in terms of a physical model for purposes of dose calculations. Secondly, detailed quantitative data concerning the distribution and fate of the different radioisotopic labels in the body are lacking. Thirdly, even if such data were available for a given procedure in normal subjects, the corresponding data in pathological conditions could be very different. The data do not therefore give more than an approximate indication of the radiation dose to the various procedures.

**Table Ⅱ. Radiation dose to the patient in red-cell survival studies**

| Label | Critical organ | Fraction of administered radioactivity reaching critical organ | Mean radiation dose to patient per μCi administered (mrad)* |
|---|---|---|---|
| $^{51}Cr$* | Spleen | 0.2 | 3.87 |
| $^{51}Cr$† | Spleen | 1.0 | 89.3 |

* Intravenous injection of labelled normal compatible cells into normal subjects.
† Intravenous injection of labelled damaged or non-compatible cells which are all sequestered selectively in the spleen.

5.2. Table II shows the dose to the critical organ or tissue-the organ or tissue of the body most likely to suffer radiation damage as a consequence of the procedure in question-per μCi of administered radioactivity.

5.2.1. When $^{51}Cr$-labelled red cells are injected, $^{51}Cr$ is slowly eluted from the cells in the circulation. The labelled cells eventually undergo destruction in the reticulo-endothelial tissues, mainly in the spleen, from which the deposited radioactivity is again slowly sluted. In these circumstances, the critical organ may be taken as the spleen. Two extreme situations are considered. The first of these corresponds to a normal red-cell survival study; the labelled cells are assumed to be removed from the circulation at the end of their normal life span, 20% being trapped in the spleen. The second corresponds to a study with damaged or non-compatible cells; the labelled cells are assumed to be rapidly removed from the circulation, 100% being trapped in the spleen. The dose to this organ is then, of course, considerably higher.

## Acknowledgment

This work was supported in large part by U.S.P.H.S. grant no. CA 19923 which financed a week's meeting of the Panel in Annapolis, Maryland, in 1975 during which time major portions of revisions of documents were made.

## REFERENCES

The following publications by the International Committee for Standardization in Haematology are referred to in this document:

Recommended methods for radioisotope red-cell survival studies. A report by the ICSH panel on Diagnostic Applications of Radioisotopes in Haematology. *British Journal of Haematology*, 1971, 21, 241—250.

Recommended methods for radioisotope red cell survival studies. *Blood*, 1971, 38, 378—386.

Recommended methods for radioisotope red cell survival studies. *Blut*, 1972, 25, 108—115.

Recommended method for radioisotope red-cell survival studies. A report by the ICSH panel on Diagnostic Applications of Radioisotopes in Haematology. *American Journal of Clinical Pathology*, 1972, 58, 71—80.

Methodes recommandées pour l'étude de la durée de vie des globules rouges, *Nouvelle Revue Francaise d'Hématologie*, 1971, 11, 517—530.

Recommended methods for measurement or red-cell and plasma volume. *Journal of Nuclear Medicine*, 1980.

放射性同位元素를 利用한 赤血球壽命測定法(ICSH 推薦), 대한핵의학회잡지 *5(1):1, 1971*